Contribution to the numerical study of a multi-stages solar still with heat recovery

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Abstract— The Desalination technology of sea water or salty ground water will increasingly be required to meet growing demands for potable water in the wide world. Various desalination methods are analyzed with respect to their primary energy consumption, sea-water treatment requirement and equipment cost. From this analysis, the multi-effect boiling evaporator is concluded to be the most suitable method for stimulation by solar energy.

The distillation system components presented in this work are a solar collector and a desalination tower.

In this paper, a computer simulation model is presented in MALAB for studying performance of a multi-stage solar still with recovery heat. This model is based on heat and mass transfer, to determine the various thermodynamic quantities listed distiller. The heat input of the distiller is made using a field of solar collectors of parabolic type, although the system can be operated with other energy sources. The parabolic-trough solar-collector is selected mainly due to its ability to function at high temperatures with high efficiency.

The numerical results calculated using ambient data show that the production rate can reach 6 kg/m^2/h. and the distillation efficiency is 80%.

Keywords: Solar still; Desalination; Numerical modelling.

Introduction

Water is an important resource for the use of humanity. Natural resources can not meet the growing demand for low-salinity water with industrial development and the growing global demand for fresh water. This has forced humanity to seek another source of water. In addition, the rapid reduction of underground aquifers and increasing salinity of these non-renewable sources will continue to aggravate the international water shortage problems in many areas of the world. desalination techniques are able to provide the solution.manque.

Somme of water desalination techniques are used, but the distillation multi effects is the most practiced technique in the world, 80% of the facilities existed around the world work with this technique. Research in the field of desalination is very active at present, due to consumption forecasts at coming years..

The various methods of desalination are analyzed with regard to their primary energy consumption, seawater processing condition and the cost of equipment. From this analysis, the multi-stage distiller can be the most appropriate instrument to be valued by solar energy. The parabolic trough solar collector is primarily chosen because of its temperature operating capability and a high performance.

The distillation system presented in this work consists of two different units: the heat source (a solar collectors) and the distillation unit. The distiller is based on the construction of a tower consists of stages containing saline water, superposed on each other, fig.1.

This contribution with other improvements aims to find a mode of operation for the distiller to get the best performance when the thermal energy is recovered several times.

I. DESCRIPTION OF THE DISTILLER.

he distiller is based on the construction of a tower consists of stages containing saline water, superposed on each other. Each stage uses the water vapor condensation heat from the lower stage, fig. 1.Only the lower layer (1) is supplied with thermal energy, fig. 2. When the water in the layer is heated by

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a heat exchanger powered by the solar field sensors which can be combined a thermal storage system, it evaporates and condenses on the bottom surface of conical layer located above. There is a formation of water droplets flowing to a gutter connected to a storage tank.

During condensation of the steam, the energy of phase change, also called the latent heat of condensation is released. This energy heats the water contained in the upper stage which is also evaporated and condenses on the bottom surface of the stage above and so on.In this way, the energy provided to heat the water the lower layer is recovered, at least in large part, to be used several times. This heat recovery process has a multiplier effect on the production of drinking water. Filling the distiller is continuously carried in each stage using pipes, fig. 2. The system is supplied with saline water flow on about equal to twice evaporated water flow.

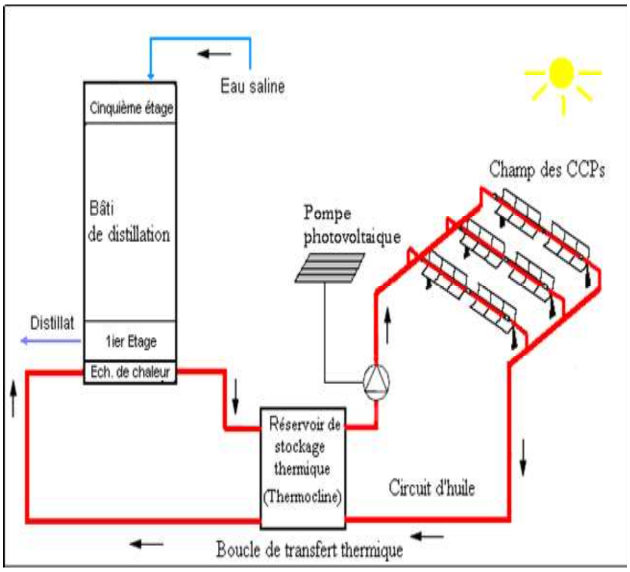
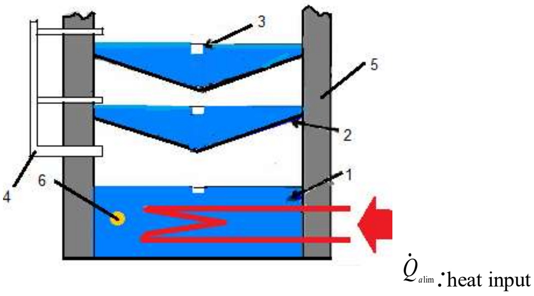


