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AN ADSORPTION REFRIGERATOR MODULE USING ACTIVATED CARBON-METHANOL PAIR

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Abstract. *This work presents the description and the results of an adsorption refrigeration module that uses the activated carbon-methanol pair. The adsorber (sorption bed) is constituted by a tube made of steel, connected to an evapo-condenser component, that works as evaporator during the adsorption process, and as condenser during the desorption process. One experimental bench was built to monitor and control the operation of the refrigeration module. Results of tests show that the control system can operate well and experimental cycles are presented for two control conditions: one when the adsorption and desorption process were quickly accomplished, and the other when those same processes were slowly done. The system is heated by an electric heater of variable potency and the cooling of the adsorber was simulated by using an ice thermo-accumulator. The experimental results indicate a performance coefficient (COP) around 0.015.*

Keywords*: Refrigeration, Adsorption, Activated Carbon-Methanol, COP.*

1. INTRODUCTION

Among the alternatives to produce cold, in substitution to the conventional systems of vapor compression, can be mentioned the adsorption refrigeration systems. These systems constitute an attraction for the use the solar energy as cheap and cleans energy source. The solar ice production could be important in developing countries for storage of agricultural products, food and medicines, especially in remote non-electrified areas.

In the last three decades, different solar adsorption systems have been proposed and tested, for the refrigeration or ice production. Adsorption techniques allow the cycling of large amounts of refrigerant fluid; this allows the dimensioning of the systems that adapt to several needs, from the ambient refrigeration (adsorption air conditioned), as for the production of ice (adsorption ice maker). The adsorptive pair should be chosen in agreement with the use of the system. On the other hand, these systems are the low coefficients of performance and the need of long periods for the adsorption completion.

Studies of solar adsorption refrigeration systems have been trying to increase the performance of their components. Severals works in that sense can be found literature, mentioning here some examples, Boubakri *et al.* (2000), Li and Wang (2002), Li *et al.* (2002), Boubakri (2003), Buchter *et al.* (2003), Andrade (2004), Gonzalez and Rodriguez (2007), Leite *et al.* (2007). Another research line has been developing prototypes that simulate the operation of refrigeration systems of great load, as the works of Kathab (2004, 2006), Ceballos, *et al*. (2004), Afonso and Silveira Jr. (2005). The work presented in this paper follows this last line.

Here, an adsorption refrigeration module that uses the activated carbon-methanol pair is described and the results of the operation are discussed. In the following sections the components of the prototype are detailed and the operation of each one. The physical quantities and the respective measure equipments are presented, as well as the operational way. Finally, the obtained results are compared with other works that use the same adsorptive pair.

2. DESCRIPTION OF THE ADSORPTION REFRIGERATION MODULE

The prototype has been designed and built based on the operation of an autonomous solar adsorption refrigerator, tested in 2003 at the Laboratório de Energia Solar, Universidade Federal da Paraíba, João Pessoa, PB.

The main component of the module is the adsorber (Fig. 1), constituted by a tube of stainless steel with an external diameter of 0.051 m and a length of 0.305 m. The adsorbent occupies an annular space between the tube wall and the axial tube formed by a metal net, through which the refrigerant fluid diffuses. The quantities of activated carbon and methanol introduced in the system are 0.175 kg and 0.2 kg, respectively.

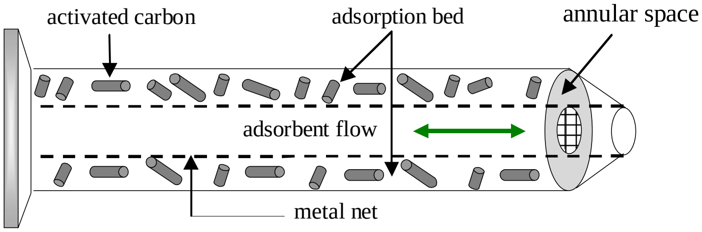


Figure 1. Scheme of the adsorber with its components.

