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Experimental Analysis of a Solar Adsorption System Refrigeration Cycle with Silica-Gel/Water Pair

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ABSTRACT

Adsorption refrigeration technology such as green refrigeration method, following environmental protection and growing economic development, has received much attention. Which are considered more environmentally friendly alternatives to conventional compression refrigeration, since they can use refrigerants that do not contribute to ozone layer depletion and global warming.

The silica gel -water is the adsorbent-adsorbate pair used in this paper . Compared with other adsorbents (activated carbon - methanol, Zeolite - water), silica gel-water presents the advantage of excellent physical and thermal properties of water (high latent heat of evaporation, low viscosity, high thermal conductivity , thermal stability in a wide range of operating temperature and a compatibility with several materials) as well as good adsorption property of silica gel (high adsorption/desorption rate and low generation temperature). The couple of silica gel-water can be classified as the best couple for adsorption cooling applications. This paper presents an experimental study of a solar adsorption refrigeration system for three typical days. The variation of the solar flux, the characteristic of temperatures of the solar collector as well as the temperatures of the various components of the adsorption chiller allowed seeing the effect of the solar flux on the various parameters and the performance of the adsorption chiller for two different cases : solar/aerothermal coupling and the solar /geothermal coupling system.

Keywords: Experimental study, Solar adsorption cooling system, Solar, Aerothermal, Geothermal

INTRODUCTION

The use of solar energy in sunny countries is an effective way to overcome the lack of energy especially in rural areas where it is sometimes difficult and expensive to feed them with the conventional power grid. Among solar thermal transformation processes, solar refrigeration is the most suitable application for storing foodstuffs and pharmaceuticals. It is therefore important to exploit this natural resource particularly in the field of cold production.

Many scientists and ecologists are therefore in favor of a technology capable of ensuring the ecological future of our planet. Alternative systems must use environmentally sound refrigerants and have high performance to reduce CO2 emissions contributing to the greenhouse effect. These environmental problems have given renewed interest to another sector of sorption refrigeration machines (absorption and adsorption), which represent an interesting alternative in this field. All fluids used in these are benign for the environment whether it is ammonia, water or alcohols.

Another concern with conventional refrigeration technology is the availability of energy. In rural areas where the conventional electricity grid is lacking, the treatment of perishable products is a serious problem, especially in developing countries. However, in these countries the solar potential is important, so solar sorption refrigeration is the right solution. The field of application of this type of refrigeration is vast, let us quote: the cold agribusiness, the commercial cold, the domestic cold, the medical cold. Several works in the field of adsorption refrigeration and tri-generation have been successful [1-5] and refrigerators have been realized [6-11].

Nidal H. et al. [12] presented a new design of a solar adsorption refrigeration unit that consists of four adsorbent beds with different types of activated carbon (jojoba seeds, palm seeds, coconut and activated charcoal). Ruud J.H. et al. [13] have designed and experimentally studied an adsorption cooling system with the silica gel / water pair. The system studied in this work consists of two identical adsorbent beds, operating in phase opposition to ensure the continuous production of cold. Chekirou [14] has developed a model of an adsorption refrigeration machine that gives the influence of the various parameters on the efficiency of the machine. Miyazakia [15] developed a model of a group of two-element sorption ice water production to study the influence of the variation of the cycle time on the performances of the group. Wang [16] experimentally studied the influence of mass and heat recovery on the performance of a chilled water production unit.

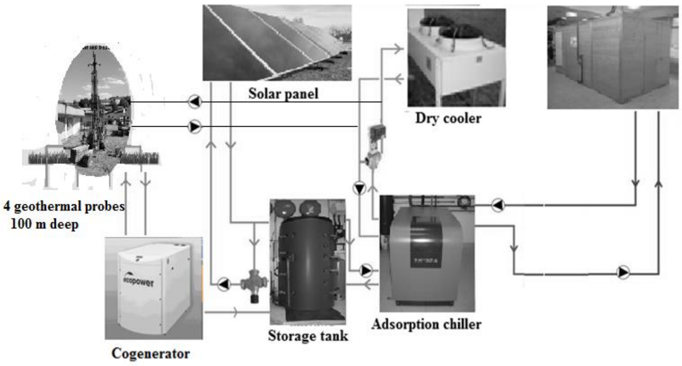
EXPERIMENTAL DEVICE

The ENERBAT platform (Fig.1) is a tri-generation unit of energy, supplemented by a renewable energy source (solar), coupled with a wooden bizonal construction. The tri-generation consists of a gas cogeneration coupled to an adsorption refrigerating machine.

