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EVALUATION OF A ZEOLITE-WATER SOLAR ADSORPTION REFRIGERATOR

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Abstract.-
This paper presents some of the experimental evaluations of a prototype solar refrigerator, based on an intermittent thermodynamic cycle of adsorption, using water as refrigerant and the mineral zeolite as adsorber. This system uses a mobile adsorber, which is regenerated out of the refrigeration cycle and no condenser is applied, because the solar regeneration is made in the ambient air For the regeneration, a SK14 solar cooker is considered. The cold chamber, with a capacity of 44 liters, is aimed for food and vaccine conservation. The objective is to analyze the advantages and disadvantages of the eventual use of this refrigerator in rural regions of Peru, where no electricity is available. On the bases of the results obtained, a new prototype of refrigerator for rural regions is designed, based on the same thermodynamic cycle, but including changes in design and operation.

1. INTRODUCTION

The use of sorption processes to produce refrigeration has been extensively studied in the last twenty years as a technological alternative to vapor compression systems. Several theoretical and experimental studies demonstrated that sorption refrigeration systems, especially those using solid-gas heat powered cycles, are well adapted to simple technology applications. They can operate without moving parts and with low-grade heat from different sources such as residual heat or solar energy. The two main technologies concerning the solid-gas sorption concept are the adsorption and the chemical reaction, including metal hydrides. The similarities and differences between these systems, as well as the advantages and disadvantages of each one are extensively described by Meunier (1998).

Refrigeration is an interesting application of solar energy because the incident radiation and the need for cold production both reach maximum levels in the same period. In developing countries, solar refrigeration is an increasingly acknowledged priority in view of the needs for food and vaccine preservation and due to the fact that solar energy is generally widely available in these countries. Different solar refrigeration systems using sorption processes have been proposed and tested with success. In relation to the solar adsorptive refrigeration systems, different types of solid-gas were considered. The zeolite-water and silica gel-water pairs were chosen for cold storage, while the activated carbon-methanol pair was chosen for ice production (Leite, 1996). The activated carbon-ammoniac pair was also employed for different refrigeration applications using solar energy. The adsorptive systems development is still limited by the adsorber/solar collector component cost, and by the intermittence of the incident solar radiation, which makes it difficult to be competitive with conventional compression systems.

In the present work the description and the operation of a solar adsorptive prototype refrigerator using the zeolite-water pair is shown. The system operates under an intermittent cycle, without heat recovering, and is aimed to regenerate the adsorber with solar energy, using a SK14 solar cooker. The adsorber is mobile and is regenerated out of the refrigerator. No condenser is applied because the solar regeneration is made in the ambient air.

The purpose of the refrigerator is food and vaccine conservation in rural areas of Peru, where no electricity is available.

2. CHARACTERISTICS OF THE ADSORBENT–ADSORBATE PAIR

The choice for the working fluid – the adsorbate – depends on the evaporator temperature and must have high latent heat of evaporation and small molecular dimensions to allow an easy adsorption.

The prototype is aimed for cold storage, using water as adsorbate., whose most important property is the high enthalpy of vaporization (2438 kJ/kg at 25ºC). The pressure necessary to obtain temperatures around 0 ºC is about below 6 hPa.

With water as adsorbate, zeolite is a very suitable adsorbent. This material is basically porous aluminum silicate that can be found raw or synthesized, is innocuous, well available and is cheap. Zeolite is widely used in industrial applications, especially in hydration processes. In our case, spherical pellets of synthesized Zeolite of 4 mm average diameter are used (Fig. 1). For 30 ºC ambient temperature, the maximal adsorption capacity of the zeolite-water pair is about 0.3 kg of adsorbate/kg of adsorbent. The free energy for the desorption of water is about 1800 kJ/kg (from X = 0,3 to X = 0,05), (Hauer and Laevemann, 1998), resulting in a C.O.P of about 0,25. To regenerate this adsorbent, temperatures around 200 – 300ºC are necessary. These temperatures can be reached with a SK14 solar cooker or with a CPC solar collector with weak concentration.

