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Coupling of a Spherical Solar Still with a Collector

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Abstract: The lack of water progresses at a rhythm that all the experts, judge dangerous for the future of humanity. The desalination of brackish water and sea water can answer the supplying drinking water, in particular of the Third World countries. If the requirements of fresh water are relatively weak, solar distillation seems an interesting solution, in particular in the arid and isolated regions. However, the output of such process remains extremely limited. The main purpose of this work consists to consider the coupling of a spherical solar still and a plane collector. The obtained results show clearly that the performances of the new device are better than those of the solar still when it is used alone. The effect of many parameters on working characteristics is also studied. The confrontation of the numerical results with those resulting from the experiment shows a good agreement.

Key words: Solar still, collector, production, efficiency

INTRODUCTION

The output of a solar still being extremely limited, we consider, in order to improve the working characteristics, the coupling of solar still with a plane collector. In this study the heat balance of the system composed by a spherical solar still, a collector and a thermosiphon is established. The temperatures on the level of each part of this system are then calculated. The influence of many parameters in particular the solar radiation and the weather conditions (wind speed) is studied.

DESCRIPTION AND PRINCIPLE OF OPERATION

The device shown in Fig. 1 is made up primarily of (Bernard *et al*., 1980):

- A wiping spherical Plexiglas still composed of three parts. A half higher sphere which ensures the radiation transmission; it creates the effect of greenhouse and it is also used as surface of condensation.

A half lower sphere is used to collect the distillate. In the median plane, a blackened metal vat containing water to be distilled.

An electrically operated wiper is attached to the top cover, it maintains the cover uniformly transparent to solar radiation and enhances thus the distilled water production.

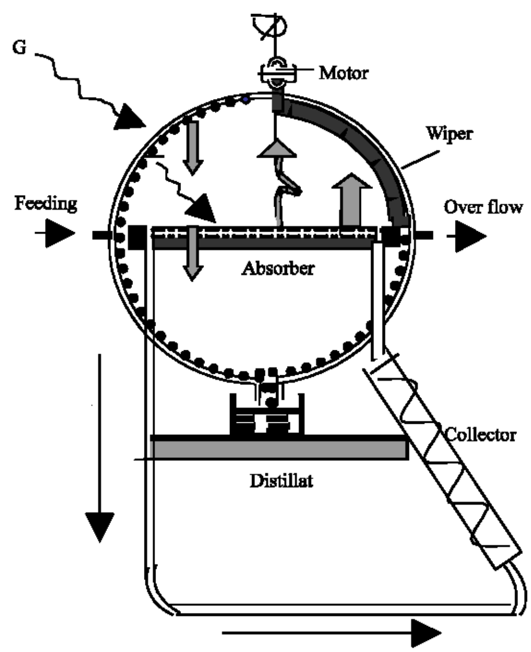

Fig. 1: Spherical solar still-plane collector

- A plane collector with liquid circulation (water), constituted from a heating coil in copper, a toughened glass top cover and glass wool insulation below the absorber (Chaker *et al*., 2003).

The still is connected to the collector by tubes and the system operates by thermosiphon circulation.

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NUMERICAL STUDY

Heat balance: In steady state, the equations governing the heat balance on the level of each part of the still are written as follows:

Heat balance of the glass cover:

- Inside glass surface

$$q_{ri} + q_{ci} + q_w = \frac{\lambda_g}{e_g}(T_{gi} - T_{ge})A_g \quad (1)$$

- Outside glass surface

$$q_{ra} + q_{ca} = \frac{\lambda_g}{e_g}(T_{gi} - T_{ge})A_g \quad (2)$$

q_{ra}, q_{ca} : Being the heat flows exchanged by radiation and convection between the glass and the environment.
T_{gi}, T_{ge} : Respectively the inside and outside cover temperatures.
e_g : Glass thickness and λ_g its thermal conductivity.

Heat balance of the water mass:

$$q_{col} - q_{ci} - q_{ri} - q_e - m_d.C_w.(T_w - T_a) - q_b = q_w \quad (3)$$

q_{ri}, q_{ci}, q_e : Respectively heat flows exchanged by radiation, convection and evaporation inside the still.
q_{col}, q_b : Respectively heat flows brought by the collector and by conduction through the vat.

