A Comparative Study between Plan Solar Still-Collector and Spherical Solar Still-Collector

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***Abstract*—Water and energy are two inseparable commodities that govern the lives of humanity and promote civilization. Unfortunately, humanity has a severe shortage of drinking water, although water represents 73% of the surface of the planet as seas and oceans. Several technologies for desalination of brackish or saline water are apparent around the worlds, such as reverse osmosis, electrodialysis...etc. These techniques are characterized by high energy consumption and adverse ecological effects on the climate. The use of renewable energy for water desalination gives a great hope, especially in arid and deserts area where solar energy is available. Relatively low needs for drinking water, solar distillation appears as one of the interesting methods. However, the productivity of a conventional solar still was not very satisfied. With a view to ameliorate the yield of the solar still, our study aims at the effect of coupling a spherical solar still with a flat plate collector on the yield of the fresh water, we have to compare between the productivity of a spherical solar still and conventional one. After having established the thermal balances of the various solar systems (plate still, spherical still, plate still-collector and spherical still-collector) at instationary regime, the differential equations are solved by using 4th order Runge–Kutta method. The numerical results obtained allow to determinate the percentage of improvement caused by coupling a spherical solar still with a flat plate collector on the yield of the fresh water.**

Keywords-plan still; spherical still; flat plate collector; production

NOMENCLATURE

A	area (m^2)
C	heat capacity per unit (j/kg.K)
e_w	water thickness(m)
F	forms factor (dimentionless)
h	heat transfer coefficient ($W/m^2.K$)
I	absorbed solar radiation (W)
L_v	latent heat of vaporization (j/kg)
m	mass (kg)
$\dot{m}_{ev}$	distillate rate (kg/s)
P	partial pressure (N/m^2)
Q	heat flux (W)
t	time (s)
T	absolute temperature (K)
Greek letters	
ε	emissivity
σ	Stefan-Boltzmann constant $5{,}669\cdot10^{-8}$ ($W/m^2.K^4$)
Subscripts	
a	ambient
b	basin linear
c	convection
co	coolant
ev	evaporation
g	glass cover
gi	inner glass cover
go	outer glass cover
i	insolent
ii	inner insolent
io	outer insolent
r	radiation
w	water

I. INTRODUCTION

Solar distillation has successfully attracting the attention of researchers because it appears as a technology that leaves no traces on the ecology and uses clean, widely available and free energy. The solar still does not require complicated structure, it work on the principle of the water cycle in nature, and their cost remains low. Most research is focus on the improvement and development of productivity of the solar still.

However the problem is the low yield of this type of process. Malik MAS, Tiwari GN [1] improve that the conventional solar still can produce average 3 liters /day. For high efficiency, the solar still should maintain a large temperature difference between feed water and condensing surface.

Coupling a solar still with a flat plat collector is used for arising the temperature of feed water. In the present study a comparison has been made to find out the effect of coupling a solar still with a flat plat collector on the solar still output, we have to compare between the productivity of a spherical solar still and conventional one.

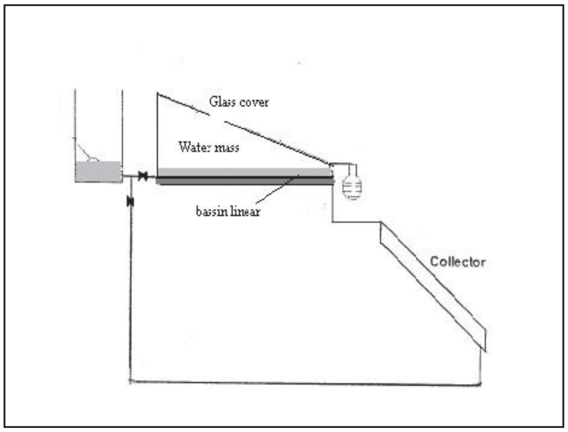


Figure 1. Schematic view of single slope solar stills coupled with flat plate collector.