The other component, the so-called condenser/evaporator (Fig. 2), is the part of the refrigerator system that exercises the condenser function, when happens desorption of the adsorbate, and exercises the evaporator function, in the moment of the adsorption. In the condenser occurs the condensation of the methanol coming of the adsorber. In the evaporator occur the production of the refrigerating effect, when happen the evaporation of the methanol, exiting of the evaporator for the adsorber.

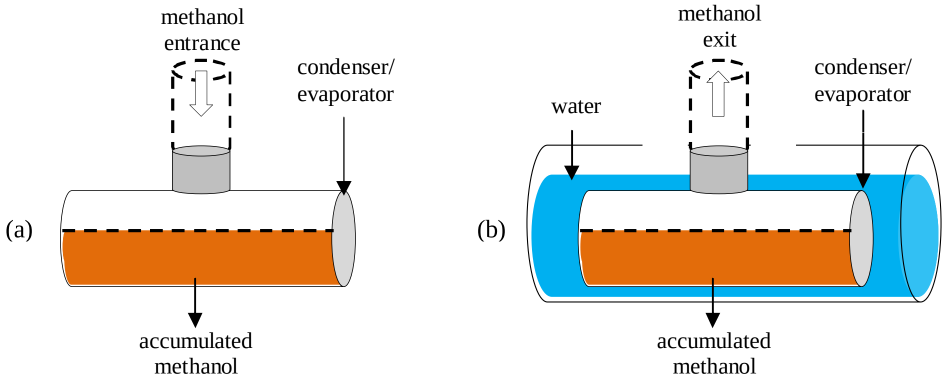


Figure 2. Scheme of the condenser/evaporator: a) stage of methanol desorption; b) stage of methanol adsorption.

The condenser/evaporator is connected with the adsorber by a tube of stainless steel and for a flexible tube. This tube owns valves, connectors, and sensor that are needed to the system operation.

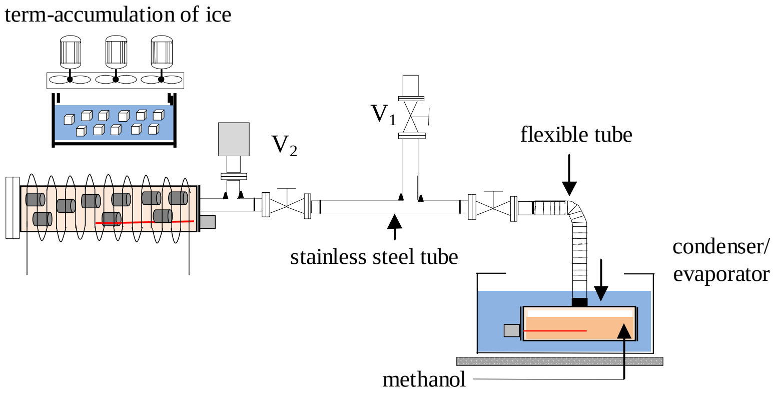


Figure 3. A general scheme of the prototype with their components and connexions.

The system still owns two components that are necessary to simulate several operational conditions: an electric resistance for heating of the bed adsorber and a reservoir of thermal accumulation of ice for the cooling, when necessary. These components allow to control the time of the adsorption and desorption processes.

A general scheme of the prototype with their components and connexions is shown in “Fig. 3”. “Figure 4” presents experimental apparatus with the arrows indicating the direction of the methanol flow during the processes of adsorption (blue) and desorption (red).

