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DESIGN A WATER DESALINATION APPARATUS OPERATES USING SOLAR ENERGY

Abd El-Whahab, M.K.[1], M.A. El-Shazly[1], S. H. Taher[2] and A. E. Sabra[1]

[1] Dept. of Agric.Eng., Fac. of Agric.,Zagazig Univ., Egypt.

[2] Dept. of Mech. Eng., Fac. of Eng. (Shoubra), Banha Univ., Egypt.

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ABSTRACT: This study aims to design, manufacture, operate, outdoor test and indicate the performance of Solar Desalination Apparatus (SDA) that will used in remote and arid areas in Egypt. The SDA consists of Single Sloped Basin Solar Still (SSBSS) coupled to Flat Plate Solar Collector (FPSC), Hot Water Storage Tank (HWST) and all connected with Connection Piping (CP). A simple mathematical model based on analytical solution of energy balance equations of the SDA has presented. Numerical computations have carried out for Cairo (30°05' N latitude & 31°17' E longitude) climatic conditions, its performance has investigated experimentally and theoretically, observing good agreements between both results. The theoretical and experimental investigations show that the productivity is highest (10.5 $l/m^2.d$) when the FPSC inclination is 30°, the SSBSS glass cover inclination is 12° and the water basin depth is 0.015 m. The productivity of SDA is double (more than double) of conventional solar still. The SDA produced fresh water has Total Dissolved Solids (TDS) of 100-300 ppm from TDS of 35500-44500 ppm of seawater.

Keywords:Solar energy, desalination, active solar desalination apparatus.

INTRODUCTION

Egypt area is 1 million km^2 (94% desert), its water resources are Nile River 55.5 billion m^3, groundwater 6.9 billion m^3 and rainfall 1.5 billion m^3. In 1990, fresh water/capita was 900 m^3/y/person, by 2025, it will be 600 m^3/y/person. Egypt has saline water, abundant solar energy, long sunshine, high temperature, soils suites agriculture and winter rainfail. Solar desalination became competitive than water transport (El-Kady and El-Shibini, 2001). In remote arid areas, choices are between low quality, good quality and mixed water. Solar Desalination Apparatus (SDA) was used to irrigate controlled environment agriculture system by combining with it. Solar desalination systems classified into passive and active, passive one collects solar energy and uses it direct, active one has two-sub systems one collects solar energy and second do desalinate. All most studies were about passive system, which has low productivity and low thermal efficiency, later few studied active system and investigated it theoretically, and experimentally (El-Sayed et al., 1994).

Kumar *et al.* (2000) presented an annual performance of active solar still, its efficiency was double than similar passive system depending on its configuration. Coupling the flat plate solar collector to solar still has increased its productivity, evaporation rate and condensation rate by increasing temperature difference between basin water and glass cover.

Boukar and Harmim (2001) studied productivity of basin solar still and similar one coupled to solar collector, both strongly depends on solar radiation and ambient temperature, for active one 8.02-11.2 l/m^2.d.

Voropoulos *et al.* (2001) coupled basin solar still to flat plate solar collector and storage tank, daily productivity doubles as result of continuous heating. Its productivity increases as the temperature difference between basin water and glazing cover was higher.

Bouchekima (2002) and Hermann *et al.* (2002) studied the performance of sea/brackish water solar desalination systems supplied with thermal energy from flat plate solar collector for feedstock preheating. High productivity, efficiency and reduced costs reached by seawater flowing through a solar collector before entering the still as brine temperature increases.

Mathioulakis and Belessiotis (2003) and Voropoulos *et al.* (2003) experimented coupling conventional solar still to flat plate solar collector and tank under real conditions. The productivity compared between coupled system and solar still only under similar climatic conditions, it was found that productivity of coupled system is about double of that of solar still only. In addition, they found that productivity during day was doubled.

Boukar and Harmim (2004) constructed solar distillation system prototype with a vertical flat absorber surface. It was tested to study parametric values affecting its performance under desert climatic conditions and its effects on the productivity.

Parekh *et al.* (2004), Singh and Tiwari (2004), Abu-Arabia and Zurigat (2005), Badran *et al.* (2005) and Tripathi and Tiwari (2005) found that the most effective way for feedstock preheating is coupling solar still to solar collector and storage tank, allows nightly operation and gives opportunity to use hot water in other usage. The yield of active solar still depends on water depth, inclination of condensing cover, inclination of collector and collector area. The active solar still had more than 70% higher productivity in comparison with the conventional solar still and glass cover cooling solar still.

