Efficiency of Multi-Stage Solar Still With Capillary Film: Effect of Certain Thermophysical Parameters

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Abstract

Drinking water Supply becomes nowadays, the most alarming problem, since the demand for water grows while the natural resources decrease or tend to disappear. One of the solutions which can contribute to increase water potentialities is the desalination of sea water or brackish water. The most adequate process to carry out this process is solar distillation, considering its simplicity, its lower cost and especially the availability of the source of this energy.

The aim of our work is to look for a better production of a fresh water using a multiple-stage solar still with capillary film. A study is then carried out by firstly comparing performances (productions) of a simple-stage solar still with capillary film with those issued from a multi-stage solar still. This study takes into consideration the effect of certain thermophysical parameters on the final production of the system, where their optimization is considered.

The study area is Ouargla (South of Algeria), where its geographical coordinates are: latitude of 31° 51' to the north and longitude is 5° 24' to the east. The simulation is carried out from the instant "t0", for each component of the solar still and at an initial temperature and with a time step equals to one hour.

The inclination of the solar still is considered equals to 30° to the horizontal and with an azimuth equals to 0° to the south. We selected 17th July as a representative day for simulation.

Solar radiation is directly absorbed by respectively the glass and the absorbing surface (absorber-evaporator) in the case of a simple-stage solar still whereas in the case of a multi-stage solar still, the overall global heat transfer is similar to the simple one, except adding, or taking into consideration, the heat transfer by conduction between the different plates separating the stages (condenser-evaporator).

The physical problem consists to determine the effect of certain thermophysical parameters on the system efficiency. In order to render the model more accessible (simplified), we should take into consideration some hypotheses of simplification.

The obtained results confirm the influence of the thermophysical parameters such as volume mass, dynamic viscosity of the stage, thermal conductivity of the brine (absorber) latent-heat of vaporization, etc. on the system performance, as these parameters are directly dependant on the temperature of the brine.

Results show that a multi-stage solar still gives better efficiencies compared to those issued from the simple one. A multi-stage distiller is then recommended for recovering a maximum energy at the condenser and when we want to reduce the energy at the condenser outlet.

Results show also that a better efficiency can be obtained if we keep the temperature difference between the evaporation surface and the condensation one as higher as possible. The same result is obtained if we realise the system with a well isolated sides, where vapour losses are reduced to the minimum possible.

Finally, a brine with high temperature leads to respectively better efficiency, higher thermal conductivity and higher specific of the brine, whereas volume mass and dynamic viscosity become low.

Key words: Solar distillation, Multi – stage distiller, Capillary film, Production

Introduction

In order to preserve the future in terms of water resources reclamation, it worth to review conventional water resources within the context of a global vision including equally non-conventional water resources such as sea water and brackish water desalination.

However, desalination needs energy, where its cost is important. It becomes then interesting to use solar energy in the water desalination process as, in addition of its ecological benefit, a real alternative to the conventional energetic resources.

Nevertheless, a simple solar still is characterised by its low production (disadvantage), where the use of a new distiller with a capillary film becomes interesting to overcome this disadvantage and, in the meantime, keeping the same advantages: rustic design, easy realisation, easy to maintain and a lower cost.

This solar still with capillary film is set up in order to favour more heat band mass transfer during the double operation evaporation and condensation. The aim of this work is to study a solar still with capillary film having a multiple stages, through the effect of certain thermophysical parameters on the system efficiency. To do so, we set up a system of equations governing the distiller performance as well as we established coefficients of thermal heat exchange. A mathematical simulation allowed us then to obtain results concerning the performance of the system.

Theoretical study

Our study is carried out in order to look for a better production of distilled water. A comparison study, in terms of performance, is carried out between solar stills with capillary films with respectively a simple and a multiple stages.

Through studies realised previously, it is shown that the production capacity of a multiple stage distiller represents 4 to 7 times that issued from a simple stage distiller [1, 2].

Performance parameters of solar stills with capillary film

These parameters are classified into two categories: external and internal parameters. The external parameters are represented by respectively solar radiation intensity, wind velocity, ambient temperature (air temperature), meteorological and geographical parameters. The internal parameters are represented respectively by thermophysical and optical parameters at the different components of the system [3, 4, 5, and 6].

