Energy and Buildings 80 (2014) 436–440

Contents lists available at ScienceDirect

Energy and Buildings

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

Review

Solar cooling system for buildings: Thermal analysis of solid absorbents applied in low power adsorption system

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ARTICLE INFO

Article history:
Received 22 May 2013
Received in revised form 15 May 2014
Accepted 17 May 2014
Available online 3 June 2014

Keywords:
Cooling
Silica gel
Solar panels
Buildings

ABSTRACT

In the last 50 years the thermal solar panels have been developed mainly for the production of sanitary hot water, but also as an additional source for heating plants.

Actually, during the summer season, there is a surplus of thermal energy which can be used as an interesting solution to produce cold by using a simple adsorption system; this can contribute to the air cooling problem with low COP values.

The most beneficial adsorbent both for its thermal/physical and low cost is the silica gel, a polymer of silicon dioxide, commonly used for its dehydrating properties, especially in the preservation of electronic material.

In this study, a performance thermodynamic balance of a small size system has been made (about 2 kW), adequate to cool an apartment of 70–80 m^2 and a TRNSYS simulation has been made to assess in what conformation (surface, storage volume, etc.). A new generation solar power plant is able to guarantee a continuous operation during the summer period.

The use of an adsorption system would be favored further in climates in which the solar energy is available, for example in the Arab countries and in some Central Africa countries.

Contents

1. Thermodynamic analysis of the main parameters of a silica gel system

In this paper it has shown the study developed a solar cooling adsorption system [1,2] by silica gel, defining the relations to describe the thermodynamic parameters [3] of a system presented in a general way in several studies as in the article by Sarbu and Sebarchievici [4].

In particular, it has analyzed a solar cooling adsorption system [5] low power going to represent some diagrams to define preliminary the thermodynamic parameters of the exchangers (condenser, evaporator) and to integrate the relationships presented in the study of Sekret and Tursky [6].

This paper refers to a single-stage water–silica gel adsorption system with two beds of adsorbent, in order to obtain a nearly continuous operation; it is assumed that the medium that exchanges heat between the various system components and the external heat sources (external environment and user) is water [6–8].

The effects of irreversibilities in heat and mass transfer are considered minor, therefore it is assumed that the temperature of the silica gel is spatially homogeneous at all times and that the value of water content in the adsorbent always corresponds to what the value would be under thermodynamic equilibrium conditions [9].

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http://dx.doi.org/10.1016/j.enbuild.2014.05.039
0378-7788/

Nomenclature

A	area of thermal exchange (m^2)
c	content of water in silica gel (kg/kg)
C	specific heat of the materials (J/kg K)
P	pressure (Pa)
R	constant of the water vapour (462 J/kg)
T	temperature (K or °C)
K	heat transmittance (w/m^2 K)
E	efficiency of the heat exchangers
τ	time (s)

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Ads	adsorber
Des	desorber
Ev	evaporator
Con	condenser
Win	water incoming
Coolin	cooling water incoming

Regarding the properties of the silica gel–water system, there are different sets of experimental data and equations of state to represent the link among water content, temperature and relative humidity and the values of heat of adsorption [7,10,11].

It has been observed that there is more than one type of silica gel with different adsorption features, in order to have a more accurate planning it is necessary to gather reliable information on the properties of the material to be used.

In this paper, to obtain simple and rapid draft assessments of the operating conditions of the system, the Freundlich ratio will be used as state equation [12]:

$$c = k\phi^{1/n}, \tag{1}$$

where $k = 0.346$ kg/kg and $n = 1.6$.

Where "c" is the water content in the gel in kg/kg and "ϕ" is relative humidity, that is the ratio between the water vapor pressure P_v and the saturation pressure $P_s(T)$ corresponding to the temperature of the silica gel.

It is assumed that during the adsorption P_v is equal to the saturation pressure at the temperature of the evaporator and during the desorption instead, it is equal to the saturation pressure determined by the temperature of the condenser. The heat adsorption values as a function of C are taken from [12–14].

To calculate the saturation pressure of water vapour (2) is used:

$$P_s(T) = P_s(T_0)\exp\left[\frac{h_{ev}}{R_v}\left(\frac{1}{T_0} - \frac{1}{T}\right)\right] \tag{2}$$

where T_0 is a reference temperature.