This study is a try to utilize solar energy to desalinate sea/brackish water and produce fresh water for domestic use and agriculture in remote arid areas. The indirect solar desalination system was chosen to be the subject of this study because of its: simple design, easily construction using wide rang of local materials, easily operation, long period operation, high productivity, high overall efficiency, not expensive and simple maintenance needed.

MATERIALS AND METHODS

A schematic diagram of the active SDA shown in Figure (1) and a photograph of the active SDA shown in Figure (2). The active SDA consists of Single Sloped Basin Solar Still (SSBSS), Flat Plate Solar Collector (FPSC), Hot Water Storage Tank (HWST) and Connection Piping (CP) connected these parts, saline water flows due to natural circulation (thermosyphon)

The SSBSS designed of rectangular section shape with a cover slope of 12°, basin area of 0.5 m^2 and water depth of 0.06 m under trough (total 0.09 m), its three views shown in Figure (3). Its internal body was made of aluminum sheet of 0.0003 m thickness formed and assembled by bending and soldering, it was fixed inside external body that made of wooden sheet of 0.02 m thickness as shown in Figure (4). The internal body insulated against

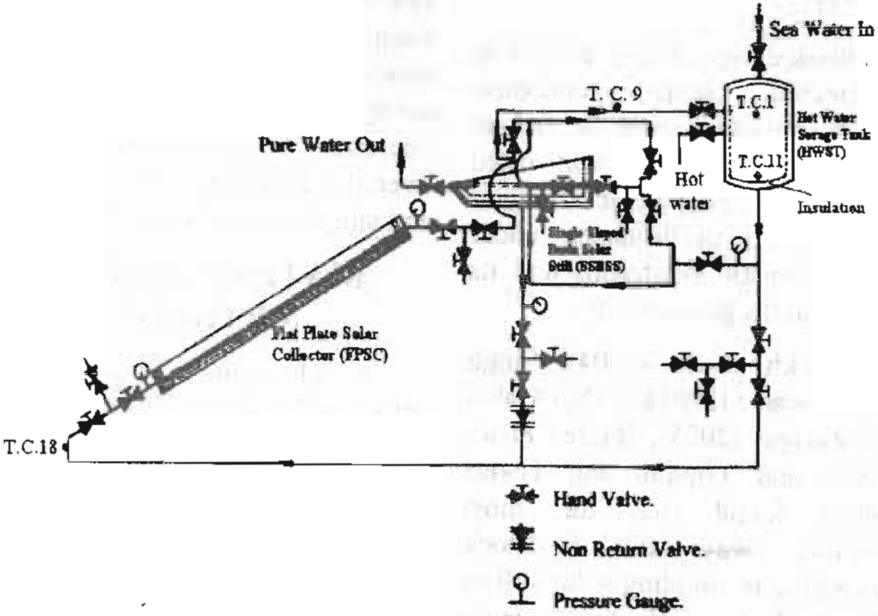

Fig. 1: Schematic diagram of the active solar desalination apparatus

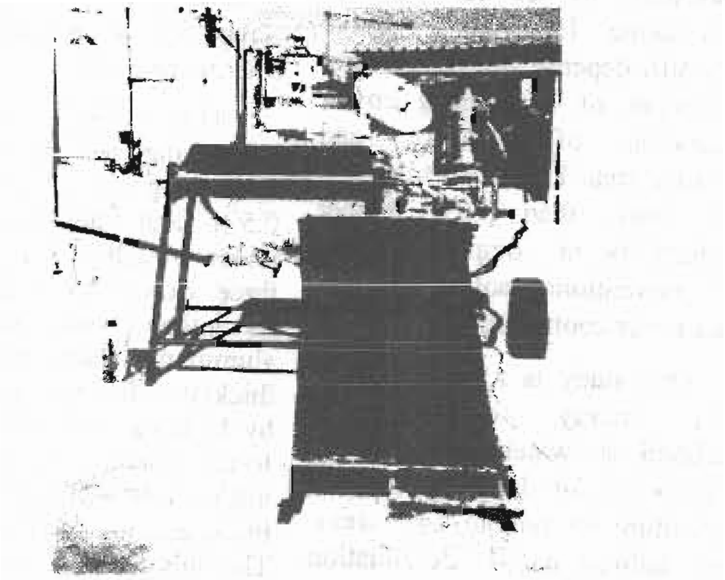

Fig. 2: Photograph of the active solar desalination apparatus

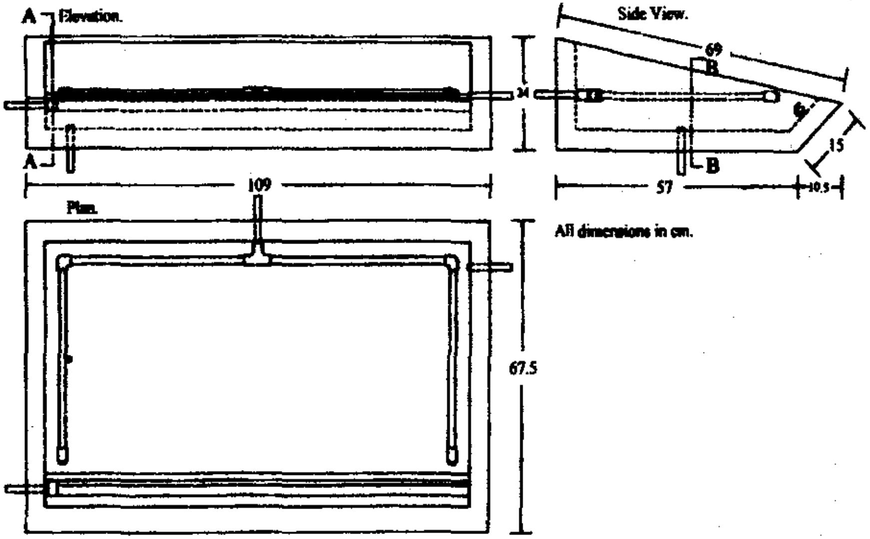

Fig. 3: The three views of the single sloped basin solar still

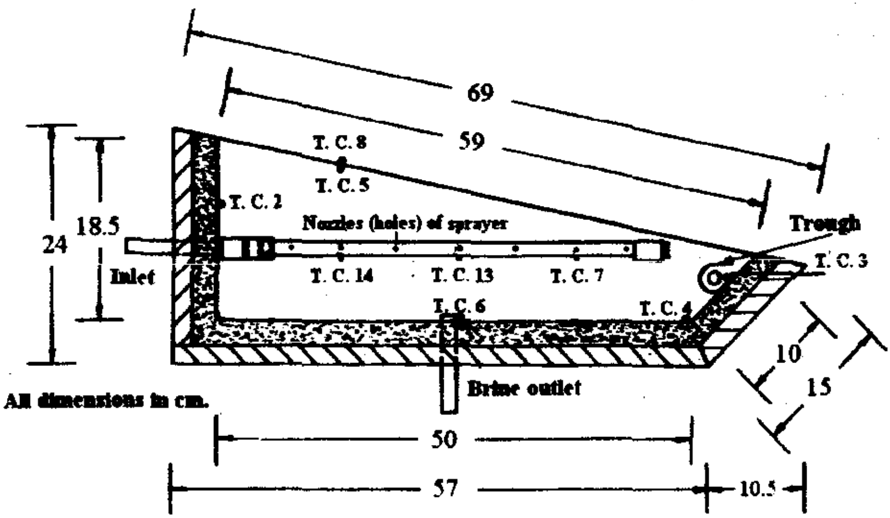

Fig. 4: Section A-A of the single sloped basin solar still

heat losing by glass-wool insulation of 0.0254 m thickness and painted with black mat painter to maximize the absorption of solar energy and minimize its reflection. The trough and the SSBSS front edge were white to prevent any evaporation to the collected fresh water. The south facing glass cover was inclined of 12° with horizontal, made of imported window glass of 0.003 m thickness and sealed tightly by temperature resistant silicone rubber sealant to reduce vapor leakage. The fresh water collected in trough attached to the lower edge of glass cover by silicone rubber, it made of PVC channel of 0.0254 m diameter (Ø) connected to PVC pipe of 0.0127 m Ø. The fresh water flowed out through simi-closed hand valve, then collected and measured directly by a measured vessel. The SSBSS has one outlet of aluminum pipe of 0.0127 m Ø soldered to its basin (so its lowest depth is 0.015 m).