Fig 1. Schematic of a solar multi-stages desalination unit



Lower layer fueled by solar energy. 2. inclined surface condensation. 3. Gutter evacuation of distilled water.4. saline water filler tube to keep the water level constant. 5.Isolation sides. 6.Point For measuring the temperature.

Fig. 2. Inside view of a section of distiller

2.Mathematical modeling

The following assumptions have been made to develop the mathematical model for the proposed solar still:

- Steady state condition throughout the solar still.
- The system is evacuated such that the atmospheric pressure.
- Temperature of the layer wall is constant over the entire surface.
- Steam and humid air are supposed saturated [13], which means that at any time the condensed water rate is equal to rate of evaporated water.
- The three modes of heat transfer (convection, conduction and radiation) coexist.
- Make up water flow rates into the system are constant.
- The system is well insulated such that the losses to the environment are negligible.

To understand the mechanism of energy transport process in a multistage distiller, we must deal separately with the various thermal flows inside the distiller, although in reality, these flows occur together.

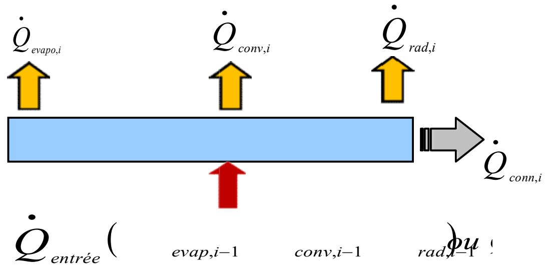


Fig.3. Heat balance for a layer of water

- Thermal balance of the heat exchanger:

$$Cp_{eau}.m_{Ech..chal}.\frac{dT_{Ech.chal}}{dt}=Q_{entrée}-\left(Q_{Evap,i}+Q_{Conv,i}+Q_{Rad,i}\right)-Q_{cond,i} \quad (1)$$

- Thermal balance between any two stages of the distiller:

$$Cp_{eau}.m_{Etage,n}.\frac{dT_{Etage,n}}{dt}=\left(Q_{Evap;n-1}+Q_{Conv,n-1}+Q_{Raai,n-1}\right)-\left(Q_{Evap;n}+Q_{Conv,n}+Q_{Raai,n}\right)-Q_{Cond,n} \quad (2)$$

To establish the model of the distiller, we must know the various expressions of the coefficients of heat exchange by radiation, convection, conduction and evaporation.

- By radiation:

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$$h_{rad}=\left(T_{eau,i+1}+T_{eau,i}\right)\left(T_{eau,i+1}^{2}+T_{eau,i}^{2}\right).\sigma.\varepsilon_{eff} \qquad (3)$$

- Coefficient of heat transfer by convection [15]:

$$h_{conv}=0.884.\left[T_{eau,i+1}-T_{eau,i}+\frac{\left(P_{eau,i+1}-P_{eau,i}\right).\left(T_{eau,i}+273.15\right)}{268.9.10^{3}-P_{eau,i}}\right]^{\frac{1}{3}} \qquad (4)$$

- The coefficient of exchange by evaporation**:**

$$h_{évap}=16,273\ 10^{-3}\ h_{conv}\left(\frac{P_{eau,i+1}-P_{eau,i}}{T_{eau,i+1}-T_{eau,i}}\right) \qquad (5)$$