The hot water storage tank, with temperature stratification, presents the central element of the system. It distributes the heat needs, both on the climatic chamber and on other equipment. It is supplied primarily by solar panels on the roof and by a natural gas co-generator in case of low sunlight. The cooling requirements are provided by an adsorption refrigeration machine fed by the stratification flask.

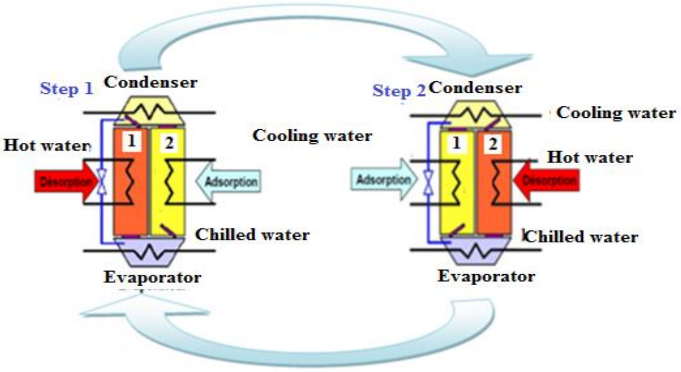
Finally, excess heat and cold produced are directed to air heaters that dissipate the surplus in the room.

Figure 1: Experimental device (Enerbat plateform).



A adsorption machine with two adsorbent beds (fig.2) comprises two compartments filled with adsorbent (silica gel), a condenser and an evaporator.

Figure 2: Schematic diagram of two bed solar-powered adsorption chiller.



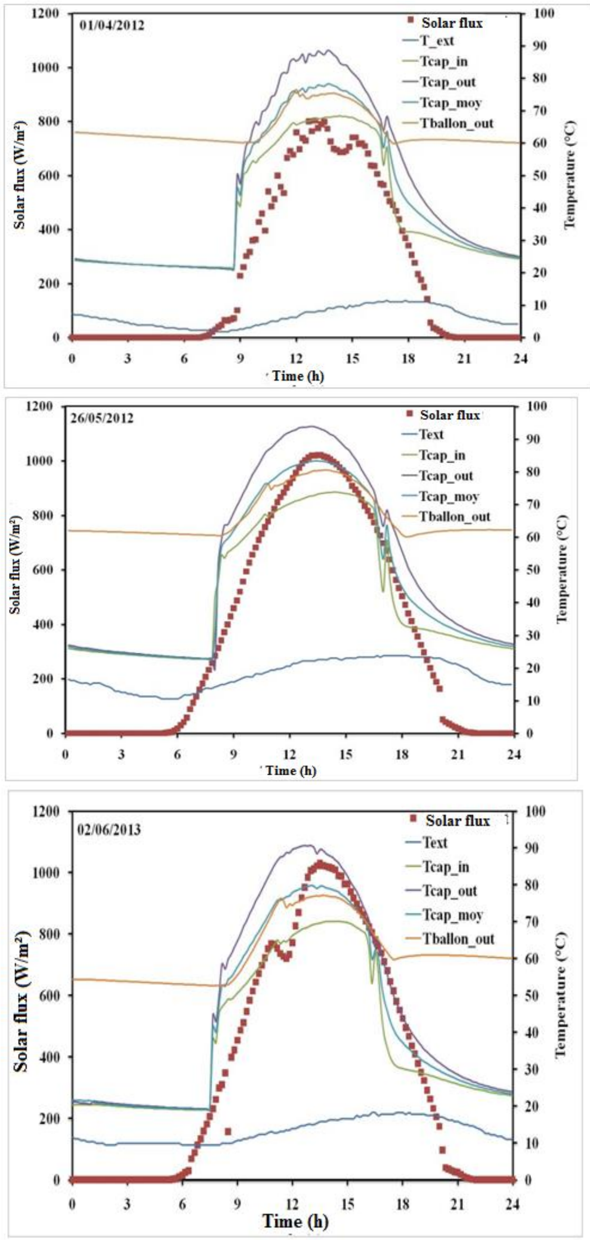
The adsorbent of the first compartment (reactor 1) is "regenerated" by heating (solar hot water), the water vapor thus generated being sent into the condenser where it condenses. The liquid water, via an expansion valve, is sent at low pressure into the evaporator where it evaporates (cold production phase). The adsorbent of compartment 2 maintains the low pressure by adsorbing this water vapor. This compartment must be cooled to maintain the adsorption process. When the production of cold decreases (saturation of the adsorbent in water vapor), the functions of the two compartments are exchanged by opening and closing valves.

