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Performance study of solar driven solid dessiccant cooling system in Algerian coastal climate

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***Abstract*—Using solar energy for cooling purposes is an attractive idea with good prospects for conventional air conditioning systems. The replacement of compressor cooling systems by solar driven desiccant cooling systems could make an important contribution to environmental protection. The main argument for the applicability of solar energy is that cooling loads and solar availability are approximately in phase. The "desiccant cooling" is an innovative technology of refreshing atmosphere using state changes of water and operating with solar energy. Our work involves the study of an evaporative cooling system by desiccation coupled with a solar installation, reducing thereby energy consumption and using clean and free energy. The results show that the system can control moisture and therefore provide acceptable comfort conditions, confirming that it is suitable for wet areas such as coastal cities of our country.**

***Keywords*— evaporative system, desiccation, humidification, solar cooling, environmental protection.**

I. INTRODUCTION

In order to limit the energy demand for air conditioning applications, it is necessary to develop alternative techniques to current refrigeration. The use of the heat generated by the solar collectors is an attractive option for the cooling process operating by heat [1, 2]. Solar cooling technologies currently available for commercial applications (absorption, adsorption, and desiccant cooling) are characterized by a thermal coefficient of performance fairly low (between 0.5 and 0.7) [3] compared to the compression process. That is why it is necessary to optimize the system to improve its average intrinsic performance and to maximize the contribution of the solar heat supply. This optimization will achieve larger primary energy savings and thus make these solutions more competitive. Desiccant dehumidification cooling technology is a viable alternative which has a successful track record over more than 60 years for industrial applications such as product drying and corrosion prevention, clean rooms, hospitals, museums, and other special cases requiring highly controlled humidity levels. A desiccant evaporative cooling system is a technology that can help address the previous shortcomings of conventional vapor compression technology. It is based on coupling active desiccant dehumidification with direct evaporative cooling. There is no need for a compressor in this case; the energy used in this system is for pumping water through the evaporative cooler, for pushing the air around the system, and to regenerate the desiccant wheel.

Both the solid and liquid desiccant cooling systems, in their various aspects, have been intensively investigated by many researchers. Henning et al. [4] conducted a parametric study of a combined desiccant/chiller solar assisted cooling systems and showed not only their feasibility but also the primary energy savings of up to 50% with a low increased overall costs. Shen et al. [5] used the molecular sieve desiccant wheel as adsorbent in a desiccant cooling system and simulated water vapour and carbon dioxide removal from the process air. The authors conducted an optimisation study involving the coefficient of performance, the temperature of desorption, the overall number of transfer units, and the adsorption time. Techajunta et al. [6] used silica gel as adsorbent and studied its regeneration with simulated solar energy in which incandescent electric bulbs were used to simulate solar irradiation. The regeneration rate was found to be strongly dependent on the solar radiation intensity while its dependence on the air-flow rate was found to be weak. Kadoma et al. [7] investigated the impact of the desiccant wheel speed, air velocity and regeneration temperature on the COP. The authors showed the existence of an optimal speed and established that the COP decreased when the airflow rate increased and, on the contrary, the temperature of regeneration and the cooling capacity had the same evolution tendency.

II. OPERATING PRINCIPLE

Desiccants are solid or liquid materials that attract moisture. Materials for HVAC desiccation are selected on the basis of their ability to hold large quantities of water, their ability to be reactivated, and their cost. To continually absorb moisture, a desiccant needs to be regenerated (dried) by passing hot air over it. When a desiccant wheel is used, the drying of process air and the regeneration of the desiccant can occur concurrently (Figure 1).The air undergoes through the following process:

A. Inlet air

1- Air filtration

2- Humid air enters the rotating bed of dry desiccant, as air passes through this bed, the desiccant attracts moisture from it than it leaves warm and dry.

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3- Passing through a heat exchanger 3/7: incoming air temperature cools to the dry exhaust air temperature.

4- Rewetting: in contact with dry air, water spray is evaporated by taking in air the latent heat of vaporization necessary, which results in a decrease in temperature and restores acceptable humidity.

5 – Ventilation

B. Exhaust air

6- Cooling by humidification: exhaust air is saturated with moisture in order to lower the maximum the temperature, and thus lower the temperature of the air entering the next step

7 and 8-the exhaust air is heated in order to allow it to absorb more moisture, first by heat recovery from the incoming air, followed by heating in the radiator 8 through a solar loop.