Overall global heat transfer of the system

The physical problem consists to define respectively the effect of certain thermophysical parameters on the performance of the multiple-stage distiller with capillary film, temperature change with time and the distilled water production.

In order to render the model more attainable, we should take into consideration some simplifying hypotheses. For the simulation purpose, we suppose then, that the regime is permanent and each component of the distiller is at a constant mean temperature [7]. This approach neglects the transitory effects.

Case of a simple stage distiller (figure 1)

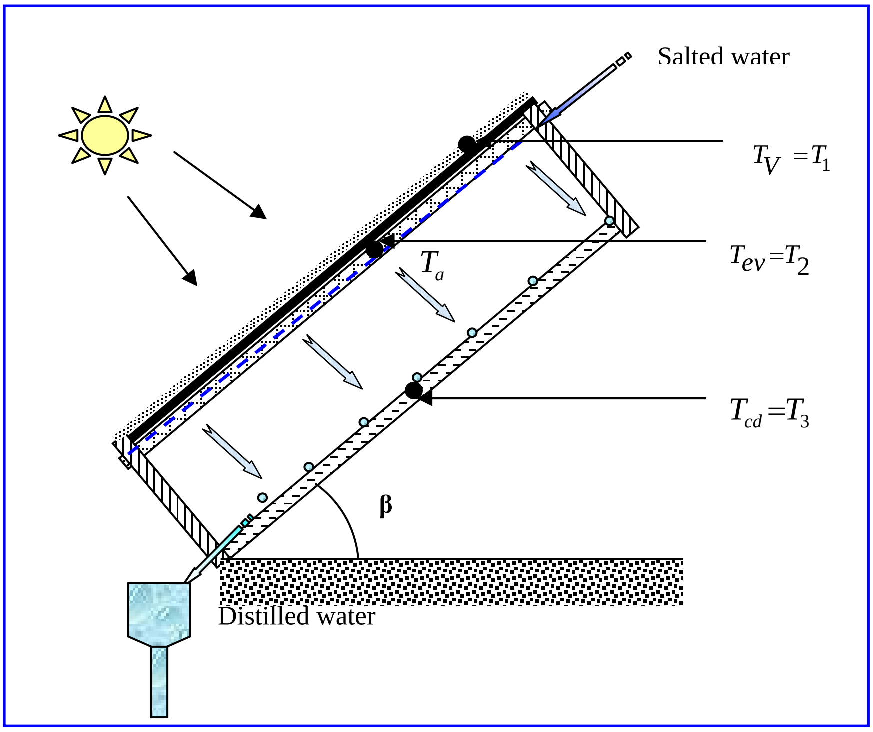


Figure 1: Simple solar still with capillary film

- At the glass:

$$Q^c_{ev\text{-}v} + Q^r_{ev\text{-}v} + P_g \times A_v = Q^c_{v\text{-}a} + Q^r_{v\text{-}a} \qquad (1)$$

- At the absorber-evaporator:

$$P_{ev} \times A_{ev} + Q^r_{ev-v} = Q^c_{ev-v} + Q^c_{ev-cd} + Q^r_{ev-v} + Q^r_{ev-cd} + Q^{ev}_{ev-cd} + Q_{ea} \qquad (2)$$

- At the condenser:

$$Q^c_{cd-a} + Q^r_{cd-a} = Q^c_{ev-cd} + Q^r_{ev-cd} + Q^{ev}_{ev-cd} \qquad (3)$$

$Q^c_{v\text{-}a}$, $Q^r_{v\text{-}a}$ - heat flows by convection and radiation respectively (glass leaves heat to the ambience);

$Q^c_{ev\text{-}v}$, $Q^r_{ev\text{-}v}$ - evaporator heat flows by convection and radiation respectively (glass receives heat flow from the evaporator);

Q^c_{cd-a}, Q^r_{cd-a} - condenser heat flows by convection and radiation respectively (condenser leaves heat flow to the ambience.

Case of a multiple stage distiller (figure 2)

For this case we selected, for our model, a distiller with four (4) stages. The overall global heat transfer in this case is similar to that of a simple (one) stage, with the exception of adding heat transfer by conduction between different plates separating these stages (condenser-evaporator).