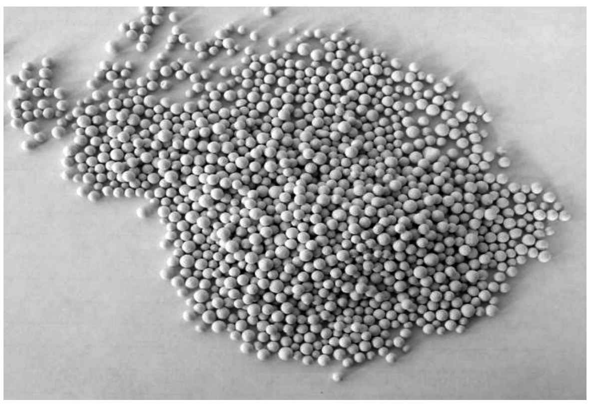

Fig.1. Pellets of synthesized zeolite (from Zeo -Tech, Germany)

3. FUNCTIONING PRINCIPLE

The refrigeration system is based on an intermittent cycle, without heat recovering. This cycle consists of two typical stages: the cooling stage, characterized by the adsorption process, when the evaporation of the working fluid (the adsorbate) takes place, and another consisting of the regeneration of the solid medium (the adsorbent) by solar energy, when the adsorbate is condensed.

The solar refrigerator for cold storage is basically composed of an evaporator positioned at the top of a cold chamber connected to an adsorber (a cylindrical steal chamber containing zeolite) and a SK14 solar cooker for regenerating the adsorbent. Its principle of functioning is shown in figures 2 and 3.

The refrigeration process begins when the adsorber chamber, with dry adsorbent, is connected with the evaporator, containing the adsorbent, and the pressure in the system is lowered below 2 hPa. At that moment, the evaporation takes place in a very quick process, attaining temperatures bellow 0 ºC, when the solid-gas equilibrium is reached and remaining at these temperatures for the whole evaporation period. When the adsorber is saturated, it is disconnected from the evaporator (letting in air at atmospheric pressure) and put in the solar cooker for regenerating.

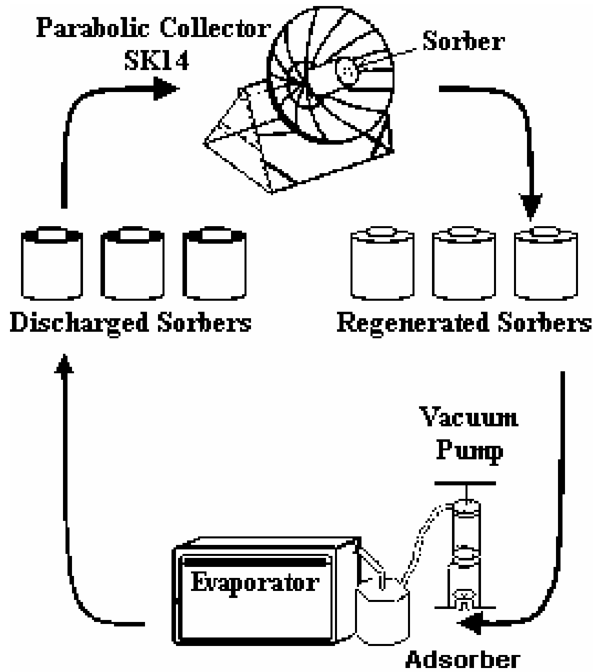

Fig.2. Scheme of solar cooler (from EG-Solar)

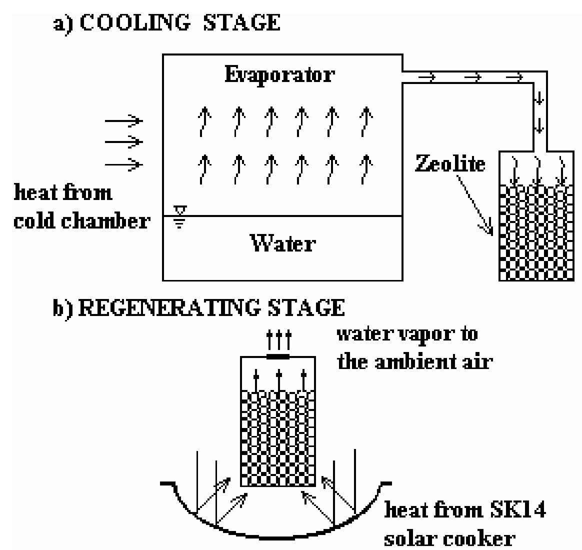

Fig.3. Scheme of functioning of the zeolite-water solar refrigerator.