9 - Regeneration of the desiccant wheel: The exhaust air heated from 45 to 90°C allows vaporizing the water molecules retained in the pores of the wheel sorption. In this way the desiccant wheel can again absorb moisture from the incoming air.

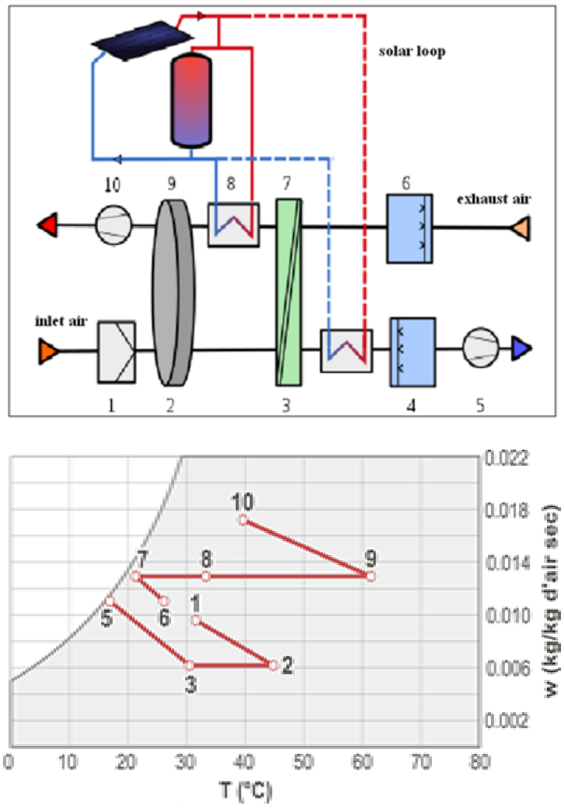

Fig. 1 Scheme of the desiccant cooling system and its evolution in psychometric chart.

III. System Modelling

A. Desiccant wheel

The desiccant wheel is modelled from the balance equations of heat and mass in a small volume element of the wheel, the mass conservation equation expresses the equality between the mass of water adsorbed by the desiccant per unit time and the mass of water lost by the air mass per unit of time[8].:

$$M_d \frac{\partial W}{\partial t} + \frac{1}{v_a} \varepsilon \left[\frac{\partial w_a}{\partial t} + u \frac{\partial w_a}{\partial z} \right] = 0 \quad (1)$$

The mass transfer equation can be written:

$$M_d \frac{\partial W}{\partial t} = h.m.S \left(w_a - w_{eq} \right) \quad (2)$$

The energy conservation equation expresses the equality between the heat gained or lost by the air and the heat lost or gained by the adsorbent material per unit of time:

$$M_d \frac{\partial H}{\partial t} + \frac{1}{v_a} \varepsilon \left[\left(\frac{\partial h_a}{\partial t} \right) + u \left(\frac{\partial h_a}{\partial z} \right) \right] = 0 \quad (3)$$

The energy transfer equation is written

$$M_d \frac{\partial H}{\partial t} = h_m.S.\left(w_a - w_{eq} \right)\left(h_{fg} + C_{pv} T_a \right) + h_c.S \left(T_a - T_m \right) \quad (4)$$

The water content of the desiccant material W varies with the equilibrium temperature of the material and the partial pressure of water vapour on the surface. The plot of the water content of the material as a function of the equilibrium relative humidity gives sorption isotherms. These isotherms vary considerably from one material to another. They are determined experimentally and are approximated by correlations of the form [9, 14]:

$$\Phi\left(T_{eq} - w_{eqm} \right) = f\left(W \right) \quad (5)$$

B. Other organs:

The non-hygroscopic rotary heat exchanger used in the system is modeled by the NUT-effective method that is used for heat exchangers [10]. The configuration of the wheel is similar to a counterflow exchanger wherein the correction factors are introduced to take account of the rotation of the wheel [11, 12].

To provide the energy required for regeneration of the desiccant wheel, the return air is heated in a regeneration battery before it enters the desiccant wheel. This battery is a heat exchanger air-liquid. A model cross-flow exchanger was used unmixed method ΔTLM [13]. (Logarithmic mean temperature difference).