EXPERIMENTAL RESULTS

In order to understand the operation of the installation, we start by analyzing the experimental results. The evolution of the global solar irradiation, the outside temperature, the inlet / outlet temperature and the average sensor temperature are shown in fig.3.

The sunshine received by the sensor field increases gradually, and the temperature of the water at the outlet of the solar collectors (Tcap_out) begins to increase to exceed the temperature of the hot water tank (Tballon_out). Under these conditions, the three-way solar circuit valve, located between the solar collector field and the hot flask, opens to heat the water in the hot water tank.

Figure 3 : Instantaneous evolution of the solar irradiation and the exit, entrance and outside temperatures for the city of Nancy, for three typical days.



There are four intervals:

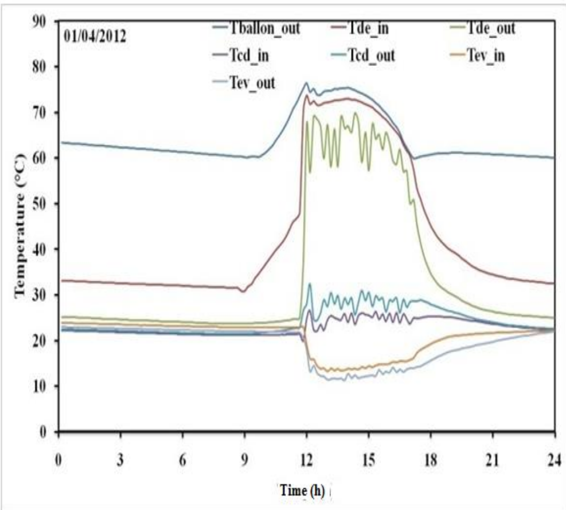
1. First Interval - There is a rise in outlet, inlet and outdoor temperatures as a function of time due to the considerable increase in overall illumination.
2. Second Interval- Exit, inlet, and outdoor temperatures continue to grow. But the rate of increase decreases

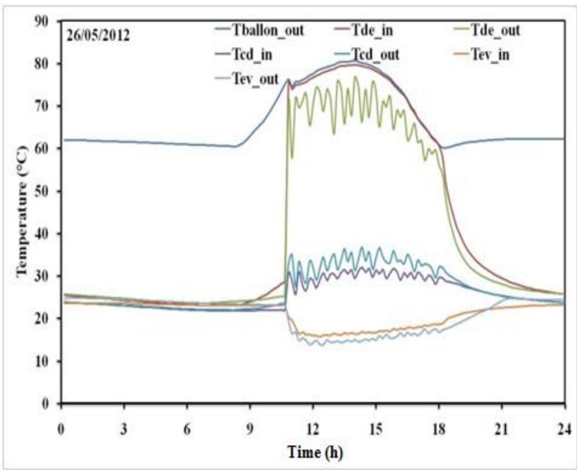
because of the stabilization of solar irradiance, this is justified by the inertia of the absorber tube.

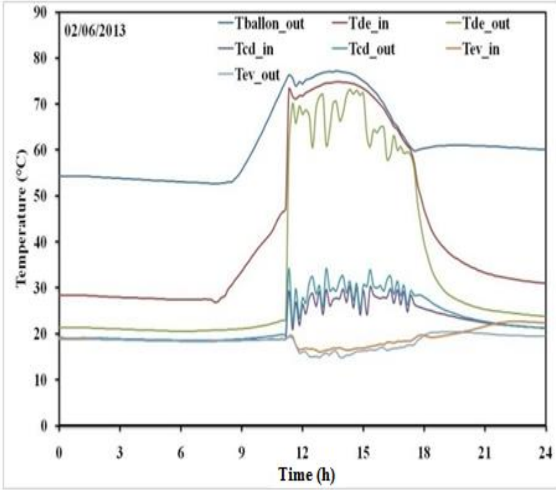
3. Third Interval- Exit, inlet and outdoor temperatures decrease with decreasing solar irradiance.
4. Fourth Interval- Lowering Output, inlet and outdoor temperatures continue, due to decreasing solar irradiance.