4. DESCRIPTION OF THE PROTOTYPE

The actual prototype of the solar refrigerator (Fig. 4) was constructed by EG-Solar, in Germany, and donated to the Renewable Energy Center of the National Engineering University (CER-UNI), in Lima, Peru, to be tested. The adsorber of this refrigerator is mobile, to allow the regenerating process out of the system, by using a solar SK14 cooker. Therefore, no condenser is used because the desorbed water is transferred to the ambient air. For each cycle, it is necessary to evacuate the system with a vacuum pump and to restore the water. The evaporator of stainless steel has the shape of a rectangular box with a heat transfer area of 0.15 m^2 and a capacity to contain up to 1 liter of water. It is positioned inside the cold storage chamber at the top, fixed to the lid. The external dimensions of the refrigerating chamber are 0.71 x 0.56 x 0.49 m and its useful capacity is of 44 liters. The adsorber is composed of a vacuum tight stainless steel cylinder containing a removable vessel with 4.2 kg of zeolite (Fig. 5) and can be connected with a vacuum hosepipe to the evaporator.

Fig.4. Zeolite-water refrigerator. The adsorber chamber, at right, can be opened, in order to remove the vessel with zeolite

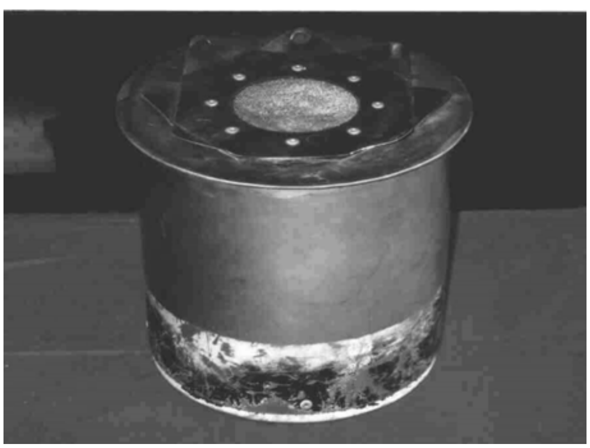

Fig.5. Metallic vessel containing the zeolite.

In figure 5 the whole refrigeration process is shown in a isosteric diagram. At the end of the refrigeration cycle, at point "B", the system is opened, loosing the vacuum, in order to extract the vessel with the zeolite and to regenerate it (drying it at high temperature in a stove or solar cooker). After regeneration of the zeolite, it is put again in the adsorber chamber and with a mechanical pump the vacuum is restored below 2 hPa.

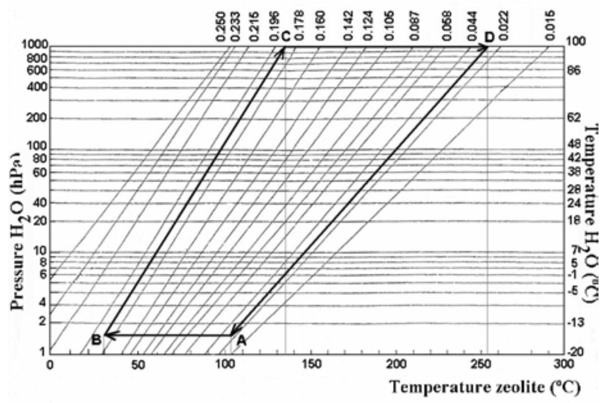

Fig.6. Isosteric diagram of the EG-SOLAR prototype refrigerator (squematic);; AB: isobaric adsorption, CD: isobaric desorption, DA: restoring of vacuum (adapted from Zanife T. (1991)).