Heat balance of the absorber:

$$q_{wb} + q_{bins} = \tau.A.G \quad (4)$$

τ : Total transmission coefficient of water and the glass.
q_{wb}, q_{bins} : Respectively heat flows yielded to the water mass and to the insulator.

Heat balance of insulator: To reduce the losses of heat through the base, an insulator which receives q_{bins} from the absorber (at the inside surface) and yields by radiation and by convection, respectively the heat flows q_{ci} and q_{rins} (at the outside surface) is used (Chaker *et al.*, 2003), from where the following equations:

$$q_{bins} = \frac{\lambda_{ins}}{e_{ins}}\left(T_{insi} - T_{inse}\right) \quad (5)$$

And

$$q_{rins} + q_{cins} = \frac{\lambda_{ins}}{e_{ins}}\left(T_{insi} - T_{inse}\right) \quad (6)$$

Numerical resolution: The equations governing the heat balance of the system are solved by a numerical approach based on the iterative Gauss-Seidel's method (Gourdin and Boumahrat, 1993).

For that, the different heat flows are replaced by their explicit expressions, then the equations of the heat balances at the level of each part composing the still, according to the temperatures are written as follows:

On the level of the outside glass surface:

$$(h_{ca} + h_{ra} + \frac{\lambda_g}{e_g})T_{ge} - \frac{\lambda_g}{e_g}.T_{gi} = h_{ca}.T_a + h_{ra}.T_c + \alpha_g.G \quad (7)$$

On the level of the inside glass surface:

$$-\frac{\lambda_g}{e_g}T_{ge} + (h_{ci} + h_{ri} + h_e - \frac{\lambda_g}{e_g})T_{gi} (h_{ci} + h_{ri} + h_e)T_w = 0 \quad (8)$$

On the level of the water mass:

$$-(h_{ci} + h_{ri} + h_e).T_{gi} + (h_{ci} + h_{ri} + h_e + h_{bw} + \frac{m_d.C_w}{\pi.r^2} + \frac{m_{ci}.C_w\left(T_f\right)}{\pi.r^2}).T_w - h_{bw}.T_b = \alpha_t.G + \frac{m_d.C_w}{\pi.r^2}T_a + \frac{m_{ci}.C_w\left(T_f\right)}{\pi.r^2}.T_f \quad (9)$$

On the level of the absorber:

$$-h_{bw}.T_w + (h_{bw} + \frac{\lambda_b}{e_b}).T_b - \frac{\lambda_b}{e_b}.T_{insi} = \tau.G.\frac{A_g}{A_b} \quad (10)$$

On the level of the inside insulator surface:

$$\frac{\lambda_b}{e_b}T_b + (\frac{\lambda_b}{e_b} + \frac{\lambda_{ins}}{e_{ins}}).T_{insi} - \frac{\lambda_{ins}}{e_{ins}}.T_{insi} = 0 \quad (11)$$

On the level of the outside insulator surface:

$$\left(h^{e}_{inse} + h^{c}_{inse} + \frac{\lambda_{ins}}{e_{ins}}\right).T_{insie} - \frac{\lambda_{ins}}{e_{ins}}.T_{insi} = h^{r}_{inse}.T_{sol} + h^{c}_{inse}.T_{a} \quad (12)$$

h_{ca} : Convective heat transfer coefficient from glass cover, to atmosphere ($W.m^{-2}.°C^{-1}$).

h_{ci} : Convective heat transfer coefficient from water to glass cover ($W.m^{-2}.°C^{-1}$).

h_{ra} : Radiative heat transfer coefficient from glass cover, to ambient air ($W.m^{-2}.°C^{-1}$).

h_{ri} : Radiative heat transfer coefficient from water to glass cover ($W.m^{-2}.°C^{-1}$).

h_{e} : Evaporative heat transfer coefficient h_{inse}: convective heat transfer coefficient of the exterior insulator face.

h_{bw} : Convective heat transfer coefficient from water to absorber ($W.m^{-2}.°C^{-1}$).

