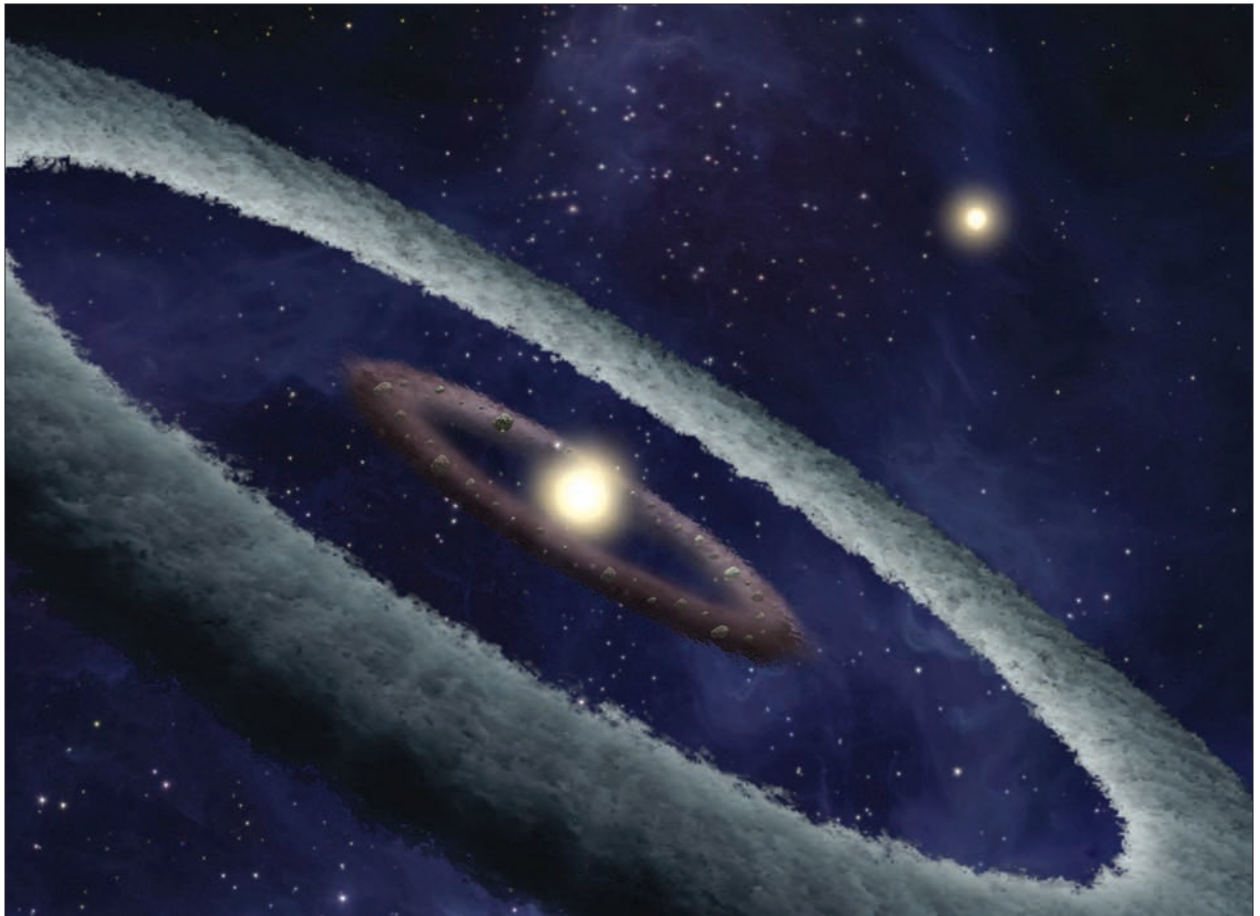




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Modelling of Solar Still for Production of Pure Water in the Abidjan Zones