The efficiency of a humidifier is defined as the ratio of the difference between the inlet temperature and the outlet temperature and the inlet temperature and the wet bulb temperature

$$\varepsilon_{hum} = \frac{t_e - t_s}{t_e - t_{hum}} \quad (6)$$

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Knowing the wet bulb temperature input, it is possible to know all the other variables in the air at the outlet of the humidifier.

The fans are considered variable-rate, but average efficiency constant. The power consumed by a fan is expressed as:

$$P_{vent} = \frac{(\Delta P.q_v)}{\varepsilon_{tot}} \qquad (7)$$

C. The solar loop

The efficiency factor of the flat plate collector is expressed as follows [9, 10]:

$$\eta = \frac{Q_u}{G.S_c} \qquad (8)$$

Useful energy can than allows calculating the fluid temperature at the outlet of the solar collector determined by the expression below

$$t_{fs} = t_{fe} + \frac{Q_u}{m_f.c_{pf}} \qquad (9)$$

Useful energy is the difference between the energy absorbed by the fluid of transfer and the heat loss from the surface of the absorber and the atmosphere. This energy is expressed by

$$Q_u = S_c\left[I_t.\tau.\alpha.h_p\left(T_p - T_a\right)\right] \qquad (10)$$

IV. RESULTS AND DISCUSSION

The influence of the choice of the operating point to parameterize the model was studied with regeneration temperatures of 60 ° C and 90 ° C, air flow regeneration and blowing are equal. We took two speeds for rotary heat exchanger for parametric calculation for each organ. The calculations was carried on basic climatic condition of Algerian coastal climate.

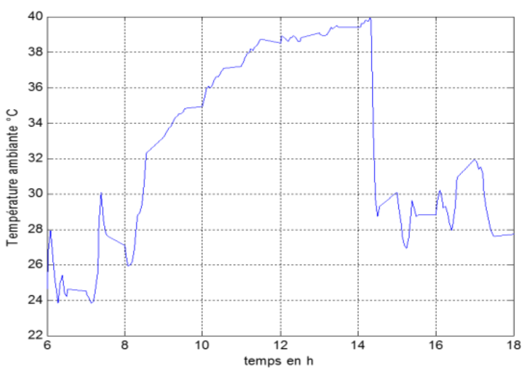

Fig. 2 Basic ambient temperature

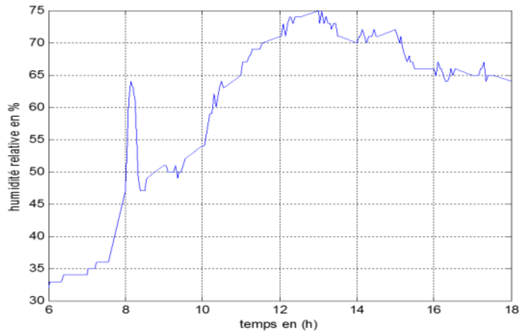

Fig. 3 Basic relative humidity of the inlet air

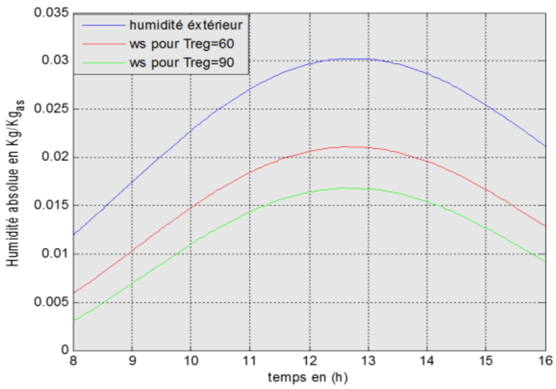

Fig. 4 Gap of the absolute humidity at the outlet of the desiccant wheel for
Tare= 60 ° C and Tare=90 ° C

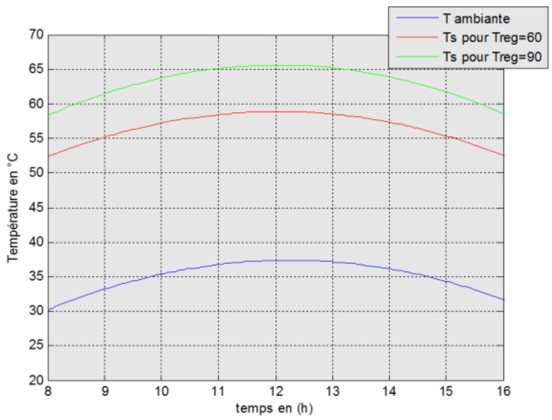

Fig. 5 Gap of the temperature at the outlet of the desiccant wheel for
Tare = 60 ° C and Tare = 90 ° C