Fig.4 shows the variation of the storage tank outlet temperature and the desorber inlet / outlet, condenser and evaporator temperatures. Note that the curves have the same variation for all days. The desorber inlet temperature follows the variation of the balloon outlet temperature (which has the same variation in solar irradiance), At 12h (1st April), 10h and 50mn (26 May) and at 11h and 20mn (2 June), the temperature of the upper level (Tballon_out) in the hot water tank reaches 74 ° C setpoint at which the adsorption machine started.

Figure 4 : Evolution of the outlet temperature of the tank, inlet/outlet temperatureof desorber, condenser and evaporator as a function of time for the city of Nancy, for three typical days.







By observing Fig.2, it can be noted that the evolutions of the inlet temperatures of the three sources are different. The temperature of the ambient source (Tcd_out) does not vary substantially throughout the day while that of the hot source (Tde_in) substantially follows the behavior of solar radiation. Finally, the temperature of the cold source decreases during the first hour before stabilizing the rest of the day. These variations have virtually no impact on refrigeration production since its value remains almost constant after the start-up phase.
One could therefore wonder about the influence of these three temperatures, on the cooling power produced and consequently on the thermal COP of the machine.

The variation of the powers of the cooling desorber (condenser + adsorber) and of the evaporator is presented in fig. 5.

The power can be written in the following form:

$$Q_{de} = mc_p(T_{de,in} - T_{de,out}) \quad (1)$$

$$Q_{ref} = mc_p(T_{ref,in} - T_{ref,out}) \quad (2)$$

$$Q_{ev} = mc_p(T_{ev,in} - T_{ev,out}) \quad (3)$$

Note that the operating time depends strongly on the value of solar irradiation. At startup, the powers called by the generator and the cooling tower are very important, as can be seen in Fig.3. These powers fall rapidly the first hour and then slightly during the entire operating period. Given the pace of these two powers, it seems that the machine does not really reach a steady state. This cooling capacity does not have the same pace as the other two powers exchanged by the machine.

In addition, we note that the average value on the day of the COP is 0.37 (April 1), 0.35 (May 26) and 0.36 (June 2).

Figure 5: Evolution of the Desorber, Cooling and Evaporator Power Versus Time for the City of Nancy