II. SYSTEMS DESCRIPTION

A schematic diagram of single slope solar still coupled with a flat plate collector is shown in Fig. 1. The still is partially filled with brine in the bottom deposit which is a black surface (collector) used to absorb incoming radiation after it passes through the glass cover (of 3 mm thick) and the brine [2].

The bottom section of basin was insulated to reduce thermal losses to the surroundings. This still was oriented along the south direction to receive maximum solar radiation.

A schematic diagram of the spherical solar still coupled with a flat plate collector is shown in Fig. 2. The still mainly consists of the circular basin and absorber plate carrying the saline water, the spherical cover. The distillate output from the still was frequently collected using a container placed under the solar still [3]. Due to spherical geometry of the glass cover, this still have not a preferred orientation.

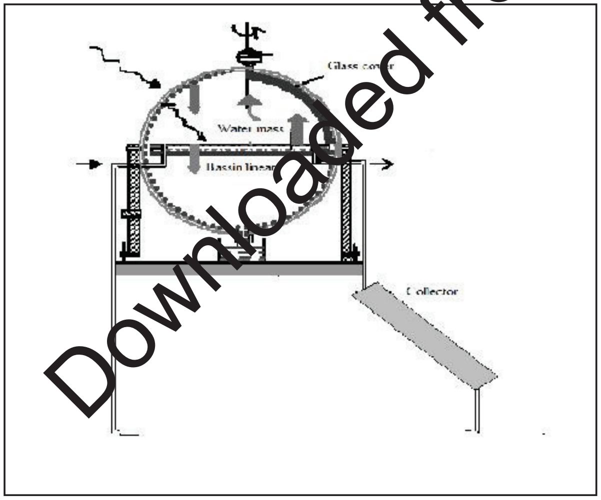


Figure 2. Schematic view of spherical solar still coupled with flat plate collector.

III. THERMAL MODELING

Writing the heat balance for each component of the still is established for the glass cover (inner and outer sides), salt water, the black surface (absorber) and the insulation (inner and outer sides). We obtained six differential equations where the unknowns are the temperatures of each component of solar still:

$$\frac{dT_{go}}{dt}=\frac{2A_g}{m_g C_g}\left[h_{go,gi}\left(T_{gi}-T_{go}\right)+h_{go,a}\left(T_a-T_{go}\right)+I_g\right] \quad (1)$$

$$\frac{dT_{gi}}{dt}=\frac{2A_g}{m_g C_g}\left[h_{go,gi}\left(T_{go}-T_{gi}\right)+h_{gi,w}\left(T_w-T_{gi}\right)+I_g\right] \quad (2)$$

$$\frac{dT_w}{dt}=\frac{A_w}{m_w C_w}\begin{bmatrix} h_{gi,w}\left(T_{gi}-T_w\right)+h_{w,b}\left(T_b-T_w\right)+h_{a,w}\left(T_a-T_w\right) \\ +h_{w,co}\left(T_{co}-T_w\right)+I_w \end{bmatrix} \quad (3)$$

$$\frac{dT_b}{dt}=\frac{A_b}{m_b C_b}\left[h_{w,b}\left(T_w-T_b\right)+h_{b,ii}\left(T_{ii}-T_b\right)+I_b\right] \quad (4)$$

$$\frac{dT_{ii}}{dt}=\frac{2A_i}{m_i C_i}\left[h_{b,ii}\left(T_b-T_{ii}\right)+h_{ii,io}\left(T_{io}-T_{ii}\right)+I_g\right] \quad (5)$$

$$\frac{dT_{io}}{dt}=\frac{2A_i}{m_i C_i}\left[h_{ii,io}\left(T_{ii}-T_{io}\right)+h_{io,a}\left(T_a-T_{io}\right)\right] \quad (6)$$

I_g: solar flux absorbed by glass cover.
I_w: solar flux absorbed by water mass.
I_b: solar flux absorbed by the basin liner.