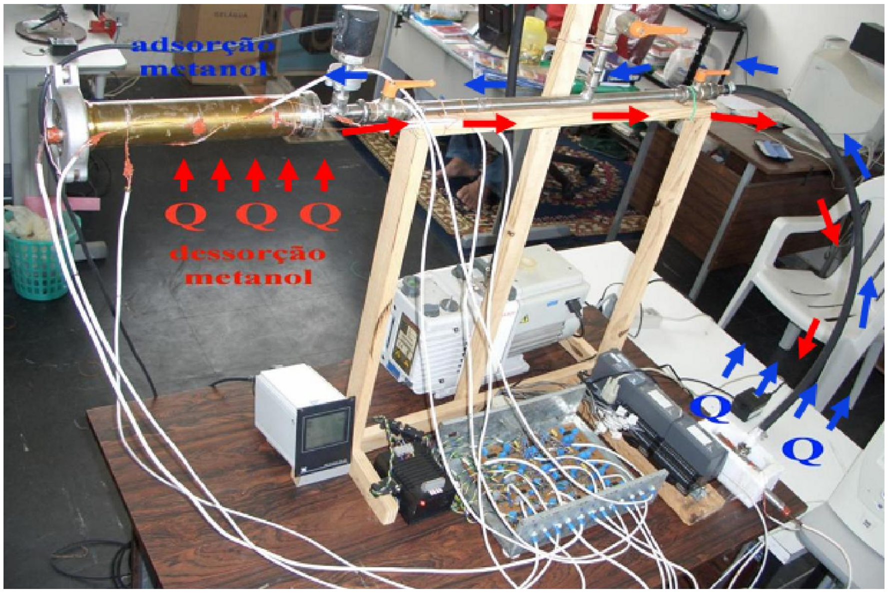


Figure 4. A general view of the experimental module.

3. ADSORPTION REFRIGERATION THERMODYNAMIC CYCLE

A solar adsorption refrigeration system is based on an intermittent cycle, which occurs without heat recovering. This cycle consists of two typical stages: one is characterized by the adsorption process, when the evaporation of the working fluid (the adsorbate) takes place; and another consists of the solid medium (the adsorptive bed) regeneration by solar energy, when the adsorbate is condensed. The adsorption refrigeration module simulates those processes, producing smaller duration cycles by the use of electric resistance and thermal accumulation of ice (Fig. 5).

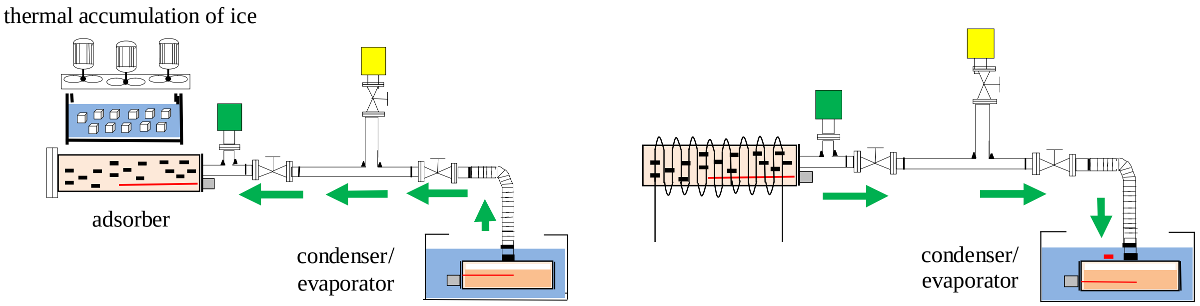


Figure. 5. Scheme of the adsorptive prototype and its operation: (a) Stage of refrigeration; (b) Stage of regeneration.

The refrigeration stage begins by the end of the heating, when the temperature and the pressure of the adsorber decrease; following an isosteric process, i.e., a process in which the adsorbed phase concentration (a) is constant. The evaporation takes place when the gaseous adsorbate flows to the adsorber, producing the refrigeration effect until the adsorber temperature reaches a minimum value. The thermal accumulation of ice can be activated to control the speed of the methanol flow that arrives in the adsorber.

By another isosteric process, the adsorber is heated by the electric resistance, increasing the temperature and pressure until they reach the condenser pressure. Then condensation takes place and the adsorbate is transferred to the condenser until the adsorber reaches a maximum temperature. The ideal thermodynamic cycle can be represented by two isosters (iso-lines with constant adsorbed phase concentration) and two intercalated isobars, as shown in “Figure 6”.

Processes 1 → 2 and 2 → 3 represent the cooling of the adsorbent and the adsorption, respectively, and processes 3 → 4 and 4 → 1 describe the regeneration stage of the adsorbent (heating and desorption).