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Abstract: This study presents theoretical consideration and results of solar water distiller system. Device was composed of glass which served as a condenser and an aluminium plate in black paint as an absorber. It was also composed of a tank of brine and a tank of distilled water. Solar water distiller system was modelled and simulated using an implicit numerical scheme, the Diabolo-Sablier algorithm. Simulation results showed that accumulated mass water greatly depended on the ambient temperature. Thus, for an increasing of 5°C of the ambient temperature, accumulated mass water roughly doubled. This inexpensive device permitted to produce 6 kg of water per day with a commonly used of collector of 2 m². Condensed mass water became significant for relative humidity of 40% at 308K temperature corresponding to conditions of dry season in the Abidjan zones.

Key words: Solar energy, solar distiller, brackish water, absorber, condenser system

INTRODUCTION

Brackish water and sea water are available in large quantities. Several studies have been made in the production of drinking water from these sources (Boucekima *et al.*, 2000; Singh and Tiwari, 2004). The process used in general is solar distillation (Al-Nimr *et al.*, 1998; Boucekima *et al.*, 2000; Haddad and Al-Nimr, 2002; Tiwari *et al.*, 2003; Singh *et al.*, 2004) and the distillers used have been classified into two groups: passive and active. Tiwari *et al.* (2003) recommend that only passive solar stills can be economical to provide pure water. An active solar distillation system can be economical from a commercial point of view.

Abidjan, the economic capital of Côte d'Ivoire is situated in humid tropical zone. As all big African country cities, the company of water distribution doesn't cover all inhabited zones. Therefore, there is a lack of water in certain zones of the city. Besides, in dry season, given the demographic pressure, this shortage increases.

To solve this problem, we propose to make numeric simulation of a simple passive solar still in order to optimize its measurements for the production of drinking water in this zone, using meteorological data of the area.

MATERIALS AND METHODS

Device Description

The solar distiller (Fig. 1) was composed of glass of 2 mm thick which served as a condenser and an aluminium plate of 3 mm thick in black paint, which served as an absorber. Glass was placed above

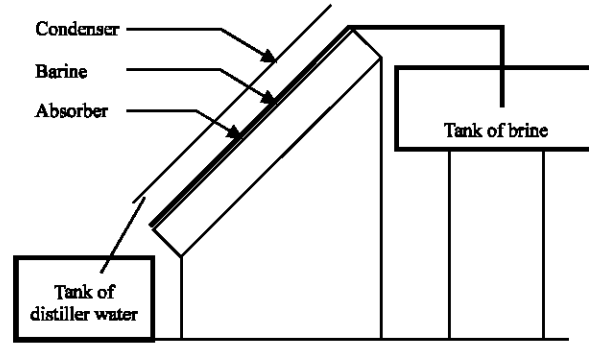


Fig. 1: Solar distiller device

aluminium plate and separated from it by a spacer of 25 mm thick. On this metal plate, a gauze of 1 mm thick was placed to cover the whole surface. It ensured the flow of the brine. An insulator was placed on rear of the aluminium plate for the reduction of losses on the rear of the solar still. The device was also composed of a tank of brine and a tank of distilled water.

The brine streams on the absorber through the gauze. The operation was based on the cycle of evaporation-condensation using solar energy as source of energy. Solar flux absorbed by the absorber increased its temperature and therefore the one of the brine until its temperature reached evaporation temperature. Difference of temperature between the evaporator and the condenser created a movement of ascending natural convection of steam on the one hand toward the condenser. On the other hand, difference of temperature between the entrance of the device and the exit dragged a movement of the mixture air steam toward the exit. Steam condensed on the glass. Collectors were placed on the level of condenser to collect distilled water (Fig. 1).