5. EXPERIMENTAL RESULTS

5.1 Regeneration process

Figure 7 shows drying curves of the used zeolite (from Zeo-Tech), obtained at atmospheric pressure with small samples of zeolite put at different temperatures in an electric stove. From these curves we conclude that it is not recommendable to reduce the humidity from its initial 30-35 % (dry bases), at saturation, to below about 5%. Further drying would result only in a small improvement of the capacity of the zeolite to adsorb water, but at the expense of a big amount of additional energy and time required.

We conclude therefore that 250 °C is an appropriate regeneration temperature. At this temperature one gets in 2,5 hours zeolite with 5 % humidity (with 84% of the water extracted). At 200 °C, one would need 6 hours to reduce the humidity to 10 % (extracting 66 % of the water).

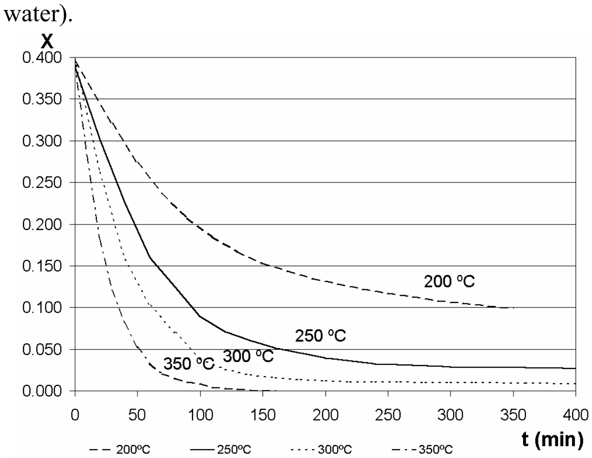

Fig. 7. Drying curves of zeolite at different temperatures (humidity in dry bases)

This high regeneration temperature of zeolite is a shortcoming of this adsorber, making it difficult to regenerate it with simple solar equipments. Originally, the EG-Solar refrigerator was thought to use the SK14 solar cooker, disseminated world wide through EG-Solar. But all our trials in Lima to dry the zeolite in the adsorber vessel putting it in the focus of the SK14 solar cooker failed, mainly because even very slow air flows around the vessel did not permit to heat the adsorber vessel up to the required 250°C. Therefore, we used only an electric furnace to regenerate the zeolite, postponing to find an appropriate solution for this stage of the solar refrigeration cycle.

5.2 Cooling process

First tests with the prototype EG-Solar refrigerator were made using a mechanical hand pump, but experiences showed that its use was unsuitable for obtaining the required pressure level of 2 hPa. Therefore, a small electrical vacuum pump, of 92 W and working at 12 Volt DC, was used. The operation time of this electrical pump to obtain the low pressure in the system was of about 10 minutes It was thought that the energy required for this pump could be provided by a small photovoltaic module (Ramos and Horn,2001).

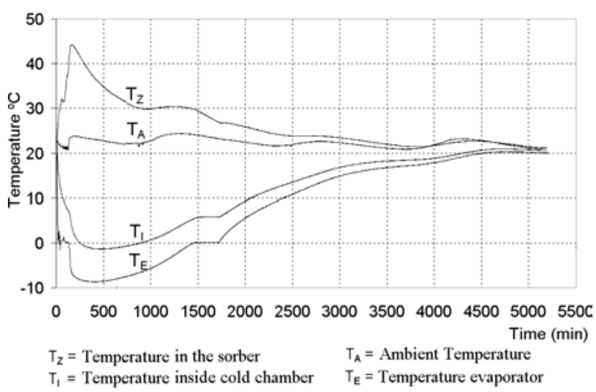

Fig.8. Different temperatures during cooling cycle; initial water amount: 0.5 kg

The results of the cooling experiments are shown in figure 8 and 9. Figure 8 shows the temperatures at different places in the system (cold chamber, evaporator, adsorber, ambient) and figure 9 gives the temperature and pressure in the evaporator for different initial water amounts.

