Adsorber efficiency in adsorbtion refrigeration

Umberto Lucia *

Dipartimento Energia, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

A B S T R A C T

The coefficient of performance, COP, of an adsorption cooling is theoretically obtained. It shows the influence of the thermophysical properties of the adsorbent-adsorbate media regardless of the design of the machine. These quantities require a detailed understanding of the influence of temperature on the adsorbent and the adsorbate conditions in a cycle, so that an accurate determination of the thermodynamic behaviour is developed in order to obtain the COP.

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Contents

1. Introduction

One of the main challenges of the industry today is to face its impact on global warming [1,2]; moreover, the greenhouse effect problem is not be solved completely yet. So, in addition to further developing the vapour compression technology, technical physicists and engineers have begun to explore new refrigeration technology such as solar cooling. Indeed, an adsorption cycle integrated into a solar energy system can be an alternative to a conventional system as a source of refrigeration [3]. This is generally more so in regions where solar flux is high and electric power is not reliably available to accommodate conventional cooling systems. Among the important applications of such refrigeration systems would be cooling for vaccine storage and for food storage [3,4]. On the contrary, in literature only a paper can be found on adsorption–desorption cycles on their thermodynamic theory [5].

The interest in the adsorption systems began in the 70s, during the oil crisis, for the new energy requirements, and continued in the 90s for the ecological problems related to the greenhouse gases. Today, the continue increase in energy consumption requires new efficient way of using energy resources [6]. Systems able to recover waste heat at low temperature can represent an interesting technology in relation to the environmental and energy use problems. Solid adsorbents (zeolites, activated carbon, silica gel, etc.) are porous materials and, at low temperatures, they can adsorb the refrigerant, while at high temperature they can release it: these materials can be used in refrigeration systems. The refrigeration cycle can be powered by thermal energy. Consequently, since the 80s, the basic principles and theory approach to solid adsorption refrigeration have been developed.

An adsorption refrigeration contains three components: container of adsorbents, condenser and evaporator. The adsorbent is packed in a hermetically sealed container. For solar adsorption refrigeration, for example, during the day, the high concentration of adsorbent and container are heated by solar radiation. At the maximum cycle temperature the refrigerant is desorbed from the adsorbent, its vapour condenses into liquid in the condenser, and heat is dissipated to the surroundings. From the condenser the liquid

* Tel.: 39 0110 904520.
  E-mail addresses: umberto.lucia@polito.it, umberto.lucia@gmail.com

Nomenclature

Latin

A	area (m^2)
c	specific heat ($J\,kg^{-1}\,K^{-1}$)
COP	Coefficient of performance
F	free Helmholtz energy (J)
G	standard free energy (J)
H	enthalpy (J)
K	equilibrium constant
m	mass (kg)
n	moles (mol)
p	pressure (Pa)
Q	heat (J)
R	universal constant gas
T	temperature (K)
V	volume (m^3)

Greek

α	quantity which give the attraction between the molecules ($N\,m^{-1}$)
β	co-area of the adsorbed molecules (m^2)
γ	interface energy ($N\,m^{-1}$)
Γ	surface concentration ($mol\,m^{-2}$)
ϑ	covering degree
μ	chemical potential ($J\,mol^{-1}$)
ν	stechiometric coefficient
π	spreading pressure ($N\,m^{-1}$)

Superscript

0	isostearic
1	state 1 of the adsorption–desorption cycle
2	state 2 of the adsorption–desorption cycle
3	state 3 of the adsorption–desorption cycle
4	state 4 of the adsorption–desorption cycle
ads	adsorption
gas	gas
σ	interface
surf	surface

goes into the evaporator for gravity. During the night, the adsorbent is cooled to near ambient temperature: when the adsorbent pressure reaches the saturated vapour pressure of the refrigerant, the refrigerant boils in the evaporator and changes heat to the environment. The resulting refrigerant vapour is readsorbed into the adsorbent and cooling is produced [7]. The physical principle of operation is that the refrigerant concentration on the adsorbent depends on temperature under constant pressure conditions, so the adsorption and desorption occur by varying the temperature of their combination. So, a classical adsorption–desorption cycle is represented in Fig. 1 and it is composed by the following four processes [3]:

1. Heating and pressurisation ($1 \rightarrow 2$): the adsorber receives heat while being closed; the adsorbent temperature increases from T_1 to T_2, which induces a pressure increase, from the evaporation pressure p_1 up to the condensation pressure p_2.

2. Heating and desorption with condensation ($2 \rightarrow 3$): the adsorber continues receiving heat while being connected to the condenser, which now superimposes its pressure; the adsorbent temperature continues increasing form T_2 to T_3, which induces desorption of vapour; this desorbed vapour is liquefied in the condenser, while the pressure is constant, p_2.

3. Cooling and depressurisation ($3 \rightarrow 4$): the adsorber releases heat while being closed; the adsorbent temperature decreases from T_3 to T_4, which induces the pressure decrease from the condensation pressure down to the evaporation pressure to p_1.

4. Cooling and adsorption with evaporation ($4 \rightarrow 1$): the adsorber continues releasing heat while being connected to the evaporator, which now superimposes its pressure; the adsorbent temperature continues decreasing to T_1, which induces adsorption of vapour; this adsorbed vapour is vaporised in the evaporator; the evaporation heat is supplied by the heat source at low temperature.

If the thermal energy supply is the solar one, cycle is drive by the natural diurnal and nocturnal solar radiation time, so the adsorption cycles are intermittent because they are based on the heating–desorption–condensation phase and on the cooling–adsorption–evaporation phase but if the cooling system has two adsorbers, they can operate out of phase with the consequence of obtaining a quasi-continuous cold production.
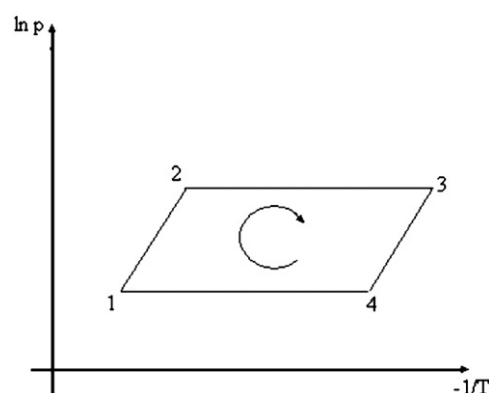

Fig. 1. A general adsorption–desorption cycle.

The aim of this paper is to discuss the coefficient of performance COP, useful to evaluate the cycle performance. Indeed, COP can show, for a given cycle, the influence of the thermophysical properties of the adsorbant–adsorbate media regardless of the design of the machine. These quantities in turn require a detailed and exact understanding of the influence of temperature on the adsorbant and the adsorbate conditions in a cycle. Consequently, in order to analyse the performance of an adsorption cycle, an accurate determination of the thermodynamic behaviour is needed under the expected operating conditions.

2. Kinds of adsorption cycles

The adsorption cooling systems may be classified in relation to the adsorbent and refrigerant combination used produced [7]

1. Adsorption cycles with water as the refrigerant: natural zeolite adsorbs large amounts of water vapour when cooled and desorbs the water vapour when heated [8]. This mineral, placed in a hermetically sealed metal container, performs the functions of energy collection and those of mechanical compressor in the conventional refrigerator [9]. The quantity of water adsorbed depends on temperature. Tchernev [9] first made a 100 dm^3