Comparative Study of Experimental and Theoretical Convective, Evaporative for Two Model Distiller

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Abstract**—**The purification of brackish seawater becomes a necessity and not a choice against demographic and industrial growth especially in third world countries. Two models can be used in this work: simple solar still and simple solar still coupled with a heat pump. In this research, the productivity of water by Simple Solar Distiller (SSD) and Simple Solar Distiller Hybrid Heat Pump (SSDHP) was determined by the orientation, the use of heat pump, the simple or double glass cover. The productivity can exceed 1.2 L/m²h for the SSDHP and 0.5 L/m²h for SSD model. The result of the global efficiency is determined for two models SSD and SSDHP give respectively 30%, 50%. The internal efficiency attained 35% for SSD and 60% of the SSDHP models. Convective heat coefficient can be determined by attained 2.5 W/m²°C and 0.5 W/m²°C respectively for SSDHP and SSD models.

Keywords**—**Productivity, efficiency, convective heat coefficient, SSD model, SSDHP model.

I. Introduction

A solar still is a device that produces clean, drinkable water from saline water using energy from the sun. Solar energy becomes the most widely used energy. Babalola et al. [1] determined the efficiency of a double-slope solar distiller both the different study parameters Munzer et al. [2] developed an equation to predict the daily productivity of a single-sloped solar still. This equation relates the dependent and independent variables which control the daily productivity.

Badran et al. [3] did an experimental study for a solar distiller under the Jordanian climate. A complete study was made to know the performance of this type of solar still. A modeling based on relevant correlations giving the heat transfer coefficients and the vaporization heat flux as a function of Rayleigh number was derived. This takes the form of a set of highly coupled nonlinear ordinary differential equations in terms of time-dependent temperatures of the still components.

Kumar and Tiwari [4] noticed a difference between the convective coefficient values that was increased with the increase of water depth (0.01-0.03). Also, a single slope is better 499.41 L/m² as compared with a double slope solar still 464.68 L/m². Cristóbal et al. [5] show that transfer coefficient is related to that of partial pressure.

II. Theoretical Study

This research gives the results of the productivity, heat transfer and efficiency for active solar still hybrid with heat pump named SSDHP and passive solar still named SSD. Dunkle [6] gives the relation of mass flow rate:

$$m_{the} = 16.273\text{x}10^3 h_{cw}\left(\frac{P_w - P_g}{L}\right)$$

where h_{cw} is given by:

$$h_{cw} = \frac{Nu \times \lambda}{d} = C(Gr.Pr)^n = C \times Ra^n$$

Nu, Gr, Pr, and Ra are Nusselt, Grashof, Prandt, and Rayleigh numbers, respectively. C and n may be constant or variable dimensionless parameters depending on hypothesis established by the authors. Nusselt, Grashof and Prandt numbers are given by:

$$Nu = C(GrPr)^n$$

$$Gr = \frac{g\ \beta\ \rho^2\ d^3}{\mu^2}\Delta T$$

$$Pr = \frac{\mu\ C_P}{\lambda}$$

The expression of the coefficient of convective transfer:

$$h_{cw} = 0.884\left[\left(T_w - T_g\right) + \left(\frac{\left(P_w - P_g\right)\left(273 + T_w\right)}{268.9\text{x}10^3 - P_w}\right)\right]^{1/3}$$

All the expressions are given for a mean water temperature of the order of 50 °C and Grashof number verifying Gr > $3.2\text{x}10^5$ [7]. Parameters C and n are constant and set to be 0.075 and 1/3, respectively. For this value of exponent n, heat transfer coefficient becomes independent of the spacing x. Table I shows values of C and n developed by different configurations for Gabes. This value of c and n are not constant it depends on operating conditions

TABLE I
Values of C, N for (000), (110), (001) and (111) Configurations

Obtained value	(000)	(110)	(001)	(111)
c	0.25	0.15	0.1	0.28
n	0.26	0.19	0.95	0.5

Aburideh et al. [7] developed a thermal model to determine convective mass transfer for different Grashof numbers for