Mathematical Formulation

Transfer equations were based on the nodal method. So, thermal balance on the different material of the solar still lead to the following equations:

- For the external cover surface of condenser

$$\frac{M_v C_{PV}}{S_f} \frac{\partial T_{VE}}{\partial t} = h_{CV} (T_A - T_{VE}) + h_{RVC} (T_{VC} - T_{VE}) + h_{RSOL} (T_{SOL} - T_{VE}) + h_{COND} (T_{VIN} - T_{VE}) \quad (1)$$

- For the inner cover surface of condenser

$$\frac{M_v C_{PV}}{S_f} \frac{\partial T_{VIN}}{\partial t} = h_{COND} (T_{VE} - T_{VIN}) + h_{CVIN} (T_{MV} - T_{VIN}) + h_{RVINP} (T_P - T_{VIN}) \quad (2)$$

- For the air-vapour mixture

$$\frac{M_{MV} C_{PMV}}{S_f} \frac{\partial T_{MV}}{\partial t} = h_{CVIN} (T_{VIN} - T_{MV}) + h_{CPE} (T_{SAU} - T_{MV}) - L_v + Pu \quad (3)$$

- For the brine

$$\frac{M_{SAU} C_{PSAU}}{S_f} \frac{\partial T_{SAU}}{\partial t} = h_{CONDS} (T_P - T_{SAU}) + h_{CPE} (T_{MV} - T_{SAU}) + \dot{m}_{EV} L_v \quad (4)$$

- For the absorber

$$\frac{M_P C_P}{S_F} \frac{\partial T_P}{\partial t} = h_{\text{CONDS}}(T_{\text{SAU}} - T_P) + h_{\text{RVINP}}(T_{\text{VIN}} - T_P) + h_{\text{CDISO}}(T_{\text{ISO}} - T_P) + \alpha_{\text{ISO}} \tau_{\text{VITRE}} P \quad (5)$$

- For the insulator

$$\frac{M_{\text{ISO}} C_{\text{PISO}}}{S_F} \frac{\partial T_{\text{ISO}}}{\partial t} = h_{\text{CDISO}}(T_P - T_{\text{ISO}}) + h_{\text{RISO}}(T_{\text{SOL}} - T_{\text{ISO}}) + h_{\text{CISO}}(T_A - T_{\text{ISO}}) \quad (6)$$

We considered that water mass was equal to evaporated water mass. It supposed that humidity rate in the air is the same as the entrance and the exit of distiller.

Transmission coefficient of condenser (glass) was 0.85 and absorption coefficient of absorber (aluminium plate of 3 mm thick in black paint) was of 0.90.

The properties of water steam and air are given by the following relations:

Thermal capacity of steam:

$$C_p = -28.695 + 0.56967T - 3.827 \times 10^{-3} T^2 + 11.2564 \times 10^{-5} T^3 - 2.0277 \times 10^{-8} T^4 + 1.2932 \times 10^{-11} T^5$$

Latent heat of water vaporization:

$$L_v = 4185(597 - 0.56(T - 273.15))$$

Vapour density:

$$\rho_v = \frac{18.02 \times 10^{-3}}{8.205 \times 10^{-5} T}$$

Thermal capacity of dry air:

$$C_{pa} = 995.7 + 0.124T - 5.454 \times 10^{-6} T^2$$

Thermal capacity of humid air:

$$C_{pah} = 4185(0.24(1 - C_v) + 0.46C_v)$$

Dry air density:

$$\rho_a = \frac{350.74}{T}$$

Humid air density:

$$\rho_{ah} = \frac{352.989 P}{T} \left(1 - \frac{0.378 C_v}{0.622 + 0.378 C_v} \right)$$

