Analysis of the Thermodynamic Parameters of Adsorption on Silica Gel Machine for Cooling, Powered Solar Energy: Application Case

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Abstract—The characteristics of solid absorbents have interesting applications in adsorption systems; the lack of rectification and the constant pressure in discontinuous engines. Besides with salt hydrates it is possible the utilization in the solar applications where the efficiency of a solar panel requires a low temperature. An interesting schema of solid absorbent cooling system and solar panel is examined for an utilization with fan-coils in the summer season. In this application it is important the utilization of hot water coming from a solar panel for powering the silica gel cooling system, with the climate data of a summer season in Rio de Janeiro. This paper identifies some salts that can conveniently operate as absorbents and this model could developed also with the climate data of other cities.

Keywords—Cooling, Silica Gel, Solar Panels

I. INTRODUCTION

O VER the last 50 years, the thermal solar panels have experienced a major technological development that has enabled a very wide usage, mainly for the production of sanitary hot water but also as an additional source for heating plants.

In this regard, today it is always more and more the case where during the summer season there is a surplus of thermal energy whose use is to be assigned within the energy optimization system.

The most immediate solution to this problem is the ability to produce cold by means of simple adsorption solutions, thus contributing to the 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 sq m 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.

Reference has been made to data related the city of Rio de Janeiro as well as vacuum solar panels.

The vacuum solar collectors are designed with the aim of significantly reducing heat loss to the outside.

In fact, the presence of a vacuum cavity allows the heat-carrying fluid (which flows through U type pipes) to heat up, minimizing heat loss to the outside.

The new generation thermal collectors have higher efficiency than the previous ones and can be used throughout the year, but are also more expensive (they can cost between 30% and 50% more than the flat plate collectors).

II. THERMODYNAMIC ANALYSIS OF THE MAIN PARAMETERS OF A SILICA GEL SYSTEM

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

The effects of irreversibilities in heat and mass transfer are considered as 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.

As regards the properties of the silica gel-water system there are different sets of experimental data and equations of state to represent the link between water content, temperature and relative humidity and the values of heat of adsorption [1], [15], [16], [17]:

What has been observed, is that there is more than one type of silica gel, with different adsorption characteristics, therefore 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 [15]:

\[ c = k\phi^n \]  \hspace{1cm} (1)

Where \( k = 0.34 \left( \frac{kg}{kg} \right) \) and \( n = 1.6 \)

where "c" is the water content in the gel in \( \frac{kg}{kg} \) and "\( \phi \)"...
is relative humidity, that is the ratio between the water vapor pressure $P_v$ and the saturation pressure $P_{	ext{v}}(T)$ corresponding to the temperature of the silica gel.

It is assumed that during the adsorption $P_{	ext{v}}$ 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 values of heat of adsorption as a function of $C$ are taken from [1].

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

$$P_{	ext{v}}(T) = P_{	ext{v}}(T_0) \exp \left[ \frac{h_{\text{ex}}}{R_v \left( \frac{1}{T_0} - \frac{1}{T} \right)} \right]$$

(2)

where $T_0$ is a reference temperature.

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

$$\dot{m}_r = \frac{A_{\text{ex}} K_{\text{ex}}}{h_{\text{ev}}} (T_{\text{out}} - T_r) \frac{\varepsilon_{\text{ev}}}{1 - \varepsilon_{\text{ev}}} \left[ \frac{1}{1 - \varepsilon_{\text{ev}}} \right]$$

(3)

$$\dot{m}_r = \frac{A_{\text{ads}} K_{\text{ads}}}{h_{\text{ads}}} (T_{\text{ads}} - T_{\text{coolin}}) \frac{\varepsilon_{\text{ads}}}{1 - \varepsilon_{\text{ads}}} \left[ \frac{1}{1 - \varepsilon_{\text{ads}}} \right]$$

(4)

$$\dot{m}_r = \frac{A A_{\text{d}} K_{\text{d}}}{h_{\text{ev}}} (T_{\text{c}} - T_{\text{coolin}}) \frac{\varepsilon_{\text{i}}}{1 - \varepsilon_{\text{i}}} \left[ \frac{1}{1 - \varepsilon_{\text{i}}} \right]$$

(5)

$$\dot{m}_r = \frac{A_{\text{des}} K_{\text{des}}}{h_{\text{ads}}} (T_{\text{win}} - T_{\text{des}}) \frac{\varepsilon_{\text{den}}}{1 - \varepsilon_{\text{den}}} \left[ \frac{1}{1 - \varepsilon_{\text{den}}} \right]$$

(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 $m_r = \pm \frac{d m_{\text{abs}}}{d \tau}$

sign (+) is valid in the adsorption and (-) in the desorption and $M_{\text{gel}}$ is the mass of silica gel.

$$h_{\text{ev}} = h_{\text{ev}} - C_i (T_r - T_r')$$

$$h_{\text{ev}} = h_{\text{ev}} + C_v (T_{\text{des}} - T_r')$$

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

$$\varepsilon = 1 - \exp (-N\text{TU})$$

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

where $A$ and $K$ indicate exchange surfaces and thermal exchange coefficients, and $m$ and $C_v$ are the capacity load and the specific heat of the fluids flowing within the heat exchangers.