The FPSC designed of rectangular section shape, its absorber plate soldered with copper pipes of two horizontal headers and six vertical soldered together and flat glass cover. The six parallel vertical pipes of hard copper soldered with silver alloy to two horizontal headers one at top and the other at bottom. The FPSC was south facing and inclined of 30° with horizontal for ensuring that it collecting maximized solar radiation. Its absorber plate and sidewalls were made of aluminum sheet of 0.0003 m thickness, painted with black mat painter and insulated from heat losing by glass-wool insulation of 0.0254 m thickness. The absorber plate soaked up heat of sunlight passed through glass cover then give the heat up to the saline water flowed in copper pipes on absorber's surface. It was fixed inside external body (box) made of wooden sheet of 0.02 m thickness. A glass cover from imported window glass of 0.003 m thickness and sealed tightly over the wooden box by temperature resistant silicone rubber to prevent hot air leakage, it allow solar radiation to strike the absorber plate and reduce the amount of heat escaped. The FPSC capacity of saline water is 1.761 liter.

The HWST located at highest level of the SDA to provide saline water from its outlet hole (at its bottom) then saline water is flowed to FPSC and due to natural circulation (thermosyphon) and exited from FPSC into inlet hole of HWST, so on saline water was naturally circulated between both of them. The HWST made from 0.003 m thick galvanized steel sheet rolled as cylinder then soldered and four black iron screwed pipes were soldering as two inlet holes (saline water feed and from FPSC) and two outlet holes (hot water for use and to FPSC), all controlled by hand valves. The HWST surrounded with glass-wool insulation of 0.0254 m thickness to prevent any heat losing and covered with sticking aluminum roll.

The CP is saline water circulation circuit that was from rubber tubes supported with metallic wires of 0.01905 m Ø (fixed with all in-outlet pipes with metal seal) and insulated with sticking rubber tube insulation to prevent any heat losing through saline water flow. This insulation is fire proof, use under high temperature of 155 °C, its thickness of 0.0003 m, width of 0.05 m, its thermal conductivity of 0.039 W/m.°K and it was covered with sticking aluminum roll.

The HWST filled with saline (brackish/sea) water early in the morning till about 8 AM the FPSC and the SSBSS are heated by the solar radiation then the hand valves (between SDA parts) opened so saline water is flowed from outlet of HWST (at its bottom) through CP to FPSC. Saline water is collected in the bottom header of FPSC and entered vertical pipes where it heated and raised up by solar energy to the top header then out. The vertical pipes acted as raisers where absorbed solar energy introduces a natural circulation mass flow rate (thermosyphon), because thermo-physical properties of water are temperature dependent, so as water's temperature increased the motions of its molecules become very vigorous. Saline water in the vertical pipes heated and raised up to the top header than the hot water flowed out from FPSC into two directions. The first into SSBSS inlet hole (small part of FPSC out flow), the second into HWST (remain part of FPSC out flow) inlet (at its top) and saline water is naturally circulated between HWST and FPSC due to the solar insolation. The hot saline water filled the SSBSS basin till the designed water depth then the over is flow back from outlet hole at the bottom of SSBSS trough CP to FPSC, also and saline water is naturally circulated between SSBSS and FPSC. Until sunset, FPSC is isolated from SDA by the hand valves all over CP, to prevent losing thermal energy stored in the water filling the HWST. At night, SSBSS supplied with hot water that stored in HWST until next morning. The CP out from SSBSS united with CP out from HWST, which as CP out from FPSC to both SSBSS and HWST. The hot saline water from FPSC is flowed into SSBSS basin that heated by solar radiation with the low design water depth (0.015 m), so saline water evaporated more quickly than deeper water depth or passive solar still. Since the saline water from FPSC filled on liner water, so it is always at a high temperature with respect to basin water. The evaporation happed as follow: saline water's temperature in SSBSS increased so its molecules motion becomes very vigorous and the molecules liberated from water liner in increasing number. Convection to air above water liner carried the evaporated molecules away to the glass cover inner surface, which its temperature is always at relatively lower temperature so vapor starts to condense on it. The glass cover adjusted with an inclined angle (12°) from horizontal to allow the formed water droplet to run down to the trough and prevent its falling back to the basin. The condensed water discharged out of SSBSS as fresh water. After the condensation happened the carrier air cooled again and becomes heavier than hot air on water liner, thus the convection current will continue to reach the thermodynamic balance inside the SSBSS. The SDA could operate in periods of low or no sunshine that happen during the day. This design leads also to higher distilled water output, due to higher basin water temperatures. There is an interesting aspect of the SDA, which is ability to use it as conventional solar water heating system by draw-off some quantity of hot water from HWST.