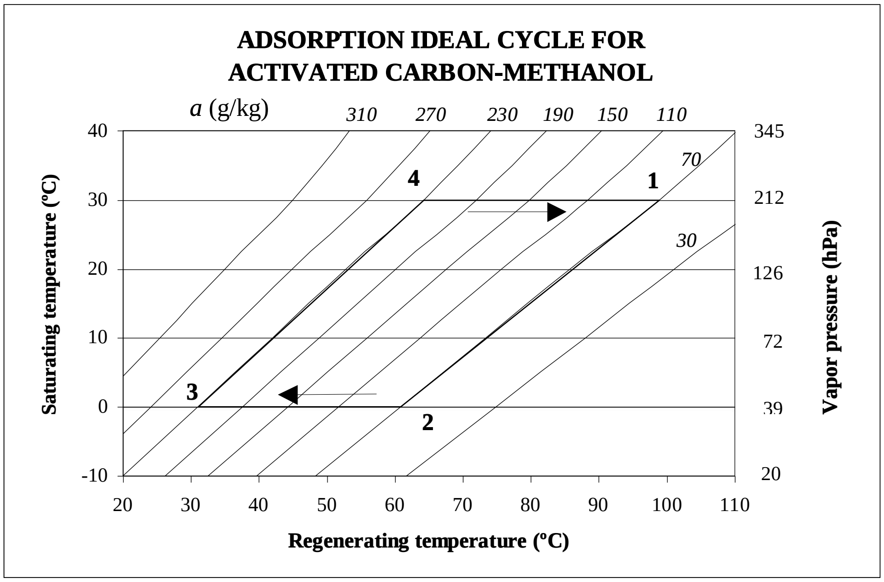
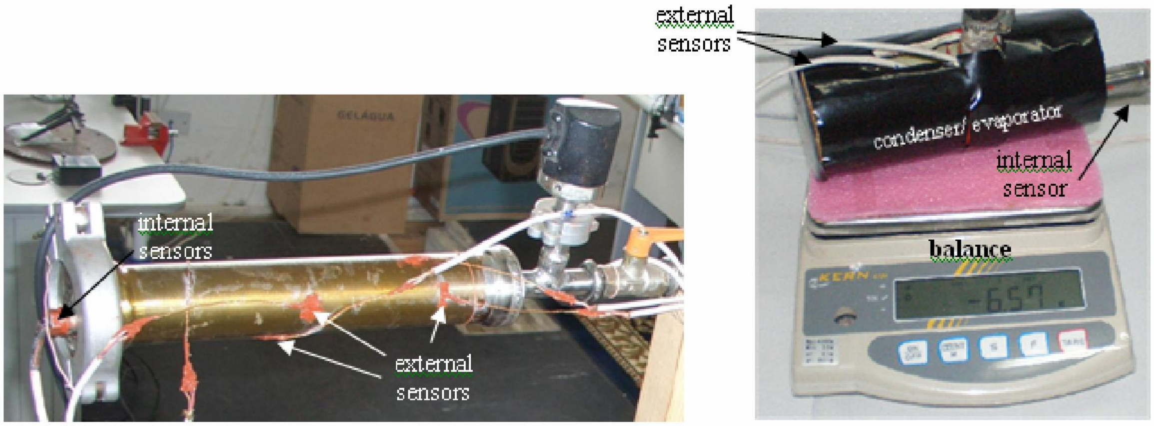


Figure 6. Network of activated carbon-methanol isosters and theoretical cycle.

4. PARAMETERS MEASUREMENT

The experimental tests involve the measure, in real time, of the following greatness: internal pressure of the system, internal and external temperatures in the adsorber and the condenser/evaporator, ambient temperature and the mass of condensed methanol.

The pressure was measured with a piezometric sensor installed between the adsorber and the condenser/evaporator (Fig. 7a and 7b). By using thermo-resistive sensors Pt-100, the temperatures in different points of the module (adsorber, condenser/evaporator) were measured and recorded at each ten minutes. The uncertainties in the measurements of the temperature is about 0,5 ^{o}C, while in the pressure measure is 0,2%. For measuring the temperature of the adsorbent and that inside the condenser/evaporator, we used a probe that was placed at a central position of these components.