Sky temperature is given by the relation:

$$T_{VC} = 0.0552 T_A^{1.5}$$

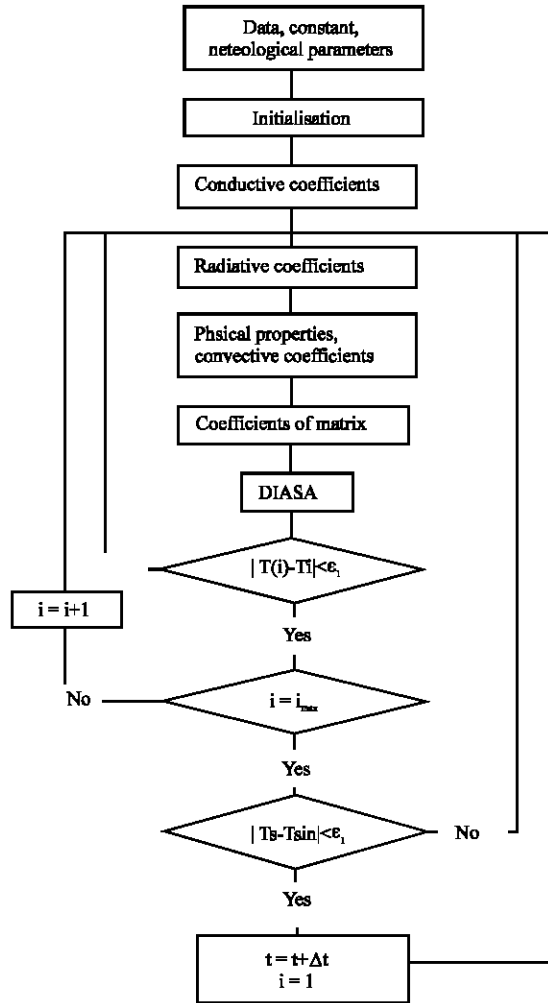


Fig. 2: Calculation diagram

To solve the system of equations that governs the behaviour of the distiller, we used the algorithm of calculation represented by Fig. 2. In the model, the mass of water condensed is taken as equal to the quantity of water evaporated. It is supposed that air has the same humidity rate as the entrance and the exit.

Equations 1-6 were solved using implicit numerical scheme and Diabolo-Sablier algorithm. As coefficients of transfer by free convection and radiation were depended on temperature of the different components of the solar still which are unknown, iterative procedure was used. Then, vapour air flow rate through the solar still was determined. An arbitrary value was affected to the exit temperature of the vapour flow allowing the calculation of the vapour flow rate. Resolution of transfer equations permitted to obtain another exit vapour temperature. While the difference between the arbitrary value affected to the exit vapour temperature and the one calculated was less than 0.1°C , calculation stopped. If this condition was not verified the temperature deduced from the resolution of transfer equations replaced the arbitrary value and calculation started again as mentioned above until the condition was satisfied. The procedure described is represented by the diagram in Fig. 2.

RESULTS AND DISCUSSION

From the meteorological data of Abidjan described in Fig. 3 and 4 the climatic conditions of working of the distillate were used for the simulation.

Thus, mean humidity rates of 40 and 55% corresponding to the dry season and 65% for the beginning of the rainy season were used. Seasonal average temperatures of 298, 303 and 308K corresponding to the low, intermediate and high temperatures for these periods were also taken.

In integration, the time span was taken as 8 h (i.e., from 8 pm to 4 am).

The numeric resolution of Eq. 1 to 6 by Diabolo-Sablier method permitted to determine the steam of water condensed according to relative humidity for different ambient temperatures for a collector of measurements (length: 2.5 m and width: 1.5 m).