An active Solar Desalination Apparatus (SDA) was designed, manufactured, developed and outdoor tested in Faculty of Engineering (Shoubra, Cairo) Zagazig University, Banha branch then completed in a privet place (building) in El-Sayada-Cairo (30°05' N latitude & 31°17' E longitude). During the period from January 2002 to February 2004 to investigate the usage of solar energy for saline water desalination using the SDA.

The temperatures at 18-location of the SDA measured using copper–constantan thermocouples (type T) during the experiments. The salinity water at different locations measured as Total Dissolved Solids (TDS) by the ability of contacting an electrical current (conductivity), the TDS is measured with unit of g/l equal ppt or mg/l equal ppm (part per million). TDS measured by pocket meter (HANNA instruments) model HI-98302 (Dist 2) and another TDS meter with high range used. The flow rates measured at different locations of the SDA by collecting a certain volume of saline or desalinate water flow during a time using a container of a known volume and stopwatch. Solar radiation on horizontal surface measured by a Precision Spectral Pyranometer Eppley sensor (model PSP). A complete meteorological data of Cairo collected for experiments days to use in this study: global solar radiation, ambient temperature, dew-point temperature, relative humidity, barometric pressure, viewing clarity, wind speed, wind direction, precipitation, events conditions, sunrise and set time and length of daylight.

A theoretical and experimental investigation were carried out on the active SDA to determine the optimum FPSC angle and SSBSS angle, which causes maximum productivity. A comparison was made between the active SDA and the traditional SSBSS under the same climatic conditions to determine the enhancement in both the daily productivity and efficiency.

Thermal Analysis

In order to write the energy balance for different components for the SDA, the following assumptions have been made (Kumar et al., 2000; Tripathi and Tiwari, 2005):

1. The SDA is vapor-leakage proof and in a quasi-steady state.
2. The heat capacity of the glass cover, insulating materials of the SDA is negligible.
3. Each component of the SDA is perfectly insulated including connecting pipes.
4. The flat plate solar collector is disconnected from still during off-sunshine hours.

The energy balance for different components of the SDA are:

* Glass cover:

$$\alpha_g.I(t).A_g + h_{lw}.(T_w-T_g).A_w = h_{lg}.(T_g-T_a).A_g \qquad (1)$$

where:

α	Absorpitivity.
I(t)	Solar radiation available at the plane of glass cover of SSBSS (W/m^2).

h_{lw} Total heat transfer coefficient from water surface to glass cover ($W/m^2.°C$).

T Temperature (°C).

A Area (m^2).

Subscripts

b Basin liner.

c FPSC.

g Glass cover.

s SSBSS.

w Water.

h_{lg} Connective heat transfer coefficient from glass cover to ambient ($W/m^2.°C$).

* Water mass:

$$Q_U + \alpha_w.(1-\alpha_w).A_w.I(t) + h_w.(T_g-T_w).A_b = (m_w.C_w).(dT_w/dt) + h_{lw}.(T_w-T_g).A_w \quad (2)$$

Q_U Rate of useful energy from FPSC (W).

h_w Connective heat transfer coefficient from basin liner to water ($W/m^2.°C$).

m_w Mass of water in basin (kg).

C_w Specific heat of water in the SDA (J/kg.°C).

t Time (s).

* Basin liner:

$$\alpha_b.(1-\alpha_g).(1-\alpha_w).A_b.I(t) = [h_w.(T_b-T_w) + h_b.(T_b-T_a)].A_b \quad (3)$$

Where:

h_b Overall heat transfer coefficient from basin liner to ambient air through bottom and side insulation ($W/m^2.°C$).

Where

$$Q_U = A_c.F_R.[(\alpha.\tau)_c.I'(t) - U_L.(T_w-T_a)].$$

F_R FPSC heat removal factor.