A. *Heat transfer coefficients*

The internal heat transfer between the glass cover and water mass can take place in three ways mainly by convection, radiation and evaporation [4]:

1) *Convective heat transfer*

Before Following V.K. DWIVEDI and G.N. TIWARI [5] [6], the rate of convective heat transfer is described by the general equation:

$$Q_c = h_c \cdot (T_w - T_{gi}) \cdot A_w \quad (7)$$

A_w is the surface of water and h_c is the convective heat transfer coefficient and it given by [7]:

$$h_{cvw} = 0{,}884.\left[(T_w - T_{vi}) + \frac{(P_w - P_v)(T_w + 273)}{268{,}9 \cdot 10^3 - P_w}\right]^{\frac{1}{3}} \quad (8)$$

P_w and P_{gi} are the partial pressures of the vapor of water respectively, in water temperature T_w and the inner glass cover temperature T_{gi}.

2) Radiative heat transfer

In the same of the convective heat transfer, the rate of radiative heat transfer can be determined from the relation:

$$Q_r = h_r \cdot (T_w - T_{gi}) \cdot A_w \tag{9}$$

Where h_r is the irradiative heat transfer coefficient and it given by [8] [9]:

$$h_{rvw} = F_{12} \cdot \varepsilon_{eff} \cdot \sigma \cdot \left[(T_w + 273)^2 + (T_{vi} + 273)^2\right] \cdot \left[T_w + T_{vi} + 546\right] \tag{10}$$

1) Evaporative heat transfer

The evaporation heat transfer from basin water to condensing cover is described by the relation [10]:

$$Q_{ev} = h_{ev} \cdot (T_w - T_{gi}) \cdot A_w \tag{11}$$

Where h_{ev} is the evaporative heat transfer coefficient and it given by [11]:

$$h_{ev} = 16.273 \cdot 10^{-3} \cdot h_{cvw} \cdot \frac{(P_w - P_{vi})}{(T_w - T_{vi})} \tag{12}$$

The hourly yield per unit area can be evaluated from known values of water and glass temperatures, and is given by [5]:

$$\dot{m}_{ev} = \frac{h_{ev} \cdot (T_w - T_{vi}) \cdot 3600}{L_v} \tag{13}$$

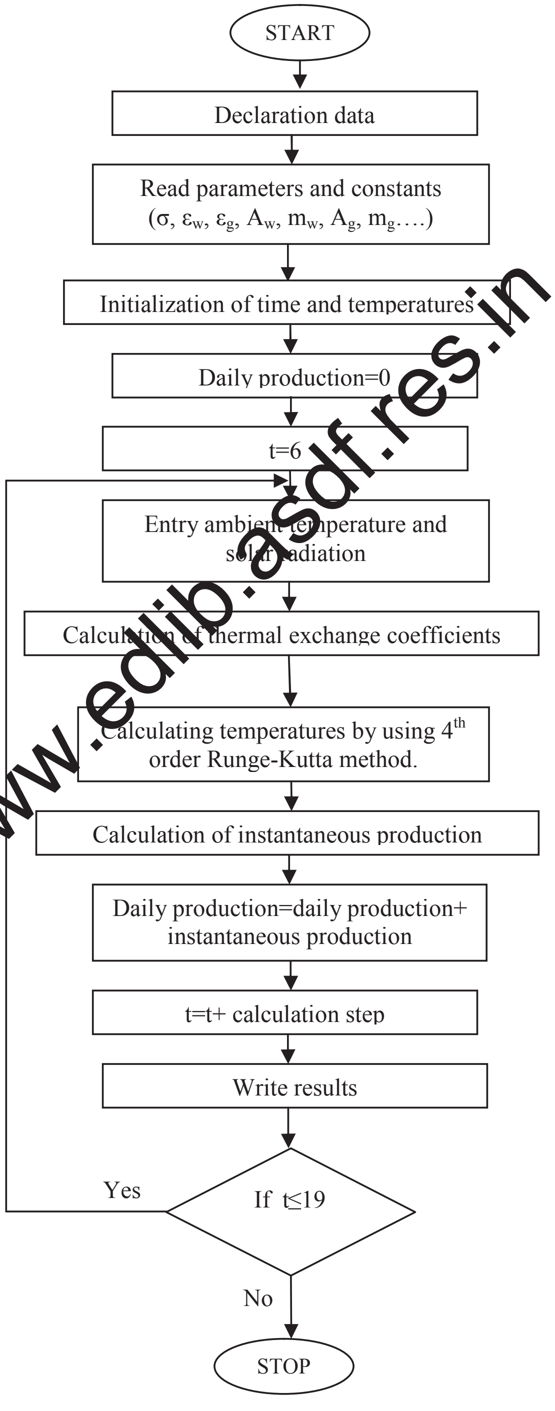
Where L_v is the latent heat of vaporization, dependent of temperature [6]:

$$L_v(T) = 3408 - 5.21 \cdot T + 0.01 \cdot T^2 - 1.194 \cdot T^3 \tag{14}$$

IV. NUMERICAL RESOLUTION

Differential equations are solved by using 4th order Runge-Kutta method [12]. The calculation of the daily production begins at six in the morning until seven o'clock in the evening for every second. We assume initially that each component of the solar still is at ambient temperature except the temperature of the absorber which is at a slightly higher temperature and the temperature of the brine is brought to the preheating temperature. The step of calculation is 10^{-6}.

The Computer programs have been developed in 'FORTRAN' language to predict the hourly variations of water temperature, glass temperature, distillate output and the various heat transfer coefficients of solar stills.



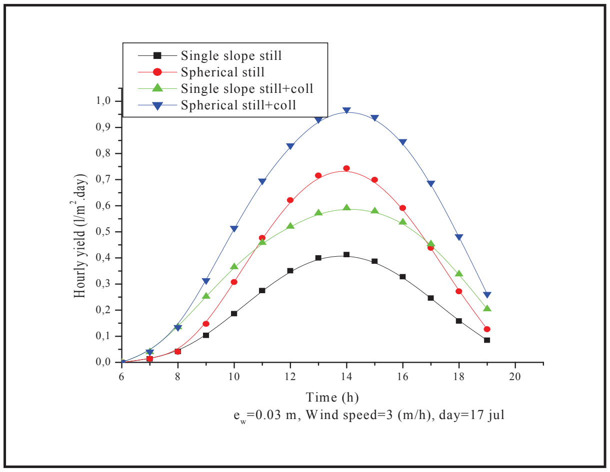


Figure 3. Temporal variation of hourly yield for all systems (single slope, spherical still, single slope+collector and spherical still+collector).

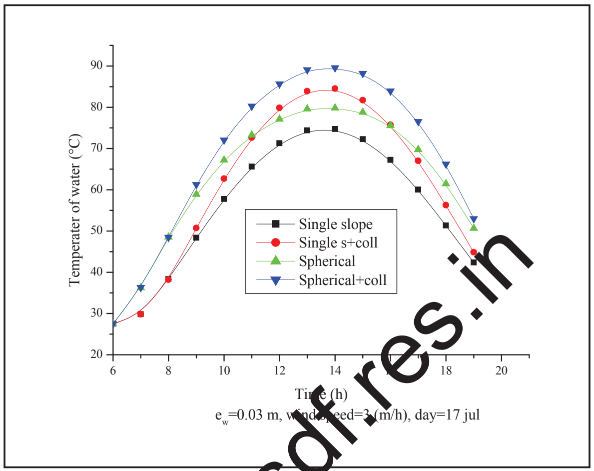


Figure 5. Hourly variation of water temperatures (single slope, spherical still, single slope+collector and spherical still+collector

V. RESULTS AND DISCUSSION

Fig.3 shows that the hourly production in both systems (single slope solar and spherical solar still) is almost zero during the first hours of the day (between 6^h and 8^h of the morning), at this time the system is turning from the ambient temperature to the operating temperature. Thereafter, production increases with the growth of solar radiation reaching a maximum at 14 hours.

The fig. 3 shows also that the two solar stills don't absorb the incoming radiations in the same way. The single slope solar still that was oriented in the south absorbed the major of solar energy between 11^h-15^h.

When the sun was in the south, The problem of orientation do not exist in the case of the spherical solar still, because the spherical geometry of the glass cover allow the admission of the incoming radiation whatever the position of the sun in the sky.