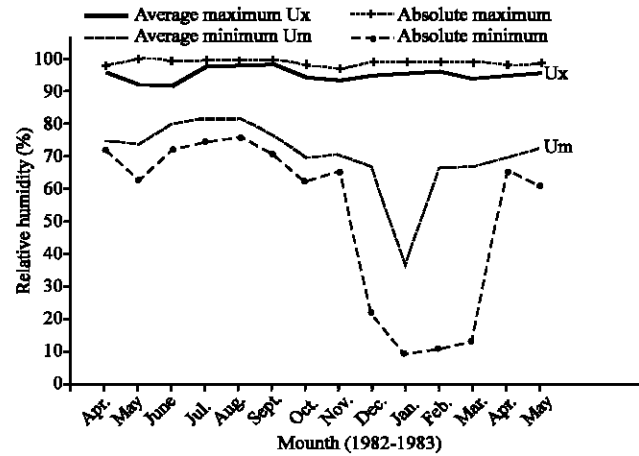


Fig. 3: Humidity rate of Abidjan

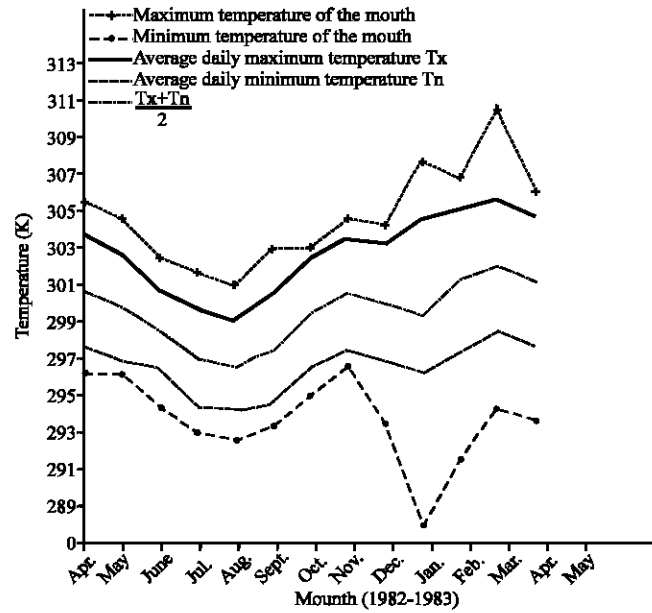


Fig. 4: Temperature of Abidjan

In Fig. 5, condensed steam was practically identical in each section of the distiller, for a given humidity rate. However, for humidity rate of 40% and for temperatures 303 and 308K and the one of 55% and temperature 308K, condensed steam improved by section of distiller. We noted that, condensed steam decreased as humidity rate increased for a given ambient temperature. It could be due to the weak coefficient exchange of convection in the distiller.

We also observed a decreasing of condensed steam at the entrance of the distiller. This decrease was probably due to the effects of side not taken into account in simulation and also, initial temperature of the iteration taken as equal to the outside ambient temperature.

In order to value performances of the still, we simulated the mass of water accumulated per day for collectors of measurements data.

Thus, the effects of the outside ambient temperature and the humidity on accumulated mass water were studied for two types of collectors currently used (Shukla *et al.*, 2007) as shown in Fig. 6 and 7.

In Fig. 6 and 7 we can observe that accumulated mass water increased with increasing of ambient temperature for collectors. It clearly showed that accumulated mass water greatly depended on the

