Automation of a solar adsorption refrigeration system

Abdellah El Fadar
Laboratory of innovation technologies (LTI)
ENSA of Tangier, Abdelmalek Essaadi University
Tangier, Morocco
aelfadar@yahoo.fr

Ali Haddi*
Laboratory of innovation technologies (LTI)
ENSA of Tangier, Abdelmalek Essaadi University
Tangier, Morocco
haddi.ensat@gmail.com

Mohamed Becherif
FCLab FR CNRS 3539,
Femto-ST UMR CNRS 6174, UTBM
90010 Belfort Cedex, France
mohamed.becherif@utbm.fr

Jacques Jay
Laboratory CETHIL/Department GEN
INSA of Lyon
69621 Villeurbanne Cedex, France
jacques.jay@insa-lyon.fr

Abstract—**The purpose of this paper is to present the automation of a solar adsorption refrigeration system powered by a parabolic trough concentrator. This automation consists of the introduction of some adequate components such as solenoid valves, sensors (pressure, temperature and level) and pumps, which will be piloted by a programmable logic controller. Besides, to produce the electric energy necessary to the working of this refrigeration system and therefore to make it totally autonomous, a second system has been designed; it is composed of a parabolic dish reflector and a turbine coupled to an alternator that converts the mechanical work into electricity. Furthermore, in order to store the excess thermal energy delivered by the concentrator, a subsystem constituted of a pump and a supplementary reservoir is integrated to the main refrigeration system; the stored heat could serve to a domestic use. In addition to entire autonomy purpose of the unit during cold production, the simulation results showed that the proposed automation could enhance the system performance.**

Keywords: solar energy; adsorption; refrigeration; parabolic trough collector; automation.

NOMENCLATURE AND ABBREVIATIONS

h_{max}	Maximum level of ammonia in the reservoir 3
h_{min}	Minimum level of ammonia in the reservoir 3
h_{Res}	Level of the ammonia in the reservoir 3
P_1	Pressure of the adsorber 1
P_2	Pressure of the adsorber 2
Pum	Pump
Res3	Liquid ammonia reservoir
R	External radius of the adsorbent bed
r	Radial coordinate in the adsorbent bed
T_{heat}	Heating temperature
V_i	Valve i
HPT	High Pressure and Temperature
HWST	Hot Water Storage Tank
LPT	Low Pressure and Temperature
PDR	Parabolic Dish Reflector
PLC	Programmable Logic Controller
PTC	Parabolic Trough Collector

I. INTRODUCTION

Contrary to the fossil energy sources (oil, coal, gas, uranium,…), the renewable energies present considerable assets : they use the inexhaustible natural resources (sun, wind, water, earth,…), their exploitation neither contribute to global warming nor generate polluting gases and could play a vital role to satisfy the increasing demand of energy due to the demographic growth and the economic development.

In terms of solar energy, Morocco has a gigantic potential e.g. average irradiation of 5 kWh/m^2 per day (it may reach 7.64 kWh/m^2/day in Ouarzazate [1-2]). This potential could be exploited in numerous applications as drying, sea water desalination [3], electricity production [4-5], heating [6-7] and cooling [8], etc.

The cooling processes achieved by the means of the conventional machines are energy-hungry, especially when it is hot, and have moreover an ominous impact on the environment. The coincidence between the needs in cooling and the availability of the solar irradiation represents however an opportunity to overcome these problems through the development of the solar refrigeration technologies.

Among the various techniques of cooling processes, the adsorption refrigeration systems are currently the focus of considerable attention because they present several advantages: they use environmentally friendly working fluids such methanol, ammonia, water, etc. (zero ozone depletion potential and zero global warming potential), their cheap working costs and low maintenance, are not noisy and could use some resources of renewable energies such as the solar energy [9].

In spite of their advantages, these systems present some drawbacks, such as low coefficient of performance and intermittent character of the cycle, which constitute barriers to a more widespread application of this technology.