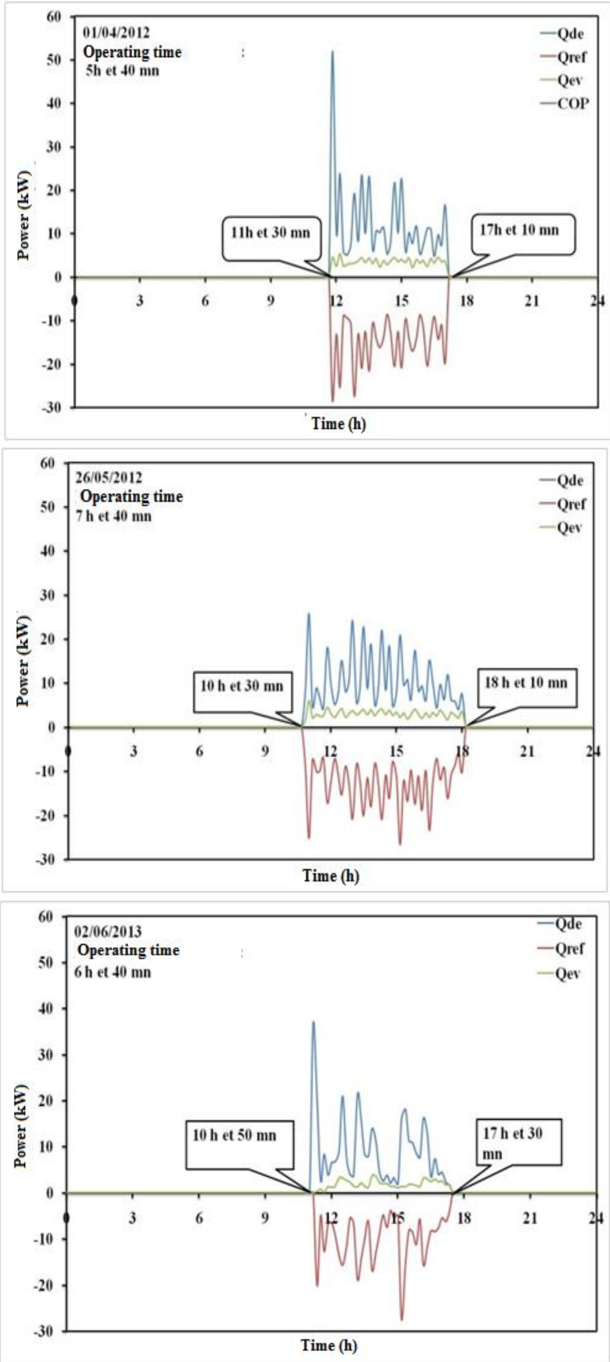


Fig.6 shows the variation of the temperature of the first sensor field as a function of the global solar irradiation. It is noted that for an irradiation of less than 200 W / m², there is no heating of water in the sensor, the sensor dissipates the heat and for an irradiation higher than 200W / m² we note that the temperature of the first sensor field (field closer to lamination balloon) increases with solar irradiation for the three typical days. It can reach a field temperature of 77 ° C for a sunshine of 1010 W / m².

Figure 6 : Evolution of the temperature of the first sensor field as a function of global.

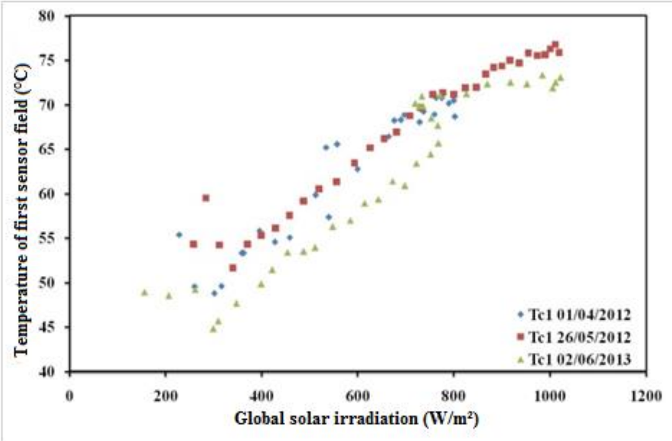


Fig.7 plots the evolution of the outlet temperature of the hot water tank (upper balloon temperature) as a function of the overall irradiation. It is noted that the temperature increases abruptly until reaching a temperature Tballon_out of 74 ° C, temperature at which the valve between the balloon and the desorber opens, after reaching the temperature of the balloon 74 ° C the temperature continues to increase but with a lower rate of increase.

Figure 7 : Evolution of the outlet temperature of the tank as a function of the overall irradiation for the city of Nancy, for three typical days.

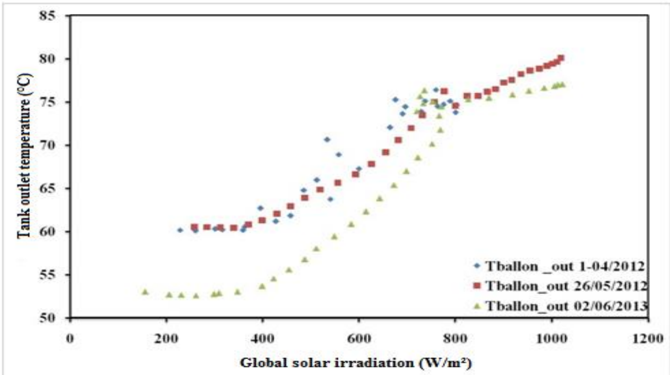
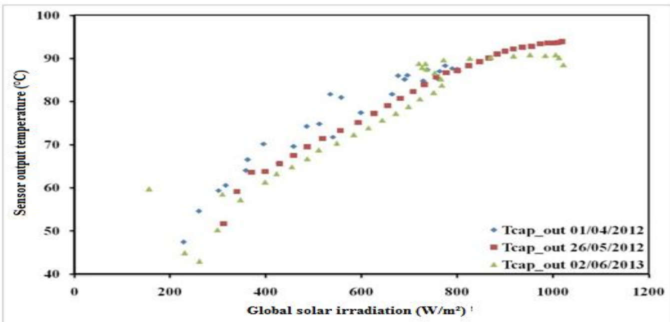