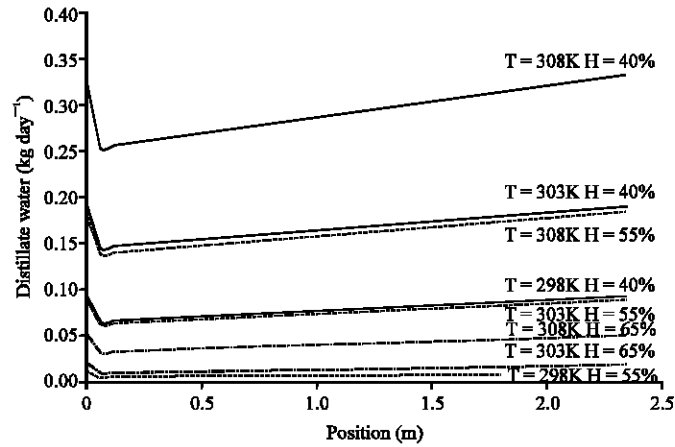


Fig. 5: Effect of ambient temperature on condensed water

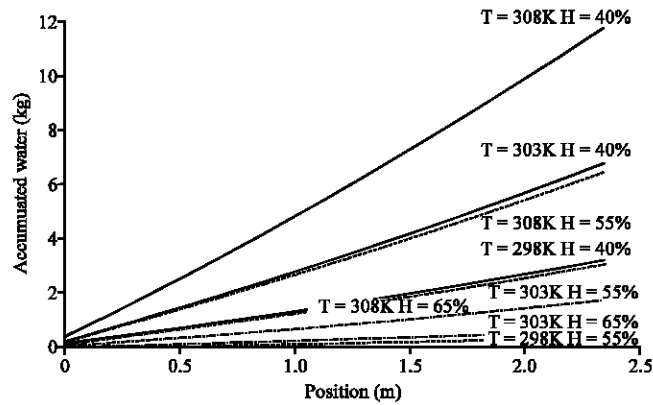


Fig. 6: Effect of ambient temperature and humidity rate on the accumulated mass for collector of length of 2.5 and 1.5 m of width

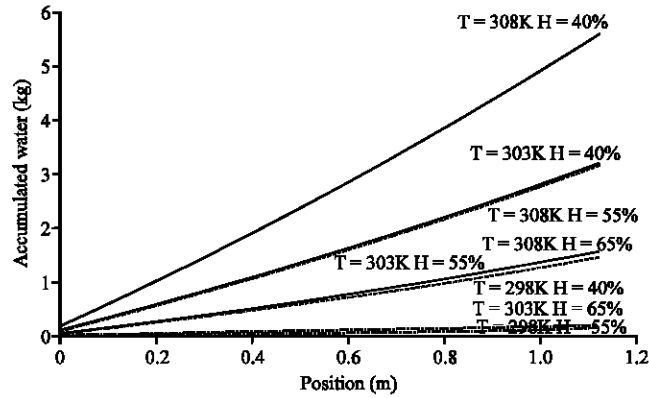


Fig. 7: Effect of ambient temperature and humidity rate on the accumulated mass for collector of length of 1.15 and 1.04 m of width

Table 1: Accumulated mass water for 40% of humidity rate

Length (m)	Width (m)	Temperature (K)	Accumulated mass water
1.115	1.04	298	1.68
		303	3.84
		308	6.68
2	1.00	298	1.62
		303	3.59
		308	6.28
2.5	1.00	298	1.60
		303	3.55
		308	6.21
2.5	1.50	298	2.42
		303	5.27
		308	9.14

ambient temperature. Thus, for an increasing of 5°C of the ambient temperature, accumulated mass water roughly doubled. These results were different from those obtained by Haddad *et al.* (2002). This difference is due to the fact that the cooling temperatures of Haddad and al. system were lower than those used in this device.

We also noted that accumulated mass water decreased with increasing of humidity rate. This decreasing could be due to lower saturation temperatures.

Accumulated mass water for different simulations are summarized in Table 1 to 3 for some collectors.

For 65% of humidity rate, accumulated water remained practically constant (lower to 2 kg). Accumulated water improved with humidity rates of 55 and 40% and temperatures of 308 and 303 K when area was higher than 2 m². This improvement became significant for relative humidity of 40% at temperature of 308 K. Thus, as it is shown in Fig. 8, condensed mass water became substantial from a surface of collector of 2 m² (up to 6 kg). These results were reported by Shukla *et al.* (2007) using another model of collector.

Humidity rate of 40% was favorable for absorption of water stream than other rate. As we have early noted that accumulated water increased with ambient temperature, temperature of 308K gave the maximum accumulated mass water. Thus temperature of 308K and humidity rate of 40% represent optimum conditions for pure water production as shown in Fig. 5-8.