(a) **(b)**

Figure 7. Positions of the pressure and temperature sensors in adsorber and condenser/evaporator.

The ambient temperature is measured by a Pt-100 exposed to the air-side. The measurement of the condensed mass of methanol is made with a semi-analytical digital balance, model Kern EW 4200, where the condenser/evaporator is always connected (Fig.7b). The uncertainties in the measurements of the temperature is the 0,01 g.

All the sensors are connected to a data acquisition system, the Field Point of National Instruments. The Field Point sends the collected data to a computer where are stored in files.

5. RESULTS AND DISCUSSION

In this section, the resulting thermodynamic cycle is presented. The cycle time was two and half hour and was initiate with the desorption stage, viz. with the heating of the adsorber bed for the electric resistance. The volume of water in the evaporator was 200 ml. Figure 8 presents the variation of the temperatures of the components of the system and of the external ambient.

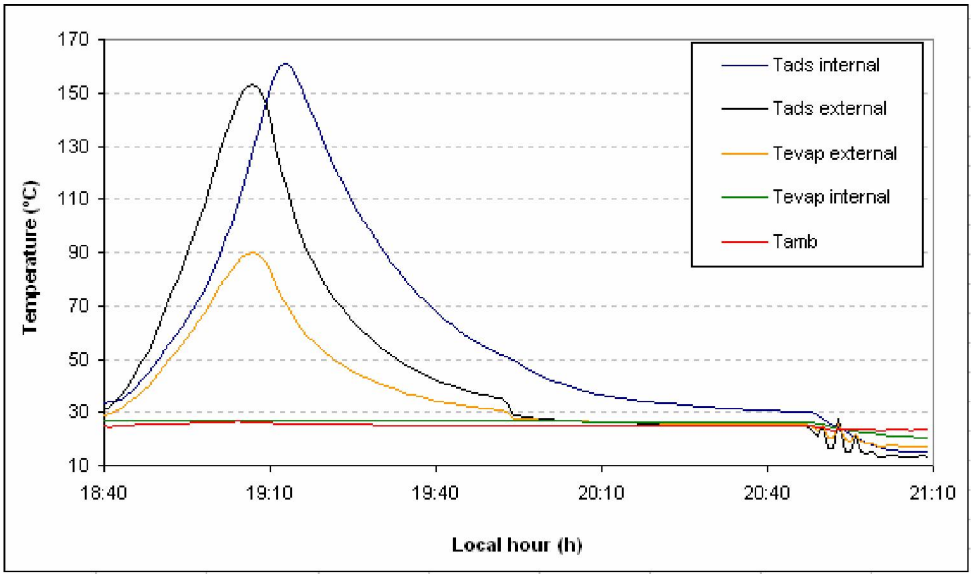


Figure 8. Positions of the pressure and temperature sensors in the adsorber and the condenser/evaporator.

During the desorption phase, when the methanol vapor is condensed, we noticed that the temperature of the condenser increases, as expected (Figure 8). After the end of the adsorber heating, when it reaches the maximum temperature, the condenser cools down until the beginning of the adsorption process. The mass variation in the condenser/evaporator can be observed in the Figure 9; the measured mass variations were compatible with the values obtained from calculations.