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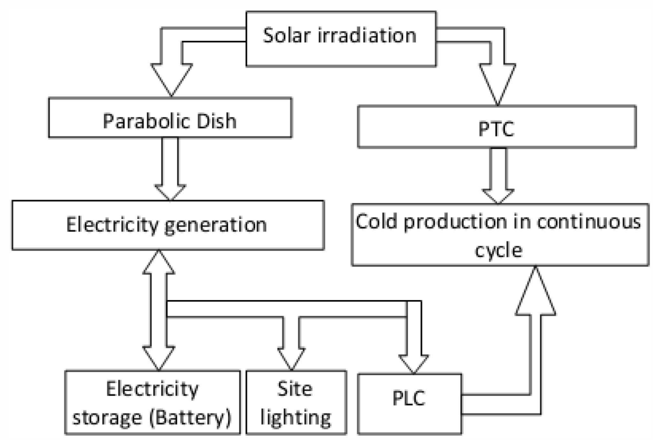

Figure 1. Schematic diagram of the global system.

In order to overcome these drawbacks, the automation of a continuous adsorption refrigeration system driven by parabolic trough collector (PTC) is proposed in this work. It consists of the integration of temperature, pressure and level sensors, which constitute the inputs of the programmable logic controller (PLC), give instantly the useful data on the working state of the system. According to the received data, the PLC, by means of a pre-established program, communicates to the refrigeration system the adequate orders via the solenoid valves and pumps, which constitute the outputs of the PLC.

II. DESCRIPTION OF THE SYSTEM

A schematic diagram of the global system is shown in Fig. 1. It is composed of three parts: the first for electricity generation, the second for cold production and the last one is conceived to produce hot water.

A. Electricity generation[4-5, 10]

To generate the electricity that should be supplied to some components of refrigeration system (PLC, solenoid valves, sun tracking system, fluid pumping, site lighting, battery charging), we propose the integration of a subsystem comprising the following elements:

- a parabolic dish reflector (PDR), that would produce the necessary electricity for the system. It tracks the sun in two axes and uses mirrors to focus radiant solar energy onto receiver located at the focal point of the dish. The thermal energy in a circulating fluid can then either be converted into electricity using an engine-generator (Stirling engine) coupled directly to the receiver, or it can be transferred via a heat transfer fluid to a central power-conversion system (Fig.2). The receiver temperature could reach nearly 1500°C [11-14].
- a battery, that should be charged by means of the PDR and would give the electric energy necessary to the whole system working during the night or cloudy days.

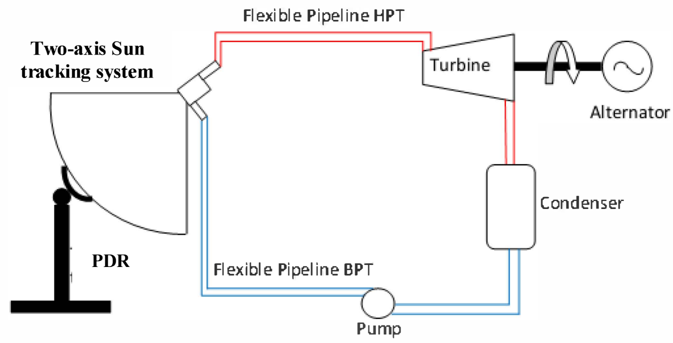

Figure 2. System of production of the electric energy.

B. Cold production

The production of the cold is achieved continuously by a solar adsorption refrigeration system [15], which is composed of the following components (Fig. 3):

- a parabolic trough collector that heats up the heat transfer fluid (water);
- two cylindrical adsorbers containing the activated carbon-ammonia pair;
- a reservoir of hot water, which allows heating of the two adsorbers and hence to generate the ammonia desorption;
- a reservoir of cold water, that allows cooling the two adsorbers and hence provoking the ammonia adsorption;
- a condenser, an evaporator, a storage tank of the liquid ammonia and solenoid valves;
- two circulating pumps: one for water pumping through the concentrator and the second for refrigerant (liquid ammonia) pumping.