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solar distillation on passive and active distillation systems for only summer climatic conditions. In their experiments, water temperature exceeds 50 °C and can reach 85.5 °C. Values of c and n are not constant, in this case, the methodology used by Malaeb et al. [8] for evaluating C and n can be presented as:

$$m_{the} = 0.0163\left(P_w - P_g\right)\left(\frac{\lambda}{d}\right)\left(\frac{3600}{L}\right) C\,(Ra)^n = K \times C \times (Ra)^n$$

where m_{the} are the mass flow rate of condensate:

$$K = 0.0163\ \left(P_w - P_g\right)\left(\frac{\lambda}{d}\right)\left(\frac{3600}{L}\right)$$

$$\frac{m_{the}}{K} = C \times (Ra)^n$$

Taking logarithm on both sides of equation gives:

$$\text{Ln}\left(\frac{m_{the}}{K}\right) = Ln\ C + n\ \text{Ln}\ (Ra)$$

This is the form of a linear equation given by:

$$y = mx + D$$

where:

$$\begin{cases} y = \text{Ln}\left(\frac{m_{the}}{K}\right) \\ x = \text{Ln}\,(Gr.Pr) \end{cases}$$

$$\begin{cases} m = n \\ D = \text{Ln}\,C \end{cases}$$

- Effect of solar cavity,
- Operating temperature ranges,
- Orientations of the condensing covers.

The global and interior efficiency for the SSD model is given by the ratio of the heat flux water use of vaporization and global energy incident by solar in horizontal surface [9]:

$$\eta_g = \frac{q_{ew}}{G.\ S} = \frac{m_e.\ L_v}{G.\ S}$$

The interior efficiency is defined by:

$$\eta_i = \frac{q_{ew}}{q_w} = \frac{m_e L_v}{q_w}$$

The global and interior efficiency in the SSDHP model is given respectively by [10]:

$$\eta_g = \frac{q_{ew}}{q_w}$$

$$\eta_i = \frac{q_{ew}}{q_{wc}}$$

where $q_{wc} = \alpha_t \times G \times S + q_{cond} = q_w + \alpha_t \times G \times S$

q_{cond} is condenser water quantity:

$$q_{cond} = COP_{PAC}\,.W$$

$$\eta_i = \frac{q_{ew}}{(\alpha_t.G.S + COP_{PAC}.W)\,3600}$$

The COP_{PAC} is given by:

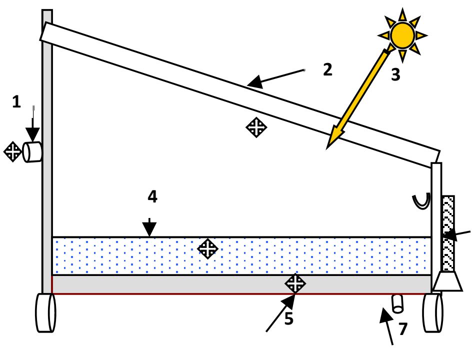
$$COP_{PAC} = \frac{q_{cond}}{W} = \frac{T_w}{T_w - T_g}$$

III. Experimental Studies

In the present study, two solar distillers were manufactured. The first solar distiller is named SSD, as its name suggests the water, in this case, is heated by the sun. In order to increase the supply of fresh water, a heat pump was added to the SSD named SSDHP. The condenser is immersed in the basin to increase the temperature of the water. The evaporator is placed just next to the glass to condense more water.

A. SSD

The depth of the water in the SSD is taken equal 30 cm throughout our work; the inclination of the glass is equal to 30°. The surface of the basin is equal to 1 m². Figs. 1 and 2 show the operation of an SSD such that the solar radiation reaches the water through the transparent lid and therefore the distilled water will be condensed.



1- Inner water, 2-Glass cover, 3-Sun, 4- Saline water, 5- Basin, 6- Distiller water, 7- Out water, 8-Thermometer position

Fig. 1 Simple Solar Distiller

Fig. 2 Photo of SSD

B. SSDHP

The first type of solar still is passive without a heat pump. In the second, a heat pump was added. The condenser is mixed in the quantity of sea water, with the aim of increasing the temperature of the latter. The evaporator is placed just below glass in order to favor well the condensation of the water. This model can operate day and night, the refrigerants used are those of R12. Figs. 3 and 4 show the model called SSDHP:

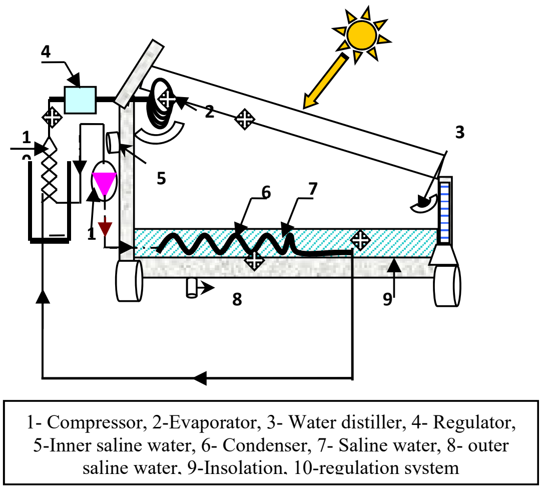


Fig. 3 Simple Solar Distiller hybrid with Heat Pump

Fig. 4 Photograph of SSDHP

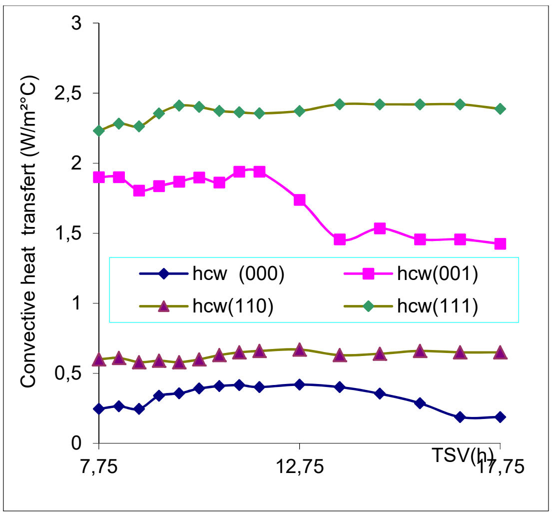


Fig. 5 Evolution of convective heat transfer t coefficient

Using linear regression analysis method coefficients C and n have been evaluated. The values of convective and evaporative heat transfer coefficients were calculated for different configuration for the two models. Based on the readings, the graphs are plotted which is shown in Fig. 5. It can be noticed that the convective coefficient is very lower for the active model then compared with the passive one 2.5W/m²°C (111) and de not aced 0.5 W/m² °C.

The results were also compared with the Dunkle model which the (000) configuration is shown in Fig. 6 consequence the value obtained not agree with the values obtained by the present experiment. This is definitely because of the violation of Dunkle [6] assumptions encountered by the real experiments. The present model gives more accurate and realistic values.