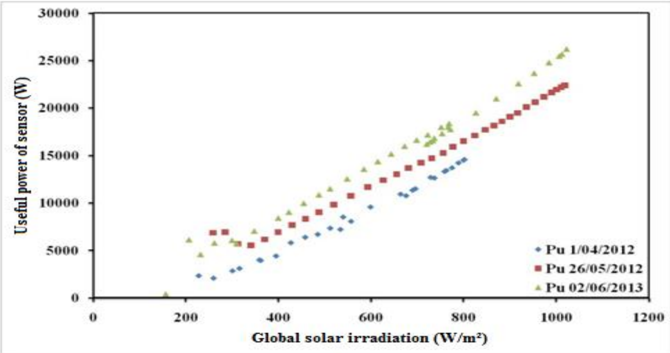
Fig.8 shows the variation of the sensor output temperature as a function of global solar irradiation. The curve has the same variation for the different days we can reach a temperature of 94 ° C for an irradiation of 1011 W / m².

Figure 8 : Evolution of the sensor output temperature as a function of global irradiation for the city of Nancy, for three typical days.



The useful sensor power is plotted in Fig. 9,

Figure 9: Evolution of the useful power sensor based on the overall radiation to the city of Nancy, for three days.



The power absorbed by the sensor can be calculated by the following formula

$P_a = G \cdot S \cdot \eta_{opt}$ (4)

$\eta_{opt} = \alpha \cdot \tau$ (5)

As S=n*s

With:

G: Sunshine; S: Total area. ; ηopt: optical efficiency; n: Number of sensors, s: Surface of a single sensor;

a: Absorptivity. (95%); τ: Diffusivity. (91.53%)

The variation is an affine line passing through the origin with a slope S. ηopt

The useful sensor power can be calculated by the following relation:

$$P_u = P_a - G * S\left[\frac{k_1(T_{cap,moy} - T_{ext})}{G} + \frac{k_{2'}(T_{cap,moy} - T_{ext})^2}{G}\right] \quad (6)$$

With S = 5.2

k1 and k2 are loss coefficients

k1 = 2.437 W / m2 , k2 = 0.0296 W / m2 K2

The useful yield : η u = Pu / Pa

The theoretical yield of the sensor is given by the following expression:

$$\eta_{th} = \eta_{opt} - \frac{k_1(T_{cap,moy} - T_{ext})}{G} - \frac{k_2(T_{cap,moy} - T_{ext})^2}{G}$$

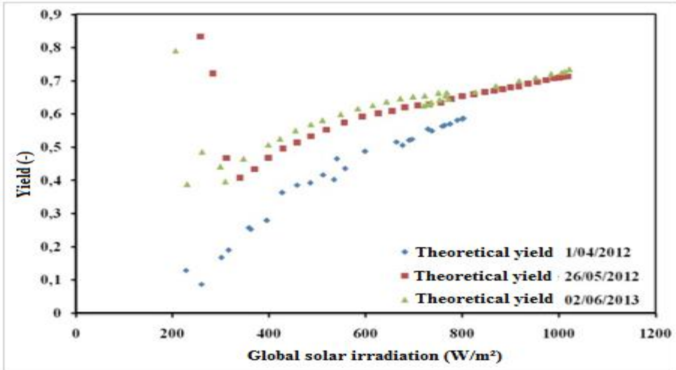
(7)

$$T_{cap,moy} = \frac{T_{cap,in} + T_{cap,out}}{2}$$

(8) For the different days the power increases with the increase of the global irradiation, the power for the month of June is the most important than that of the months of May and April. Power is highly dependent on solar irradiation.

The variation of the theoretical yield of the sensor as a function of global solar irradiation is shown in Fig. 10. The yield increases with solar irradiation for the two days of May and June. The irradiations are close so their evolutions are almost identical. The maximum yield is 73.33% for an overall irradiation of 1022 W / m².