Water from the hot water storage tank 1 (HWST1) is pumped through the receiver, placed along the focal line of the PTC, where it is heated and then flows back into the HWST1. The heat gained by the PTC from the solar radiation is accumulated in HWST1. Hot water from the storage tank is then used for heating the two adsorbers. The HWST1 temperature can be controlled by a differential thermostat controller.

For producing cold continuously, the two adsorbers have to be operated out-of-phase, i.e. when one adsorber is being heated up and then desorbs refrigerant into the condenser under high temperature and high pressure, the other adsorber is cooled down and adsorbs refrigerant vapour from the evaporator under low temperature and low pressure.

C. Hot water production

To store the excess thermal energy delivered by the PTC and hence to produce hot water for domestic use, a subsystem comprising an additional hot water storage tank (HWST2) and circulating pump is integrated to the refrigeration system.

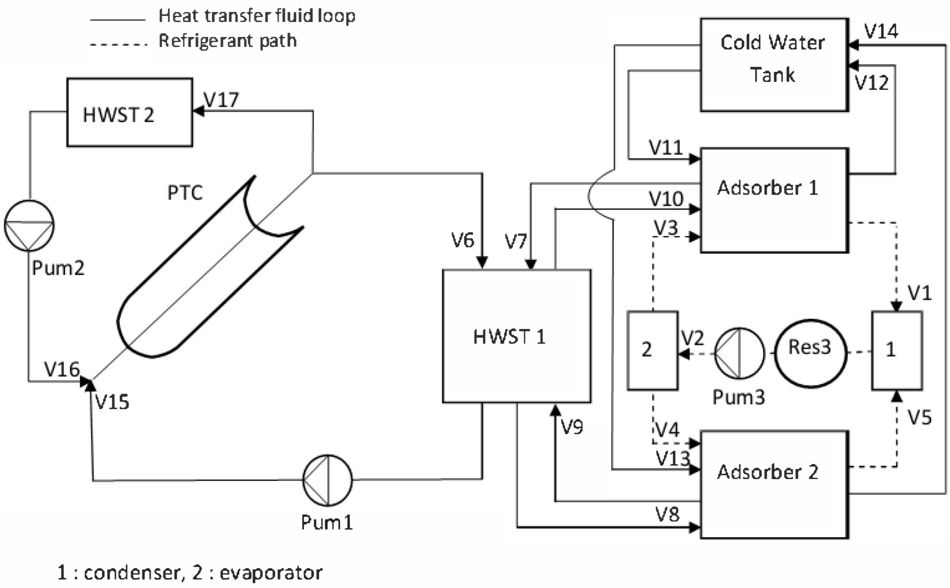

Figure 3. Schematic diagram of the solar powered continuous adsorption refrigeration system.

III. AUTOMATION OF THE SYSTEM

To automate different processes of the system working, it is proposed to utilize a control system comprising essentially a Programmable Logic Controller, which would control the opening or closing of different valves and pumps, according to the flow chart of the simulation program given in Fig. 4, which can be detailed as follows:

In the beginning of the heating process, the temperature of the hot water storage tank 1 (HWST1) is lower than a minimal temperature chosen equal to T_{min} = 70°C, the PLC operates the valves V_6, V_{15} and the pump 1; this allows to heat up progressively the water in HWST1. But, when the temperature of this tank reaches a maximal temperature taken equal to T_{max}=100°C, the heating process of HWST1 will stop, and heating of HWST2 will start (valves V_{16} and V_{17} will be opened).