Table 2: Accumulated mass water for 55% of humidity rate

Length (m)	Width (m)	Temperature (K)	Accumulated mass water
1.115	1.04	298	0.16
		303	1.73
		308	3.79
2	1.00	298	0.14
		303	1.57
		308	3.47
2.5	1.00	298	0.14
		303	1.71
		308	3.49
2.5	1.50	298	0.22
		303	2.40
		308	5.27

Table 3: Accumulated mass water for 65% of humidity rate

Length (m)	Width	Temperature (K)	Accumulated mass water
1.115	1.04	303	0.32
		308	1.92
2	1.00	303	0.29
		308	1.77
2.5	1.00	303	0.28
		308	1.74
2.5	1.50	303	0.43
		308	1.33

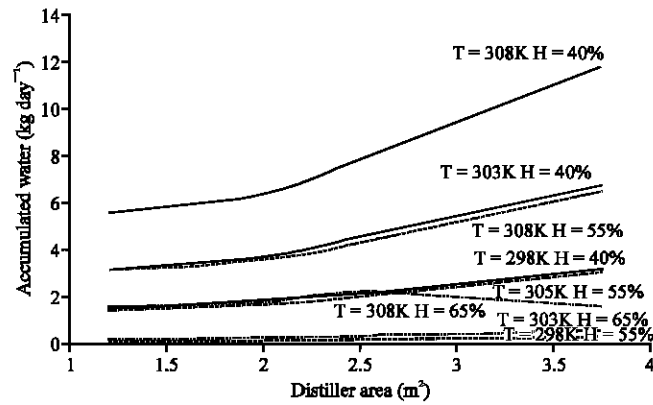


Fig. 8: Effect of collector area on accumulated mass water

Considering the lack of water noted in urban zones in March with relative humidity of 40% and average temperature of 308K, distiller can be used as additional system to classic system of water distribution.

This condensed mass water would be completed by the one obtained by condensation of water steam in the air not taken into account in simulation model.

CONCLUSION

The results of the mathematical model of solar water distiller system showed that accumulated mass water greatly depended on the ambient temperature. This model indicated pure water condensed of within the range 0.5-7 kg day⁻¹ for current surface of collector. Pure water condensed became significant for relative humidity of 40% at temperature of 308K corresponding to conditions of dry season. Further experiments should be carried out to test the studied device in described conditions.

NOMENCLATURE

T	: Temperature (K)
C _p	: Specific heat at constant pressure (J/kg/K)
C _v	: Molar fraction.
h _R	: Radiation heat transfer (W/m ² /K)
h _{COND}	: Coefficient of transfer by conduction (W/m ² /K)
h _c	: Coefficient of transfer by natural convection (W/m ² /K)
m _{ev}	: Evaporation mass-flow rate of brine (kg sec ⁻¹)
L _v	: Latent heat of vaporization of water (J kg ⁻¹)
P _u	: Density of useful power (W m ⁻²)
P	: Density of solar flux (W m ⁻²)
M	: Mass
α	: Absorption coefficient
τ	: Coefficient of transmission of the glass

Indice

V	: Glass
A	: Air
ISO	: Insulating
MV	: Vapour
P	: Absorber
SAU	: Brine
VC	: Sky
VE	: External surface of the glass
VIN	: Inner surface of the glass
Sol	: Gromnd

REFERENCES

- Al-Nimr, M.A. and O. Haddad, 1998. Water distiller/condenser by radiative cooling of ambient air. *Renewable Energy*, 13: 323-331.
- Bouchekima, B., B. Gros, R. Ouahes and M. Diboun, 2000. Theoretical study and practical application of the capillary film solar distiller. *Int. J. Therm. Sci.*, 39: 442-459.
- Haddad, O.M. and M.A. Al-Nimr, 2002. Transient behavior of a radiative distiller/condenser system. *Applied Energy*, 71: 341-349.
- Shukla, S.K. and A.K. Rai, 2007. Thermal modeling of double slope solar still by using inner glass cover temperature. *Int. J. Applied Eng. Res.*, 2: 569-584.
- Singh, H.N. and G.N. Tiwari, 2004. Monthly performance of passive and active solar stills for different Indian climatic conditions. *Desalination*, 168: 145-150.
- Tiwari, G.N., H.N. Singh and R. Tripathi, 2003. Present status of solar distillation. *Solar Energy*, 75: 367-373.