The equivalent conductivity:

$$k_{cond}=\frac{1}{\sum_{i=1}^{n}\frac{1}{\lambda_i}.In\left[\frac{r_{i+1}}{r_i}\right]}. \qquad (6)$$

We replace the different flows of heat through their explicit expressions, then we write the equations of heat balances in each component of distiller depending on temperature:

- For the lower layer:

$$\frac{dT_{eau1}}{dt}=\frac{1}{Cp_{eau}.m_{eau1}}\left[\begin{array}{l}Q_{entrée}-\left(k_{cond}.A_{cond}\right)\left(T_{eau,1}-T_{amb}\right)-\left(\alpha_{ra}.A_{ra}\right)\left(T_{eau,1}-T_{eau,2}\right)-\\ \left(\alpha_{conv}.A_{conv}\right)\left(T_{eau,1}-T_{eau,2}\right)-\dot{m}_{conv1}.L_v\end{array}\right] \qquad (7)$$

- For all stages i:

$$\frac{dT_{eau,i}}{dt}=\frac{1}{c_{p,eau}.m_{eau,i}}\left[\begin{array}{l}\dot{Q}_{a\lim,i}-\left(k_{cond}.A_{cond}\right).\left(T_{eau.i}-T_{amb}\right)-\left(\alpha_{ra}.A_{ra}\right).\left(T_{eau,i-1}-T_{eau,i}\right)-\\ \left(\alpha_{conv}.A_{conv}\right).\left(T_{eau,i-1}-T_{eau,i}\right)-\dot{m}_{conv,i}.L_v\end{array}\right] \qquad (8)$$

or: $i=2\ ;5$

We determine the temperature of each stage and the production of distilled water. It is further to determine the ratio between the production and the change in temperature between stages. Then we calculate the efficiency and system performance.

-The condensed water rate is given by:

$$m_{cond,eau}=\frac{\dot{Q}_{evap}}{L_v} \qquad (9)$$

The efficiency of a stage is calculated by:

$$\eta_{Et,n}=\frac{m_{cond}.L_V}{\left(Q_{Evap,n-1}+Q_{conv,n-1}+Q_{Rad;n-1}\right)-\left[m_{eau}.Cp_{eau}.\frac{\Delta T_n}{\Delta t}\right]} \qquad (10)$$

-The coefficient of performance:

$$COP=\frac{\dot{Q}_{Evap}}{\dot{Q}_{A\lim}-Q_{capTh}}=\frac{m_{cond,\Sigma}.L_V}{\dot{Q}_{A\lim}-\left[\left(m_{eau,\Sigma}.C_{p,eau}\right)\frac{\Delta T_m}{\Delta t}\right]} \qquad (11)$$

3- Results and discussion

A computer program has been developed based on the equations outline above, it was written in MATLAB.10 . The equations have been solved using the Runge-Kutta method of 4th order. The results reported in this section use heat input of 200-1400 w which equivalent to solar insolation of 300 to 1500 W/m^2 when a 1.8 m^2 solar collector is used. These values for solar insolation cover the average daily solar insolation in parts of South of Algeria.

Fig.4 shows the temperature profiles for one day, we can clearly see that after some time, each stage reaches steady state and temperature profiles become almost constant during eight hours. The lower stage of the distiller has maximum heat due to the heat source that supplies the distiller. Practically, the system temperature decreases continuously to the top stage as shown by the figure. The maximum water temperature of the 1st, 2nd, 3rd, 4th and 5th stage reach respectively:97.67° C, 83.80 ° C ,75.76 ° C, 71.3 ° C, 69.47 ° C and 67.66 ° C.

We note that this is the lowest stage which undergoes the highest elevation of temperature just after that of the heat exchanger. Then, this temperature drops more gradually as the stage away from the heat source.

The variation of the thermal flow exchanged in each stage is dependent of the corresponding temperature and temperatures differences (ΔT).The greater part of heat transfer from one stage to another is effected by the heat of evaporation; this energy transfer down gradually as the stages temperature levels decrease, fig.5.