A temperature of 0°C was reached in the evaporator in about 20 minutes, maintaining the temperature below 0°C for about 24 hours (or less, if less water was initially in the evaporator). The coldest temperature reached in the evaporator was minus 8,7 °C, with a pressure of 1,8 hPa (the saturation pressure of ice at this temperature is 3hPa). In the absorber, the temperature raised up to 45°C in 90 minutes, falling then slowly to room temperature (about 28°C), while, at the same time, in the evaporator the temperature increases in 3,5 days to room temperature and the pressure increases up to 6 hPa.

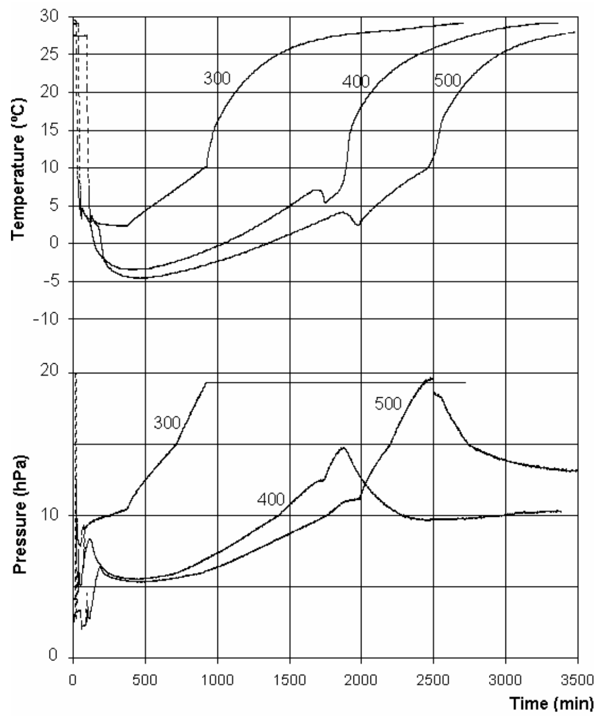

Fig. 8. Temperature and pressure in evaporator for different initial water amounts: 0,3 kg, 0,4 kg, 0,5 kg.

After some hours, during the period when the temperature and the pressure again rise in the evaporator, one observes again a falling of these parameters during some time. The moment this happens depends of the initial amount of water in the evaporator, and does not happen with initially 0,3 kg of water, as can be seen in figure 8. We think that this phenomena is caused by an initial partial obstruction with ice of the tube connecting the evaporator with the adsorber, if an initial grand amount of water in the evaporator violently evaporates, and subsequently cools below freezing, even in the hose, reducing so the possibility of the zeolite to adsorb water vapor in the evaporator. After some time this obstruction disappears and the adsorption process speeds again up, resulting in a new increase of the cooling during some time.

6. CONCLUSIONS

The evaluation of the EG Solar prototype refrigerator has shown that the intermittent water – zeolite adsorption cycle is appropriate for a refrigerator for food conservation in rural areas where no electricity is available. However, the prototype has some shortcomings, that have to be still resolved:

- The SK14 solar cooker does not permit to regenerate the zeolite (at least not with the geometry of the used adsorber vessel).
- The geometry of the used adsorber vessel does not facilitate homogeneous adsorption and desorption processes.
- Water freezes in the hose connecting the evaporator and the adsorber, obstructing so the adsorption process.
- The necessity to open the system in each cycle and to introduce distilled water (otherwise the porous of the zeolite will soon be obstructed) and to pump each time in order to get, and maintain, the necessary low pressure, is very difficult to fulfill in rural areas (for where the refrigerator is thought for).

Based on these results, we are now designing a modification of the refrigerator, based on the same intermittent water-zeolite adsorption cycle, but with a closed system (only at factory one has to pump the system), with a condenser and using a CPC solar collector, or a wood stove (in the jungle), for regeneration.

7. ACKNOWLEDGEMENT

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