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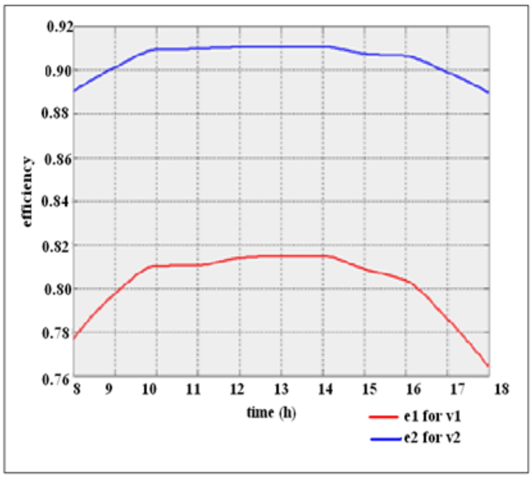

Fig. 6 Efficiency of the rotary heat exchanger for two speeds

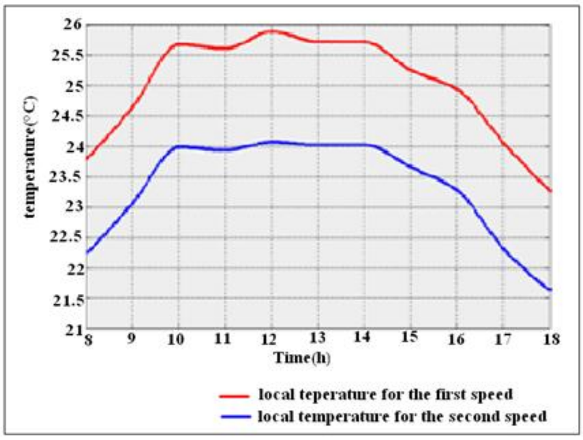

Fig. 7 Evolution of the local temperature for tow rotation speed

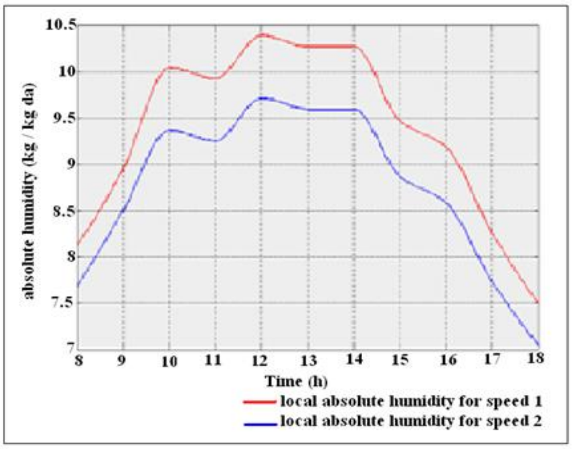

Fig. 8 Evolution of the local humidity for tow rotation speeds

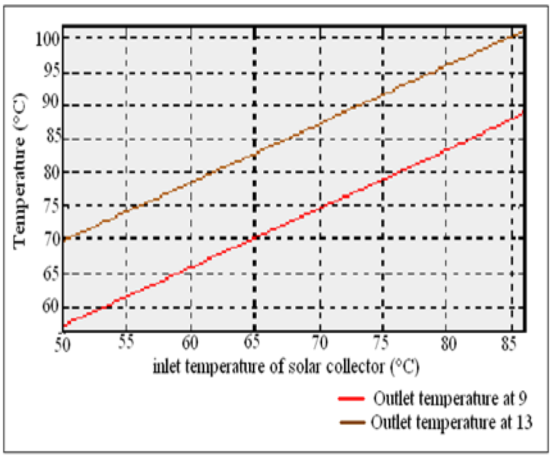

Fig. 9 Outlet solar collector temperature for specific hours

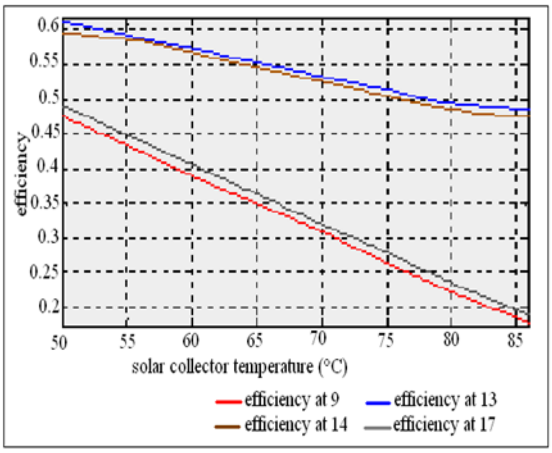

Fig. 10 Efficiency of the solar collector for specific hours

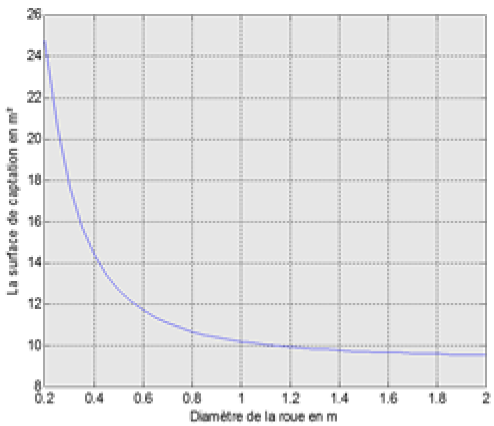

Fig. 10 Evolution of the solar collector surface for different wheel diameters

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Temperature and absolute humidity at the outlet desiccant wheel were calculated, the influence of different components on the temperature and humidity of the local was studied. Thus the effect of each element is shown in figures above. For the desiccant wheel, when the regeneration temperature increases the outlet temperature changes in the same direction but the absolute humidity decreases the process air is than efficiently dried and this yield to an increase of its temperature. The efficiency of the no hygroscopic rotary heat exchanger increases when its speed increases, which causes a drop in temperature in the local as seen in figures 6, 7 and 8. We note for the solar loop that the inlet temperature of the solar collector has an important influence on the performance evaluation so that if the inlet temperature decreases, the outlet temperature increases. We also note that the solar flux density plays an important role in the performance evaluation. The solar collector surface is concerned by the wheel diameter, a well dimensioned wheel offers a substantial economy of energy by minimizing the number of solar collectors.