T_{insi}, T_{inse} : Respectively temperatures of internal and external insulator surfaces.

The system thus obtained, consists of Eq. 6 whose unknown factors are the temperatures.

RESULTS AND INTERPRETATION

The choice of a solar still depends primarily on his working characteristics (Malik *et al*., 1985). Solar radiation being the most influential parameter on the operating of the system, it would be interesting to study its effect on those characteristics.

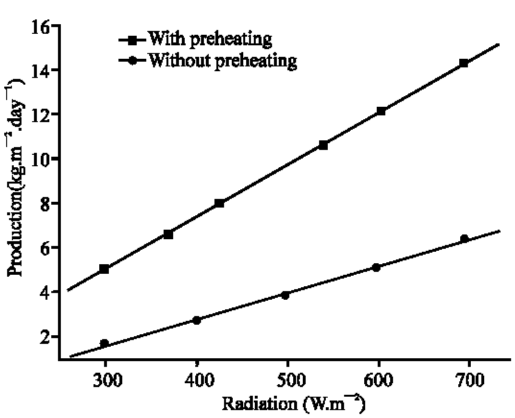

Fig. 2: Variation of production as a function of solar radiation

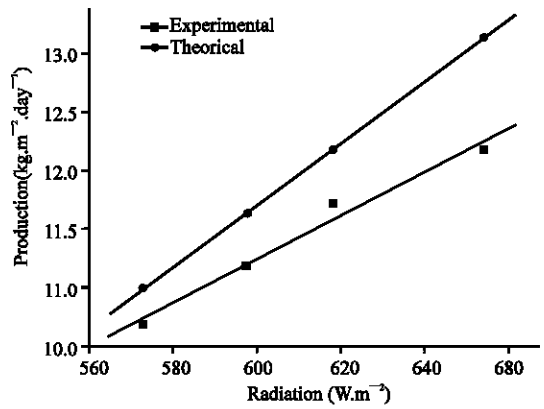

Fig. 3: Theoretical and experimental Productions values

Still production: The effect of the solar radiation on still production is clearly highlighted on Fig. 2 which shows a linear increase. Furthermore, it can be noticed that the production of the coupled system is higher than that of the still when it operates alone. The variation is more significant as the radiation increases.

It can be observed in Fig. 3 that numerical values are close to experimental results.

Internal efficiency: The curves presented on Fig. 4 allow to observe that the internal efficiency of coupled system (still-collector) which increases with solar radiation is higher than that of the still alone.

A comparison between the theoretical internal efficiencies values with the obtained experimental results (Fig. 5), show a good agreement.

Overall efficiency: Figure 6 illustrates the effect of preheating of water by the collector on overall efficiency of coupled system. One notice an improvement of about 9-12%.

Internal and overall efficiency: Like in the case of a solar still, Fig. 7 allows to observe that internal efficiency of studied system is higher than overall efficiency.

Effect of the wind: The increase of the wind speed lead in first time to an augmentation of coupled system production, but over a value about 1.5-2 $m.s^{-1}$ the opposite effect occurs. Indeed a rather increase of wind speed enhances the evaporation process, it results from this an augmentation in the production. Therefore, high speeds cause the cooling of the exterior glass surface, it follows that a decrease of the brackish water temperature, leading thus to a fall of the production.