When the adsorber 1 is being heated up (valves V_7 and V_{10} are opened, whereas valves V_8 and V_9 are kept closed) and then desorbs refrigerant into the condenser, the adsorber 2 is cooled down (V_{13} and V_{14} are opened; V_{11} and V_{12} are closed) and adsorbs refrigerant vapour from the evaporator.

During the heating process of the adsorber 1, its pressure increases and when the value of the condenser pressure is reached, the valve 1 will be opened allowing the gaseous ammonia to flow toward the condenser, where it condenses and pass then to the reservoir 3.

Simultaneously, the adsorber 2 is cooled down, its pressure decreases, and when this pressure reaches the evaporator pressure, the adsorber 2 is connected to the evaporator (pum 3 and V_2 are opened) in which the liquid ammonia evaporates. The resulting refrigerant vapour is readsorbed into the adsorbent bed contained in the adsorber 2 (V_4 is opened), while cooling is produced.

From the data indicated by the different sensors (temperature, pressure and level sensors), which are integrated to the installation, the heating and cooling processes of the two adsorbers are automatically inverted when the temperature of the adsorber being heated is maximum, but also when the level of the liquid ammonia in the reservoir 3 (Res3) reaches its maximum value.

IV. RESULTS AND DISCUSSION

In order to put in evidence the effect of the automation on the efficiency of the solar adsorption refrigeration system, a numerical study, based on a computer program written in Fortran is presented in this section. This study was described in detail in a previous work [15]. On the other hand, since the system operating is designed in a manner that the temperature of the HWST1 (heating temperature) ranges between 70 and 100 °C, we have undertaken this study with values of T_{heat} in this suitable range for desorbing a larger amount of refrigerant.

Figs. 5–9 represent the temperature variation of both adsorbers. It is observed that there is a temperature gradient in adsorbent beds, which depends of external radius of adsorbent bed, R, and heating temperature of the adsorbers, T_{heat}. After a certain time of heating process of each adsorber, the thermal equilibrium is reached. This time varies roughly between 35 min (obtained for high values of T_{heat} and low values of R) and 80 min (required for low values of T_{heat} and high values of R). At the thermal equilibrium, all points in the adsorbers have the same temperature value, which is equal to the maximum temperature in the adsorber being heated, and it is equal to the minimum temperature in the adsorber being cooled.

The thermal equilibrium point corresponds to the appropriate moment for inverting the heating and cooling processes of the two adsorbers, and hence improving the refrigeration system efficiency. This is because, beyond this optimal point, heating and cooling of the adsorbers cause respectively desorption and adsorption of very small quantities of ammonia. The automation undertaken in this work would clearly allow enhancing the refrigeration system performance.