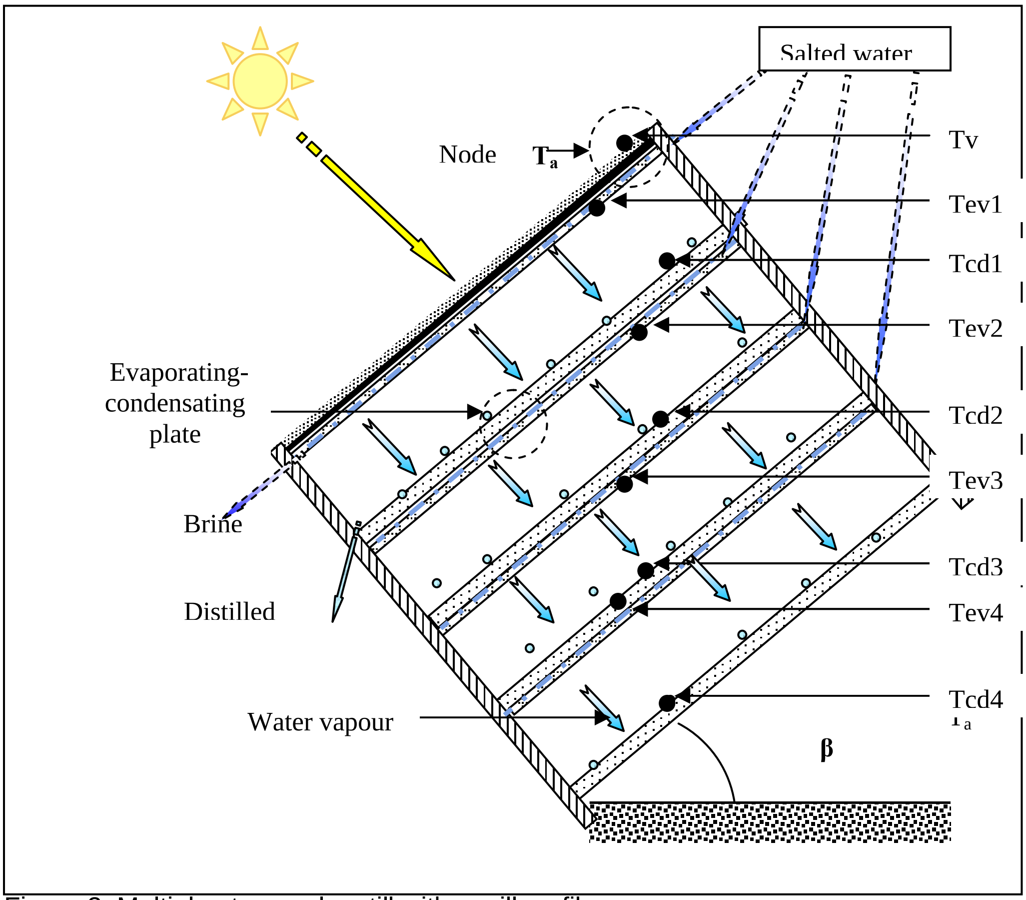


Figure 2: Multiple-stage solar still with capillary film

Characteristics of solar still performance

As a characteristic of solar still performance, we distinguish constantly, the global and internal efficiencies as well as the performance [8, 9 and 10]:

<u>- Global efficiency:</u>

$$\eta_g = \frac{Q_{ev}}{I_G \times A_g} \qquad (4)$$

$$\eta_g = \frac{(total \text{ quantity of distilled water}) \times L_v}{(Solar \text{ radiation received by the glass})}$$

where, L_v represents the latent heat of vaporisation.

<u>- Internal efficiency:</u>

$$\eta_i = \frac{Q_{ev}}{Q_w} \qquad (5)$$

Q_w represents the solar energy received by the glass.

Performance:

It is characterised by the Hourly Performance Factor (HPF)