The theoretical results obtained in this work indicated that the yield of a single slope solar still (The hours ranges were between 6^h and 19^h) is 2.99 l/m². Day, however the yield of the single slope solar still coupled with a flat plate collector is about 5. 19 l/m².day, recorded an improvement to 42.39%.

The experimental results of Badran and Al-Tahaineh [13] show that coupling a flat plate collector, augmented the productivity of single slop solar still by 36%, where Rai et al [14] obtained a maximum distillate of 6.75 kg/m² in the cas of solar still coupled with flat plate collector. But if we use a spherical glass cover, the yield is about 5.05 l/m².day and the added of the collector increase the production to 7.62 l/m².day, which means an improvement of 33.72% (fig. 4). The experimental results obtained by B. Ismail [15], found that the daily distillate produced from the still ranged from approximately 2.8 to 5.7 l/m².

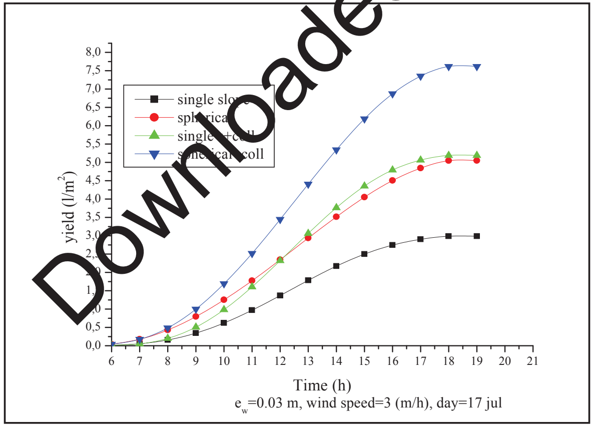


Figure 4. Comparative variation of still productivity (single slope, spherical still, single slope+collector and spherical still+collector).

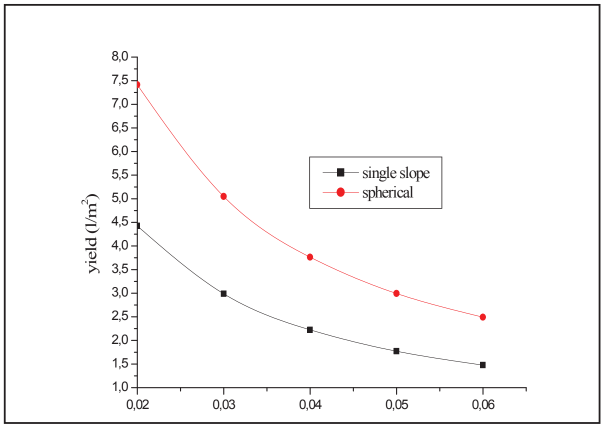


Figure 6. Variation of yield of solar still with thickness of water mass

Fig. 5 compared hourly temperatures of saline water obtained for all systems. The highest temperatures occurred between the hours of 11^h–15^h in the case of a single slope solar still, where the temperature of feed water reached 75°C, however the preheat of water arise the temperate to 84.5°C.

The fig. 6 explains the variation of distillate output with depth of basin water. As depth of basin water increases the output in the two types of solar stills.

In the spherical solar still, the feed water record a temperature of 79.81°C without preheat, because of the spherical geometry of the glass cover who receive an important quantity of solar energy, preheat the water rising water temperature at 89°C .

VI. CONCLUSION

It is clear that there is a good agreement between theoretical and experimental results. The theoretical and numerical study allows us to study the influence of many parameters affect the operation of the solar still.

On the basis of present studies the following are the conclusions drawn:

- The solar radiations are the main factors affecting the productivity of the solar still.
- The daily yield of single slope solar still is about 2.99 l/m^2, however the yield of spherical solar still is 5.05 l/m^2.
- In our case, add a collector increase the productivity of solar still between 30-50%, where the productivity of a single slope coupled with a collector was about 5. 19 l/m^2, and that of spherical still coupled with a collector was about 7.62 l/m^2.day.
- There is a direct relation between decrease the thickness of feed water and the productivity of still.

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