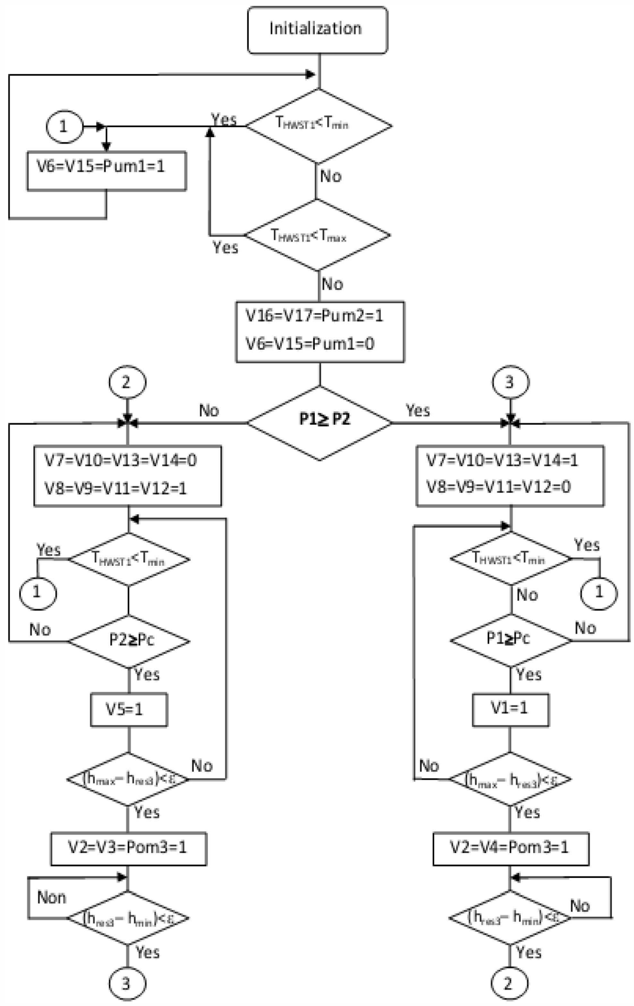

Figure 4. Flow chart of the computer program.

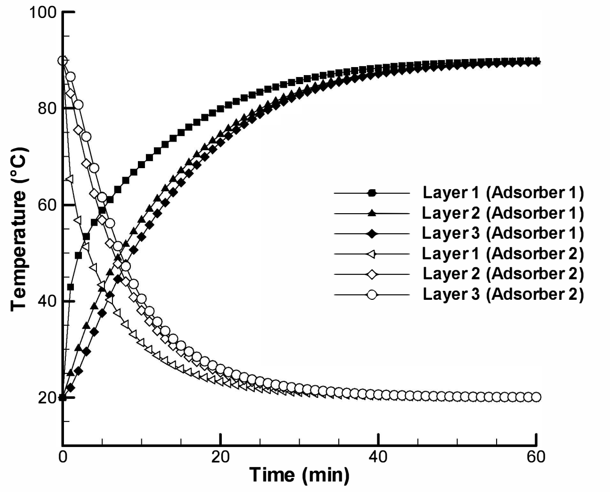

Figure 6. Temperature variation for the two adsorbers with time; Layer 1: r = 20.2 mm; Layer 2: r = 29.8 mm; Layer 3: r = 39.8 mm (R = 40 mm; T_{heat} = 90 °C).

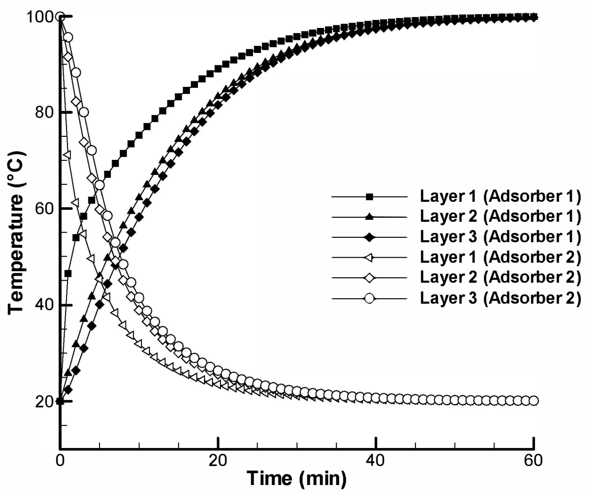

Figure 5. Temperature variation for the two adsorbers with time; layer 1: r = 20.2 mm; layer 2: r = 29.8 mm; layer 3: r = 39.8 mm (R = 40 mm; T_{heat} = 100 °C).