Fig.8 shows the effect of (ΔT) between each two successive stages on the production of distilled water. We noted that production decreased significantly with the increase of (ΔT).If temperature difference reach 15°C, production will decrease by 20%. It was evidently depends on heat input and the evaporation surface.

To more accurately determine the yield of a layer, we must be considered function of time, because the system is in a transient state, fig. 9. The maximum distilled water yield was that of lower layer 95%. We noted that all almost time the yields are constant, except for the first and second layer, where it after they reach respectively in yields of 70% and 80%, they drop to achieve values varied between 50% and 58%.The maximum accumulative distilled water yield of 6 kg/h occurs at the heat input of 1400 w. The total daily productivity of the solar still based on 8 h operation is shown in fig 7.

Fig.10 represents the trace of COP. This heat recovery coefficient increases in function of two main parameters; high temperature at all layers and a temperature difference (ΔT) minimal between layers, when the COP increases continuously it reached a value of 4.4. It is correlated with the production of condensate: it drops, when this production decreases take an optimum operating point with a temperature in the heat exchanger of 98 ° C and a temperature difference (ΔT)between the stages at about 5 ° C.

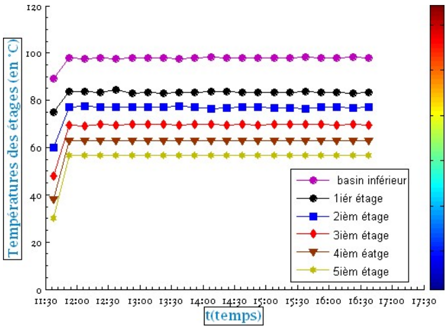

Fig.4. Temperature profiles of a five-stage distiller

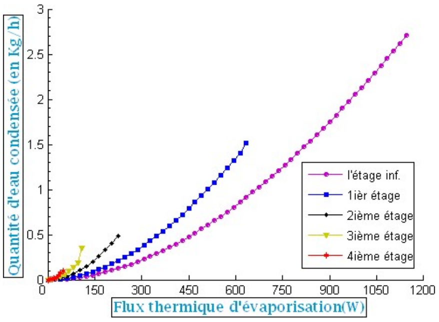

Fig. 5. Distilled water flow rate of the different stages vs the heat of evaporation

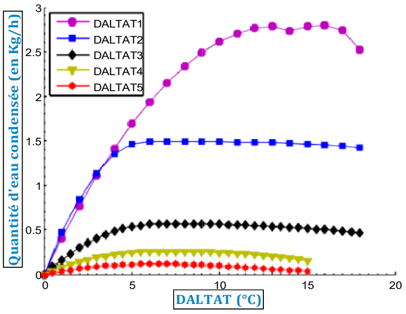

Fig. 6. Distilled water flow rate obtained vs (ΔT)

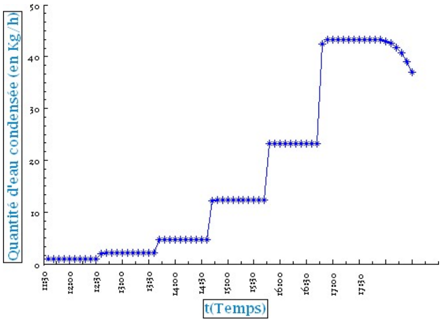

Fig.7. Production of water condensed by 30 min interval.

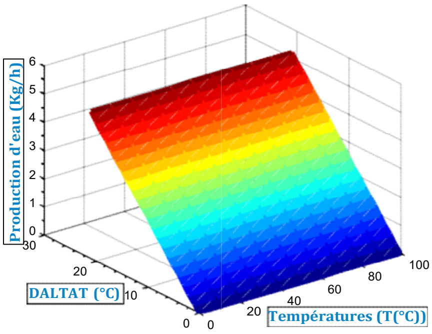

Fig.8. Production of distilled water vs the temperatures of the stages and the (AT)