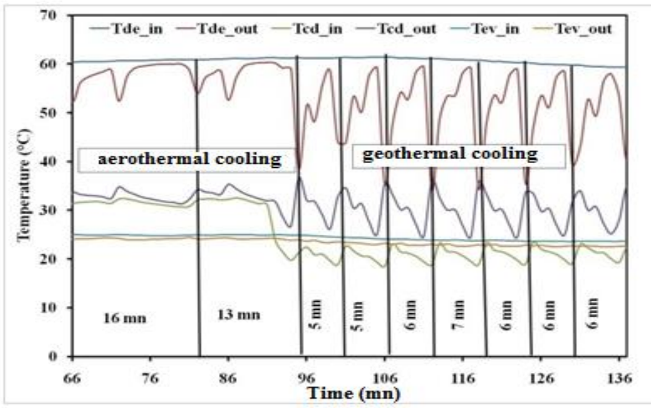
Figure 10: Evolution of the theoretical efficiency of the sensor as a function of the overall irradiation for the city of Nancy, for three typical days.



This part aims at studying the variation of the various parameters according to the source of cooling, two sources were studied a cooling with the ambient air and a geothermal cooling for depth of 100m.

Fig.11 shows the variation Cycle time as a function of the cooling source; the heating is done by a 100% solar source with the help of single-panes flat sensors and the cooling water of the adsorber and condenser is evacuated by cooling by the ambient air (aero-refrigerant) for the first 30 minutes and in the rest the cooling is linked to the geothermal pump, the setting in regime is established in 66 mn.

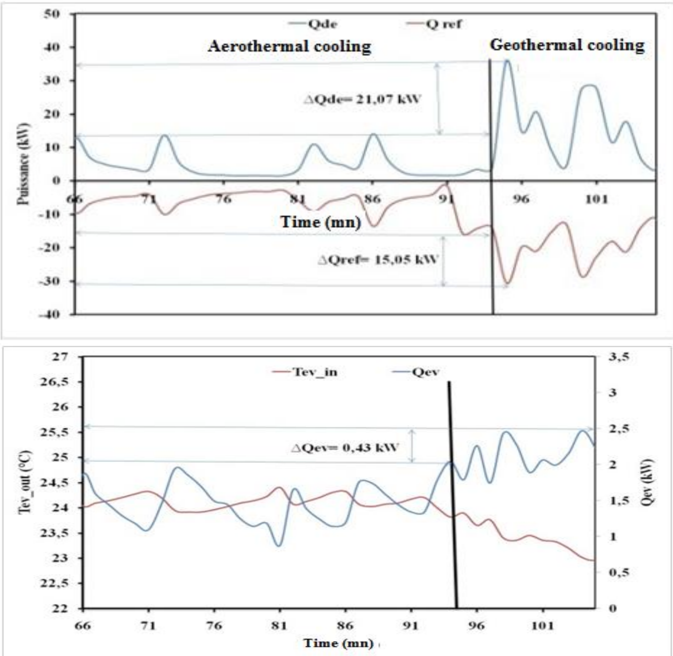
Figure 11: Variation of the cycle time according to cooling source.



It should be noted that the cycle time with geothermal cooling is shorter (almost half) than that with aero-refrigerant, the cooling of the adsorber at very low temperatures makes it possible to increase the adsorption rate. Condensation is much faster for lower condenser cooling temperatures.

Fig.12 shows the desorber, cooling and evaporator powers as a function of time for aerothermal cooling and geothermal cooling. Note that the desorber power with geothermal cooling is higher due to ΔT; the desorber at the beginning was adsorber the bed coolant was 28.5 ° C and then it will be heated to a temperature of 61 ° C, which requires a greater amount of heat to allow the desorption of water. As well as the production of cold is more important with that of geothermal cooling.

Figure 12: Variation of the powers of the different circuits for different cooling sources.



CONCLUSIONS

The study presented allowed the determination of the performances of a flat water solar collector. The operating principle, as well as the parameters influencing the efficiency of the planar sensors have been identified and defined.

The different temperatures measured at the sensor and the storage tank and the adsorption machine were presented and discussed. The effect of global solar irradiation on the different parameters is studied. The daily efficiency obtained indicates that the realized sensor is well designed.

In addition, it should be noted that the tests (clear sky) are performed for three typical days. From the analysis of the results some improvements can be proposed to increase the performance of the system, such as the study of the effect of inlet temperatures of different sources of the adsorption machine on its performance. It can be the subject of a numerical system.

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