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 was considered as negligible.

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

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

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

The above stated equations enable us to determine the Twin values required to make desorption when varying other operating parameters, which are compared with 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 variable between 0.3 and 0.5 kg. Fig 1 shows the trend of average power temperatures (Twin) depending on the chilled water outlet temperature from the evaporator (Teout), for temperatures of the cooling medium in the condenser and adsorber (Tcoolin) respectively 30 °C, 35 °C and 40 °C.

Fig. 1 Trends of the warm water temperature (°K) as function of the temperature (°C) of the fluid in the evaporator exchanger for three values of Tcoolin.

As (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.

Fig.2 Trend of the due temperature of water incoming (°K) in the refrigerator system from the solar panels respect the (kW) of the refrigerator system.
It is similarly interesting to note (Fig. 2) how the cooling capacity varies depending on 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 per Twin = 57°C to a value of about 12 KwT per Twin = 97°C.

Fig. 3 shows how the power temperature to the desorber changes depending on the characteristics of the heat exchangers (AK);

when the cooling power is 2 KW, Teout = 10°C e Tcoolin = 30°C, what can be noted is that Twin rapidly increases for AK values less than 1, while it remains almost constant for AK values greater than 1.

In the latter case, it does not seem convenient to increase the exchange surfaces as a marginal advantage can be observed.

![Fig. 3 Trend of the due temperature of water incoming (°K) in the refrigerator system from the solar panels respect the heat thermal features of the adsorber and desorber exchangers](image)

![Fig. 4 Trend of the due temperature of water incoming (°K) in the condenser system from the solar panels respect the heat thermal features of the condenser exchangers](image)

Fig. 5 shows how the COP varies with the variations of Δc (variation of the concentration of silica gel in water);

The previous results have been obtained assuming that the variation of "c" in the phases of adsorption and desorption are very small (Δc < 0.02 kg kg⁻¹) and, consequently, Tads and Tdes are practically constant over time;

this requires high values of silica gel mass, Mgel and low COP values.

![Fig. 5 Trend of the COP of the refrigerator system respect the varying concentration of the water in the silica gel (kg/kg)](image)

![Fig. 6 Scheme of the silica gel cooling system](image)

On the other hand, by decreasing Mgel, the change in water content during both desorption and absorption, for a given power and then for a given amount of water adsorbed in a cycle, becomes larger and consequently the variation of TADS and TDES increases; the same goes for the Twin, which must be greater than Tdesmax:

for a cooling power of 2.2 kW a Teout = 149°C and a Tcoolin = 35°C, when the Mgel shifts from 15 kg to 6 kg, the Twin request goes from 70°C to 76°C.

III. SIMULATION MODEL OF THE ABSORPTION SYSTEM POWERED BY SOLAR PANELS.

Analysis of the aforementioned data reported show how reasonable it is to assume that a system following the pattern shown in Fig. 5a envisages an accumulation of 70/72°C, a value that leads to cold temperatures.

Fig. 5b shows the operating points of the system on a diagram p, T, x. After defining the operating conditions a choice was made towards the most adequate type of solar panel system to have the system performance at its best.
The basic scheme envisages thermal panels with a storage serving as a buffer; the combinations are numerous and range from those involving accumulations with different volumes to those with the possibility of integration by means of an auxiliary boiler.

For the simulation of the system as a whole, to avoid entering a special type with the risk of overloading the program, the system is viewed as a particular heat exchanger that requires water at a certain temperature and at that returns it cold with a constant $\Delta T = 5^\circ C$.

The model also includes a controller to lock the pump of the solar collectors should the temperature of the tank reach $95^\circ C$, a value that proved to be possible in the simulation as well as another controller to simulate the switching on and off of the users according to preset daily and weekly schedules.

At this point the METEO type which simulates the weather behaviour and its influence on plants and buildings has been included. The reference is always made to the city of Rio de Janeiro.

For the simulation to take place, the system's power on the basis of the considerations being made has been determined (2 to 5 kW refrigeration load involving, as we have seen, the use of about 6 to 10 thermal kW).

Under these conditions several coupling possibilities between the surface of the collectors and the storage volume can be obtained, thus providing users with hot water at least at a temperature of $70^\circ C$ and allowing for the operation of a small air conditioning system.

The results of the simulation that has had as a constraint the fact that the temperature inside the storage tank is never lower than $70^\circ C$, indicates an average temperature of about $85^\circ C$. In this framework, the results summarized in the curves shown in Fig. 7 have been obtained.
Roberto de Lieto Vollaro was born in Rome, Italy, on November 25, 1977. He received the M.S. degree in Mechanical Engineering, and the Ph.D. degree in Industrial Engineering, from University of Perugia (Italy) in 2003 and 2007, respectively. From 2006 to present he researched two important topics: the thermal comfort inside the vehicles for public urban transport and the conductivity of the ground in presence of electric cables buried. He is Contract Professor of Applied Physics at the College of Architecture of “La Sapienza” University of Rome. From 2008 he is Research Professor of Acoustic and Lighting Engineering at the Department of Industrial and Mechanical Engineering of the University of Roma3. He is author or co-author of more than 30 scientific works, published in prominent international and national journals and conferences on heat transfer, applied acoustics and lighting systems.