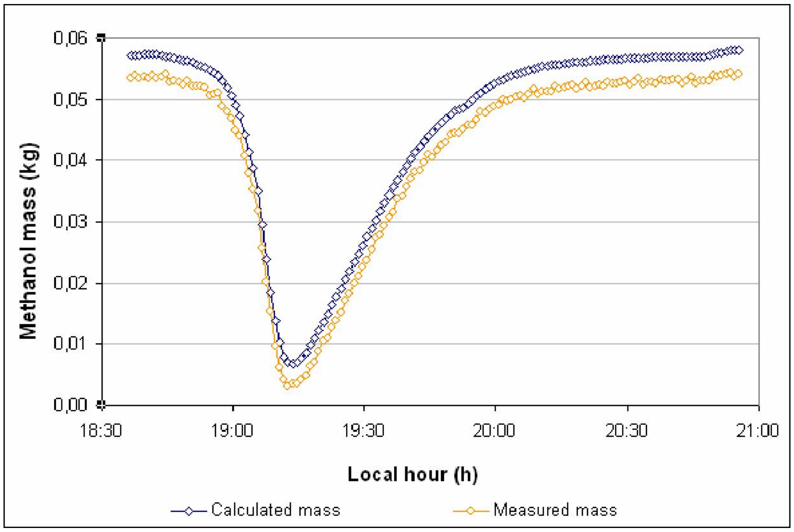


Figure 9. The mass variation in the condenser/evaporator (blue, the calculated mass; yellow, the measured mass).

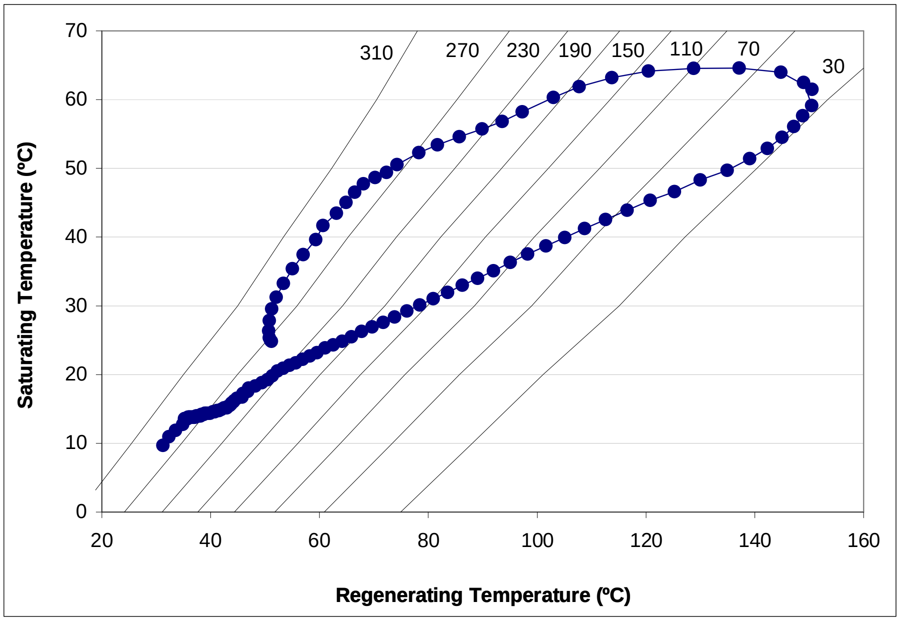


Figure 10. Experimental adsorption thermodynamic cycle.

Figure 10 shows the experimental adsorption thermodynamic cycle. From the plotted cycle, we can easily obtain the extreme temperatures concerning the desorption and the adsorption processes. Moreover, another practical aspect of the adsorption cycles consists in obtaining directly the minimum temperature of the saturated methanol inside the evaporator. For this cycle, the value was about 10^oC.

According to Figures 8 and 9, the desorption period was around 45 minutes while the adsorption period was around one hour and 45 minutes. This can explain the low system performance. The smallest temperature reached by the evaporator depends on the desorbed methanol mass, since the desorption process is a slow phenomenon (Ruthven, 1984).

6. CONCLUSION

In this work an adsorption refrigeration module that uses the activated carbon-methanol pair was described and the results of the operation were discussed.

Results of tests show that the control system can operate well and experimental cycles are presented for two control conditions: one when the adsorption and desorption process were quickly accomplished, and the other when those same processes were slowly done.

The system is heated by an electric heater of variable potency and the cooling of the adsorber was simulated by using an ice thermo-accumulator. The experimental results indicate a performance coefficient (COP) around 0.015

This value is considerably smaller than other experimental results, as the ones obtained by Khattab (2004) and by Ceballos et al. (2005), whose values were, respectively 0.15 and 0.2. This discrepancy is due to a scale factor that implies in a very small amount of methanol and, consequently, a lot of useful energy losses in the different components of the refrigeration module.

7. ACKNOWLEDGEMENTS

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