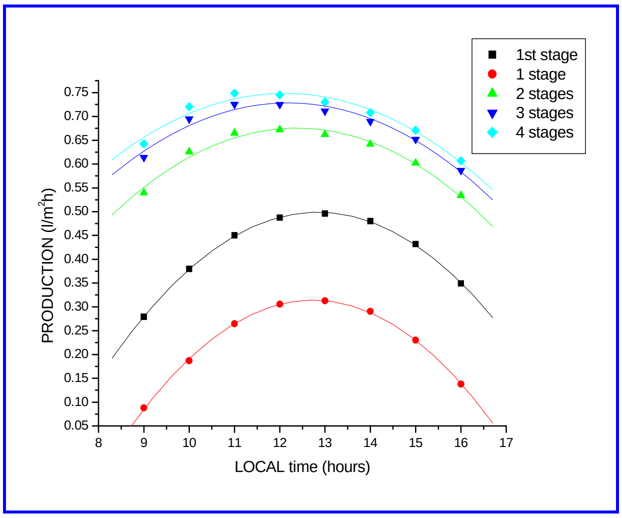
$$FPH = \frac{(\text{Distilled water produced in one hour})}{(\text{Energy introduced to the system in one hour})}$$

Results and Discussion

The simulation is carried out according to the geographical coordinates of Ouargla (south of Algeria) [11]: Latitude of 31° 57 to the north and longitude of 5° 24 to the east. 17th of July is selected as a pseudo-representative day for our simulation.

Through the obtained results and comparing, in terms of efficiency and performance, the multiple-stage solar still to the simple one, we can notice the following observations:

- Distiller with multiple stages is more efficient than the simple one (figure 3), where we notice that production of distilled water increases with the number of stages. We can obtain, in the case of a simple distiller about 2.18 litres per squared meters of distilled water in 8 hours of working whereas a distiller with 4 stages could reach 6.56 litres in the same conditions.



$Md_{1st\ stage}$ = -1, 93887 + 0,37974xt - 0, 01479 xt², R²=0, 99907, P<0.0001

Md_{1stage} = -2, 42624 + 0,4299B1xt - 0, 01685xt², R²=0, 99982, P<0.0001

$Md_{2stages}$ = -0, 72452 + 0,22948xt - 0, 00942xt², R²=0, 99497, P<0.0001

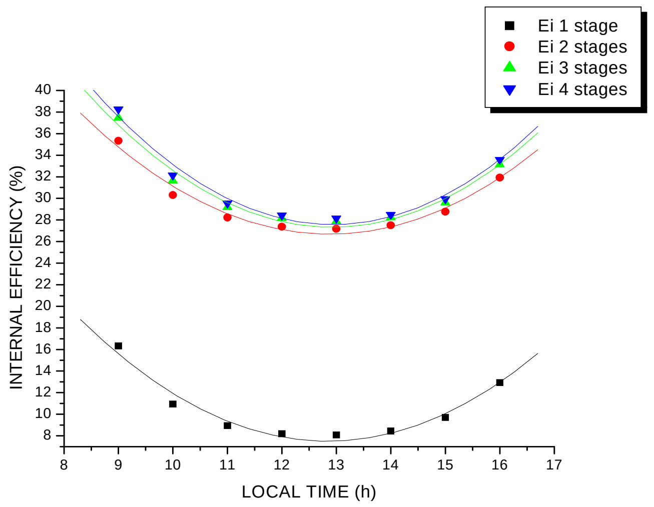
$Md_{3stages}$ = -0, 41931 + 0,19279xt - 0, 00811xt², R²=0, 99409, P<0.0001

$Md_{4stages}$ =-0,31498 + 0,18061xt - 0,00768xt², R²=0, 99403, P<0.0001

Figure 3: Change of production with time

- In the case of a distiller with 4 stages, we notice that, at the first stage, distilled water production is more important than that issued from a simple stage distiller. This is due to the fact that the condensing plate in the simple distiller is cooled by the ambient air whereas that in the multiple one works as an evaporating plate for the second stage, etc...

- We notice also that the production increases with the number of stages. However, it becomes insignificant in the last stage (fourth stage).
- Figures 4, 5 and 6 show that internal and global efficiencies as well as performance factor increase when the number of stages increases. This increase is important between the first and the second stage, even between the second and the third stage, but becomes insignificant between the third and the fourth stage. We then conclude that the system should be optimised in terms of the number of stages to be used.