V. CONCLUSIONS

The parametric study of the various components of the desiccant cooling system was developed to bring up their interest in the field of refreshing air, the results meet the requirements to maintain comfort in the room to be conditioned. The results of the parametric study gave the evolution of temperature and humidity of the various organs of the plant and the local. The performance of the system has been shown for the Algerian coastal climate, which proves the feasibility of the system in such climate. This study should be extended for the rest of the highly diversified Algerian climate, hot and humid, hot and dry, warm and humid …to show the where the desiccant cooling system could be effective.

NOMENCLATURE

Cpv : Specific heat of water vapor (kJ/kg•K)
Cpf : Specific heat of thermal fluid (kJ/kg•K)
G : total solar radiation per surface unit (W/m2)
H: Enthalpy of dessiccant (kJ/kg)
hfg: specific enthalpy (kJ/kg)
hc : convective heat-transfer coefficient (W / K m2)
hm : convective mass-transfer coefficient (kg/m2s)
hp: coefficient of heat loss
It : solar flux density (W/m2)
Md :Mass of adsorbent (kg)
mf : Mass of thermal fluid (kg)
Pvent : fan power (W)
Qu :useful energy (kJ)
S wheel : wheel surface (m2)
Sc :solar collector surface (m2)
Ta: air temperature (K)
Tm : dessiccant temperature (K)
Tfs : fluid temperature at the outlet of the solar collector (K)
Tp: absorber plate temperature (K)
v_a : specific air volume (m3)
W: water vapor in the dessiccant (kg/kg ad)
W_a : specific air humidity (kg/kg as)
W_{eq}: specific air humidity at equilibrium (kg/kg as)
α : absoption coefficient of solar collector
ε : vacuum fraction
ε_{hum}: efficiency of the humidifier
η: Efficiency of solar collector
τ: Transmission coefficient of solar collector

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