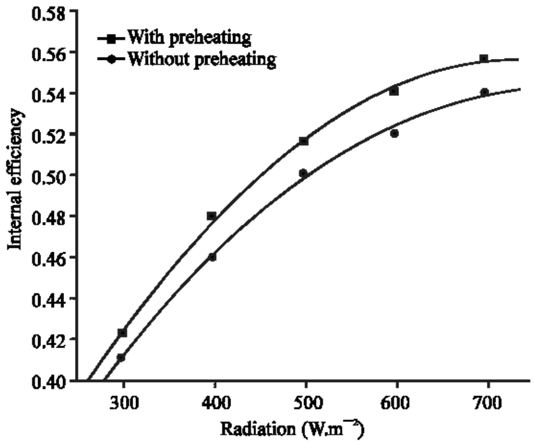

Fig. 4: Effect of solar radiation on internal efficiency

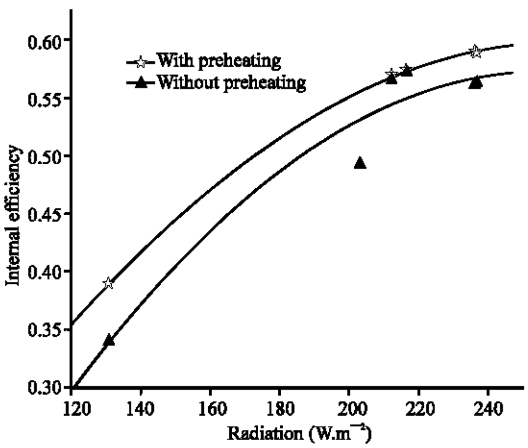

Fig. 5: Theoretical and experimental internal efficiencies values

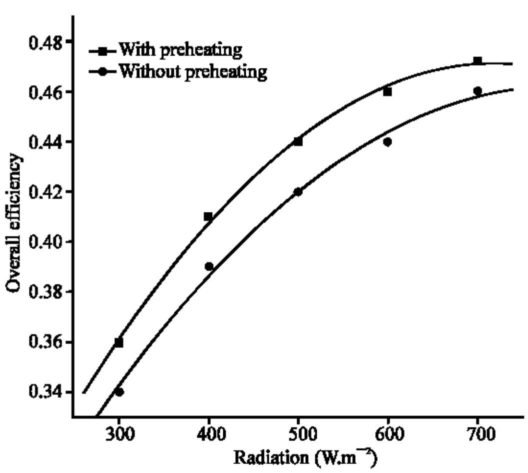

Fig. 6: Variation of overall efficiency as a function of solar radiation

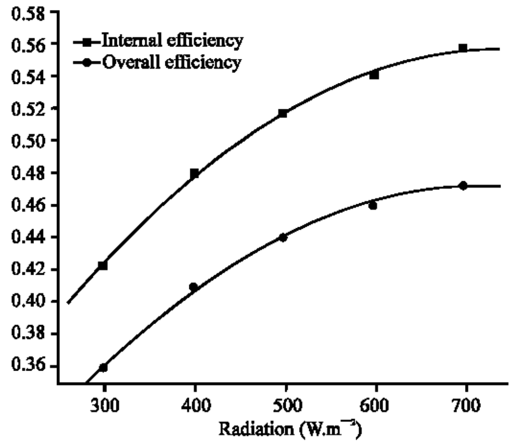

Fig. 7: Overall and internal efficiencies of coupled system as function of solar radiation

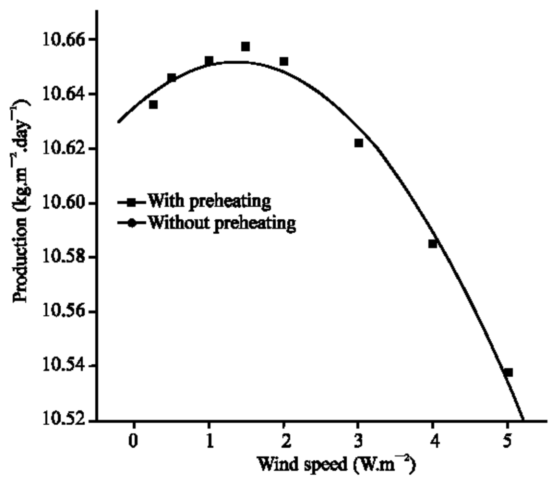

Fig. 8: Effect of wind speed on still production

CONCLUSION

The present study is considered to be a further contribution to the development of the use of solar distillation in order to supply fresh water to villages and small cities with limited consumption. The efficiency of such processes is extremely limited. For this reason the coupling of a solar still with a plane collector is planed.

A wiping spherical solar still which allows to have a production higher than that of a plan still and whose thermal looses are less importance, has been chosen (Chaker and Boukerzaza, 2005). The obtained results show clearly that the production and the performance coupled system are improved. The confrontation of computed values with the results obtained from the experiment shows a good agreement.

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