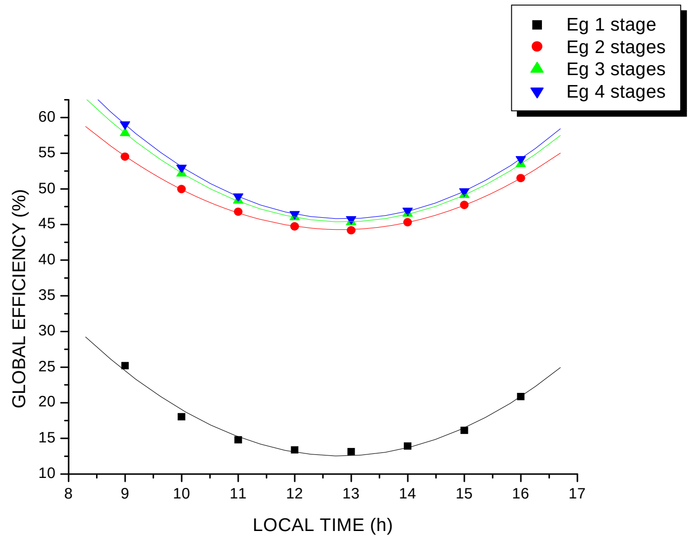
Ei 1stage = 97.732 - 14.050xt + 0.547xt², R²=0.96142, P<0.0001

Ei 2stages = 115.493 - 13.793xt + 0.535xt², R²=0.97239, P<0.0001

Ei 3stages = 129.742 - 15.850xt + 0.613xt², R²=0.9732, P<0.0001

Ei 4stages = 135.162 - 16.633xt + 0.642xt², R²=0.97301, P<0.0001

Figure 4: Efficiency change with time



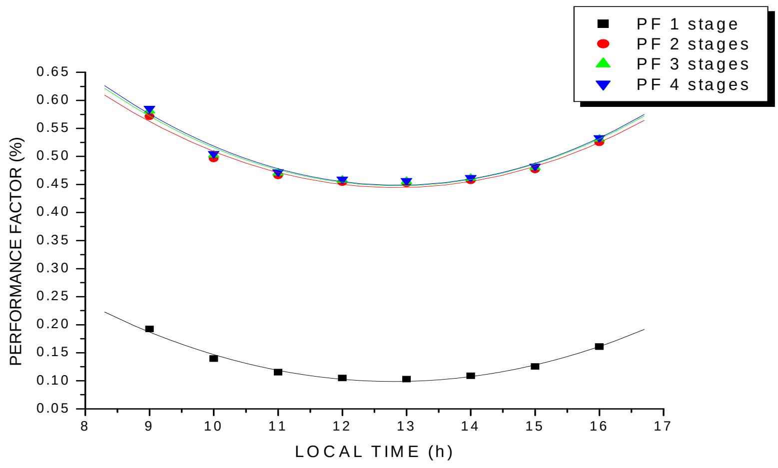
Eg 1stage = 147.069 - 21.001xt + 0.819xt², R^2=0.98194, $P<0.0001$

Eg 2 stages = 160.711 - 18.173xt + 0.709xt², R^2=0.99941, $P<0.0001$

Eg 3stages = 182.411 - 21.290xt + 0.826xt², R^2=0.99984, $P<0.0001$

Eg 4stages = 190.660 - 22.475xt + 0.871xt², R^2=0.99979, $P<0.0001$

Figure 5: Global efficiency change with time



PF 1stage = 1.099 - 0.156xt + 0.006xt², R^2=0.98253, $P<0.0001$

PF 2stages = 1.765 - 0.205xt + 0.0083xt², R^2=0.96971, $P<0.0001$

PF 3stages = 1.834 - 0.215xt + 0.0084xt², R^2=0.97014, $P<0.0001$

PF 4stages = 1.860 - 0.219xt + 0.0085xt², R^2=0.97013, $P<0.0001$

Figure 6: Performance Factor change with time Conclusion

This study is carried out in order to look for the evolution of distilled water with time and according to the number of stages. The obtained results allowed us to make a comparison, in terms of efficiency, between a simple solar still with a capillary film and a multistage one.

Taking into account the considered hypotheses, we conclude that:

- A multi-stage distiller is recommended to recover quantity of energy to the condenser in one side and to reduce the temperature at the condenser outlet in the other side.
- To obtain better efficiency, we should maintain a large temperature difference between the evaporation surface and the condensation surface, in one side and maintain waterproof sides in order to avoid vapour losses.
- A brine with high temperature leads respectively to better efficiency, a high specific heat, a high thermal conductivity, low mass volume and low dynamic viscosity.
- The use of an absorber (brine) with high thermal conductivity and high specific heat allows improving the efficiency system in a low degree.

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