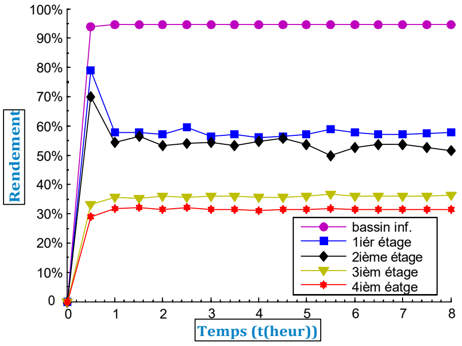

Fig. 9. Performance of each stage of the distiller

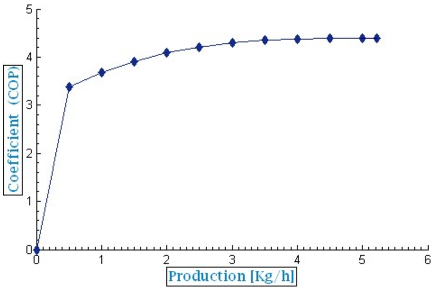

Fig. 10. *The COP coefficient vs water production*

conclusion

The main advantage of evaporation processes is that the water obtained is very pure, it must be recharged even in minerals, and energy consumption is independent of salinity.

The incident solar radiation is the most important factor that directly affects at the instantaneous variations of temperatures of all components of the distiller and the production of distilled water.

Distilled water flow to the requirements listed is 6 kg/m2/h, with a distillation efficiency of 78% corresponding to 1.4 kWh of supply energy. There was a large temperature gradient between the lower layer and the first stage, which promotes condensation with a good yield of about 95%. In other words, it is found that the system provides a good yield when: the lower level reaches a temperature between 95 ° C and 98 ° C, the temperature difference is between 7 ° C and 13 ° C.

We conclude that we must minimize heat loss by conduction using good isolation of walls of the distiller.

When we added all the heat flow exchanged in the heat exchanger, we obtained a thermal power below that thermal power supply. The energy difference does not take part in the distillation process. This means that during the period of cooling, heat flow takes the direction opposite direction. The values of heat exchange coefficients which were determined show that variations in each stage is so low, which allowed us

to say that we draws from to calculate these coefficients for average temperatures values, and considering constant in each stage.

Finally, we note that the results of this simulation are encouraging. This allowed us to achieve using simple technical means based on solar energy a modest supply of potable water especially in rural and desert areas with high solar insolation, to solve the problems posed by the lack of fresh water in those areas.

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NOMENCLATURE

A_{cond} : Surface d'échange par conduction, m²
A_{conv} : Surface d'échange par convection, m²
A_{ra} : Surface d'échange par rayonnement, m²
Cp : Capacité thermique, J/kg.K
COP : Coefficient de Performance
h : Coefficient d'échange de chaleur, W/m². K
$h_{M,ev}$: Coefficient de transfert massique, s/m
h_{con} : Coefficient de chaleur par convection, W/m².K
h_{rad} : Coefficient d'échange de chaleur par rayonnement, W/m².K
h_{evap} : Coefficient d'échange de chaleur par évaporation, W/m².K
k_{cond} : Résistance du passage thermique par conduction, m².K/W
K_{int} :The coefficient thermal transmittance
L_v : Chaleur latente de vaporisation, kJ/kg
M : Masse molaire, g/mole
m_{cond} : Débit massique de l'eau distillée, kg/h
m_{eau} : Masse d'eau contenue dans un bassin, kg
P : Pression de saturation, Pa
P_{vap} : Pression partielle de la vapeur d'eau, Pa
$\dot{Q}_{entrée}$: Flux thermique d'alimentation, W/m²
$\dot{Q}_{évapo}$: Flux thermique par évaporation, W/m²
$\dot{Q}_{rad}$: Flux thermique par radiation, W/m²
$\dot{Q}_{conv}$: Flux thermique par convection, W/m²
$\dot{Q}_{cond}$: Flux thermique par conduction, W/m²
$\dot{Q}_{eau}$: Flux thermique absorbée par l'eau, W/m²
$T_{eau,i}$: Température de bassin i, °C
ΔT : Différence de température, °C
T_a : Température ambiante, °C
T_e : Température d'entrée du fluide caloporteur, °C
σ : Constante de Stefan-Boltzmann, 5,6697 10^{-8} W/m².K^4
λ : Conductivité thermique, W/m.K

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