The heat balances in the various components of the system are the following:

$$\dot{m}_r = \frac{A_{ev}K_{ev}}{h'_{ev}}(T_{eout} - T_e)\frac{\varepsilon_{ev}}{1-\varepsilon_{ev}}\frac{1}{l_n(1/1-\varepsilon_{ev})} \tag{3}$$

$$\dot{m}_r = \frac{A_{ads}K_{ads}}{h_{ads}}(T_{ads} - T_{coolin})\frac{\varepsilon_{ads}}{l_n(1/1-\varepsilon_{ads})} \tag{4}$$

$$\dot{m}_r = \frac{A_cK_c}{h''_{ev}}(T_c - T_{coolin})\frac{\varepsilon_i}{l_n(1/1-\varepsilon_i)} \tag{5}$$

$$\dot{m}_r = \frac{A_{des}K_{des}}{h'_{ads}}(T_{win} - T_{des})\frac{\varepsilon_{den}}{l_n(1/1-\varepsilon_{des})} \tag{6}$$

where m_r is the amount of vapour adsorbed in time units in (3) and (4) as well as the amount evaporated from the adsorbent in (5) and (6): where the $\dot{m}_r = \pm m_{gel}(dc/d\tau)$ sign (+) is valid in the adsorption and (−) in the desorption and m_{gel} is the mass of silica gel.

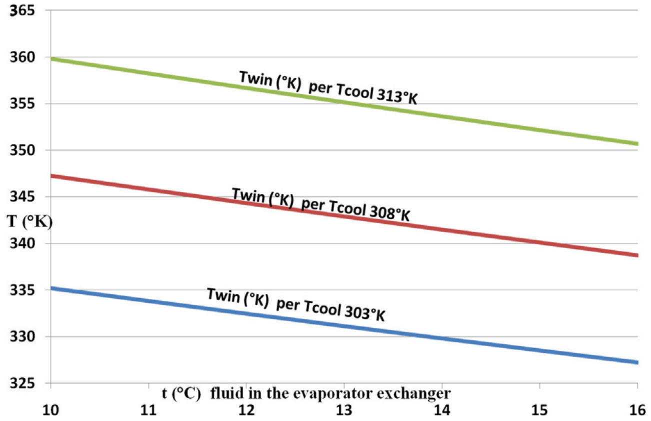

Fig. 1. Warm water temperature pattern (K) as a function of the temperature (°C) of the fluid in the evaporator exchanger for three values of T_{coolin}.

$$h'_{ev} = h_{ev} - C_l(T_c - T_e)$$

$$h'_{ev} = h_{ev} + C_v(T_{des} - T_c)$$

The efficiency of the heat exchangers is given by the following formula:

$$\varepsilon = 1 - \exp(-NTU)$$

where $NTU = \frac{KA}{mCe}$

Where A and K indicate exchange surfaces and thermal exchange coefficients, and m and Ce are the capacity load and the specific heat of the fluids flowing within the heat exchangers [10,15].

In (3)–(6) the heat necessary to change the adsorbent temperature and the temperature of the structures of the system during the adsorption and desorption processes were considered negligible.

The duration of adsorption stage, τ_{ads}, is equal to that of desorption τ_{des}, and equal to 300 s whereas the transition time between the two phases is set equal to 30 s.

For the efficiencies of heat exchangers, the following values have been taken as assumed:

$$\varepsilon_{ev} = 0.6; \quad \varepsilon_{ads} = 0.6; \quad \varepsilon_c = 0.7$$

The above stated equations can determine the T_{win} values required to make desorption, when other operating parameters varies, which are compared to the fluid temperature resulting from the solar panels.

In order to assess the amount of energy needed for the real process operation, a small system is considered, then the mass of water treated in a cycle, (m_r), is set as a variable between 0.3 and 0.5 kg. Fig. 1 shows the pattern of average power temperatures (T_{win}) depending on the chilled water outlet temperature from the evaporator (T_{eout}), for temperatures of the cooling medium in the condenser and adsorber (T_{coolin}), respectively, 30 °C, 35 °C and 40 °C.

As it (Fig. 1) shows, to maintain the water temperature leaving the evaporator at 10 °C, it is necessary to bring the hot water temperature coming from the solar panels from ~62 °C to ~82 °C.

It is interesting to note (Fig. 2) how the cooling capacity varies according to the temperature of the water supply (at a constant temperature of the cooling medium); in fact we shift from a value of about 1.2 kWt (thermal unit Capacity) per T_{win} = 57 °C to a value of about 12 kWt (thermal unit Capacity) per T_{win} = 97 °C.

Fig. 3 shows how the power temperature to the desorber changes depending on the characteristics of thermal exchange of heat exchangers (AK); when the cooling power is 2 kW, T_{eout} = 10 °C