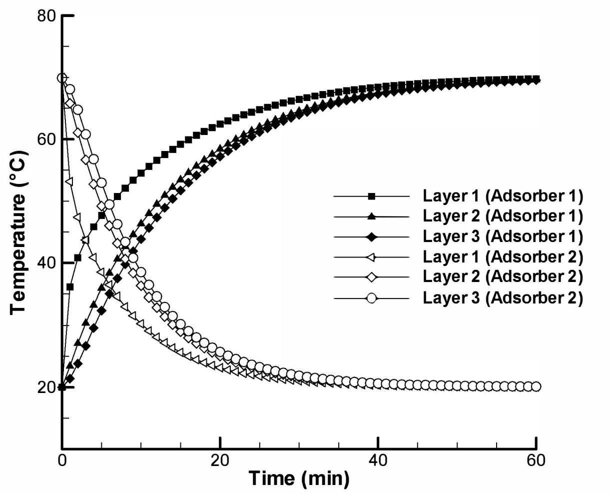

Figure 7. Temperature variation for the two adsorbers with time; layer 1: r = 20.2 mm; layer 2: r = 29.8 mm; layer 3: r = 39.8 mm (R = 40 mm; T_{heat} = 70 °C).

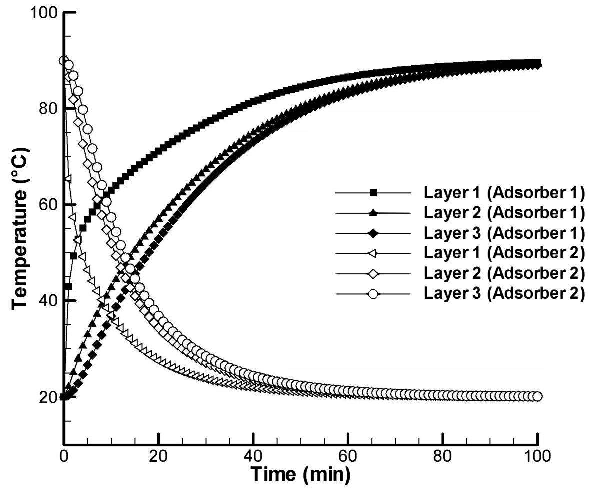

Figure 8. Temperature variation for the two adsorbers with time; layer 1: r = 20.2 mm; layer 2: r = 29.8 mm; layer 3: r = 39.8 mm (R = 50 mm; T_{heat} = 90 °C).

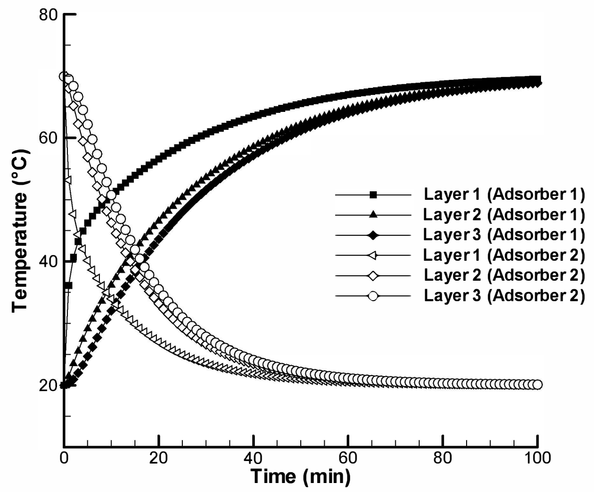

Figure 9. Temperature variation for the two adsorbers with time; layer 1: r = 20.2 mm; layer 2: r = 29.8 mm; layer 3: r = 39.8 mm (R = 50 mm; T_{heat} = 70 °C).

V. CONCLUSION

In this work, we have proposed the automation of a continuous adsorption refrigeration system powered by parabolic trough solar collector. The main objective of this automation is to liberate the human operator and to improve the system performance.

Furthermore, to optimize the solar energy utilization, we have integrated to this cooling system two subsystems:

- The first one is designed to produce hot water for domestic use by storing the excess thermal energy delivered by the parabolic trough collector.
- The second one is conceived to generate the electricity that should be supplied to different components of the whole system. A battery has been incorporated to store the electric energy and then utilize it during the night or cloudy days.

Finally, this cooling adsorption system, which has environmental benefits, operates autonomously and produces cooling continuously from freely available solar energy, could be further improved by performing more developmental researches which could make the current technology more widespread and would achieve its numerous advantages.

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