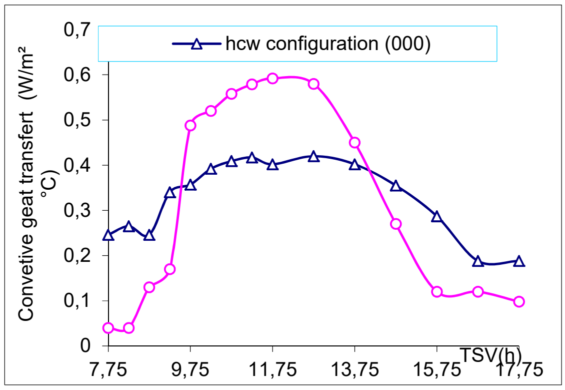


Fig. 6 Comparative convective heat transfer with the Dunk relation

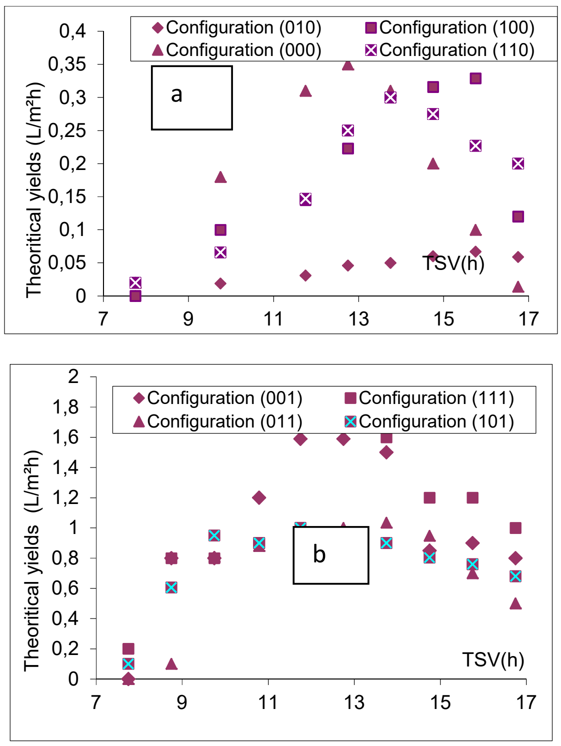
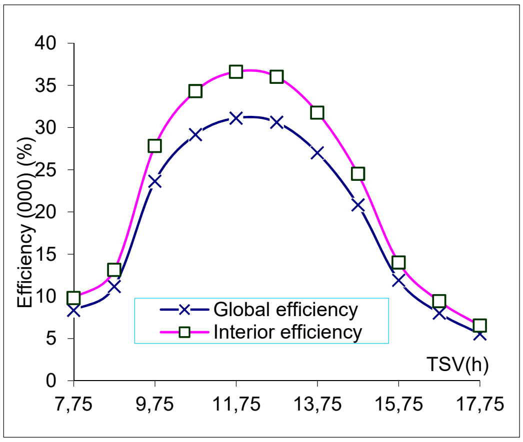
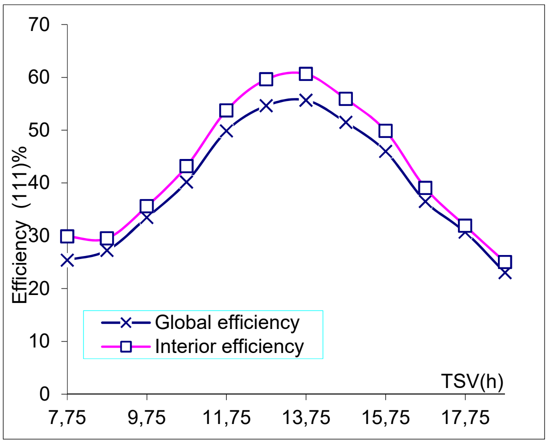


Fig. 7 Variation of experimental yields value

Figs. 7 (a) and (b) show that the maximum experimental mass flow rate for the SSD model is about 350mL/m^{2}h, obtained at 14h25, in this case the configuration (111) configuration have 1800 mL/m^{2}h. As time proceeds, experimental mass flow rate decreases from its maximum value to reach 40 g/m^{2}h at 16h 25 (000) configuration. The decrease of both values can be explained by the fact that, in one hand, the quantity of evaporated, then condensed water decreases due to the decrease of natural convection process, since solar radiation intensity decreases. On the other hand, in theoretical considerations, the condensed water is neglected, which is in reality not the case.



(a)



(b)

Fig. 8 Variation of global and interior efficiency

Figs. 8 (a) and (b) shows the thermal efficiency of active solar still is lower than the thermal efficiency of passive solar still. The energy efficiency of active solar still is higher 60% (internal) than the energy efficiency of passive solar still 35% (internal).

VI. Conclusion

It shows that the use of the active solar distiller named SSDHP has a higher value of the convective coefficient that an SSD model. Equal 2.5W/m²°C configuration (111) and does not exceed 0.5W/m² ° C of the configuration (110). Similarly, the evaporative coefficients 40W/m² ° C (111) configuration compared with the SSD model equal to 15W/m² ° C for the (000) configuration. The comparative study with the model of Dunke shows a gap with that found in our work. The mass recovered in the model SSDHP attained 1.8L/m² ° C is 5 times larger than the SSD 0.35L/m²°C. Finally internal efficiency is always greater than that of the overall efficiency in both models (internal efficiency is equal 60% and 30% respectively for the SSDHP and SSD models)

Nomenclature

COP:	coefficient of performance
C:	constant
c,n:	constant
hcw:	convection heat transfer coefficient, W.m^{-2}.°C
m_e:	experimental yields mL
m_{the}:	theoretical yields mL
L:	Specific length, m
$P_{w,g}$:	(water, glass) Pressure N.m^{-2}
$q_{ew,w,cw}$:	(evaporation, water convection) heat flux, W.m^{-2}
Ra:	Rayleigh number
$T_{w,g}$:	(water, glass) temperature K°
W:	compressor power W
α:	absorptivity
Nu:	Nusselt number
S:	surface caption m²
G:	solar flux W.m^{-2}

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