$(\alpha\tau)_c$ Product of absorpitivity and transmission of FPSC.

$I'(t)$ Solar radiation available at the plane of the absorber of FPSC (W/m^2).

U_L Heat loss coefficient for FPSC ($W/m^2.°C$).

$$m_w = A_b.d_w.\rho.$$

In Equations (1), (2) and (3) the different heat transfer coefficients are as follows:

$$h_{lg} = 5.7 + 3.8(v).$$

v Wind velocity (m/s).

$$h_{lw} = h_{cw} + h_{rw} + h_{ew}.$$

h_{cw} Connective heat transfer coefficient from water surface to glass cover ($W/m^2.°C$).

h_{ew} Evaporative heat transfer coefficient from water surface to glass cover ($W/m^2.°C$).

h_{rw} Radiative heat transfer coefficient from water surface to glass cover (W/m².°C).

$h_{cw} = 0.884[(T_w-T_g) + (P_w-P_g).(T_w+273) / (268.9(10^3)-P_w)]^{1/3}$.

P_g Partial vapor pressure at glass temperature (N/m²).

P_w Partial vapor pressure at water temperature (N/m²).

$h_{rw} = 0.884(\varepsilon_{eff}.\sigma).[(T_w+273)^4-(T_g+273)^4/(T_w-T_g)]$.

ε_{eff} Effective emissivity.

σ Stefan Boltzman constant = $(56.7).10^{-9}$ (W/m².K⁴).

$h_{ew} = 16.273(10^{-3}).h_{cw}.[(P_w-P_g) / (T_w-T_g)]$.

where

$\varepsilon_{eff} = [(1/\varepsilon_g) + (1/\varepsilon_w) - 1]^{-1}$.

ε Emissivity.

Where the expression for saturated vapor pressure as a function of temperature (°C) are as follows (Fernandez and Chargoy, 1990):

$P_w = \exp[25.317(5144)/(T_w+273.15)]$.

$P_g = \exp[25.317(5144)/(T_g+273.15)]$.

The useful energy of the collector is:

$Q_u = m.C_w.(T_{fo}-T_{fi})$.

T_{fi} Intel temperature of FPSC fluid (°C).

T_{fo} Outlet temperature of FPSC fluid (°C).

Where:

$T_{fo} = [(\alpha.\tau)_c.I'(t) / U_L + T_a].[1-\exp(-A_c.U_L.F'/m.C_w)] + [T_{fi}.\exp(-A_c.U_L.F'/m.C_w)]$.

F' FPSC efficiency factor.

m Flow rate through the FPSC (kg/h).

Then

$Q_U = A_c.F_R.[(\alpha.\tau)_c.I'(t) - U_L.(T_{fi}-T_a)]$.

Where

$F_R = [m.C_w/A_c.U_L].[1 - \exp(-A_c.U_L.F'/m.C_w)]$.

In the above equation, $T_{fi} = T_w$, then

$Q_U = A_c.F_R.[(\alpha.\tau)_c.I'(t) - U_L.(T_w-T_a)]$.

The expressions for various respective heat transfer coefficients and method for calculating I(t) and I'(t) for each month are given in (El-Sayed *et al.*, 1994; Kumar *et al.*, 2000).

Since $A_b = A_g.\cos(\beta_s)$, Equation (1) can be rearranged as follows:

$$T_g = [\alpha_g.I(t) + h_{lw}.\cos(\beta_s)T_w + h_{lg}.T_a] / [h_{lw}.\cos(\beta_s) + h_{lg}] \quad (4)$$

β Slope of surface to horizontal (°).

From Equation (3) one gets:

$T_b = [\alpha_b.(1-\alpha_g).(1-\alpha_w).I(t) + h_w.T_w + h_b.T_a] / [h_w + h_b]$ (5)

With the help of Equations (4) and (5), Equation (2) can written in form of first-order differential equation (Kumar et al., 2000; Tripathi and Tiwari, 2005) as:

$dT_w/dT + a.T_w = f(t)$ (6)

Where

$a = U'_L / m_w.C_w$.

U'_L Overall heat transfer rate (W/°C).

$U'_L = A_c.F_R + U_{lb}.A_b + U_{lg}.A_b$.

U_{lb} Heat loss coefficient from bottom to ambient ($W/m^2.°C$).

U_{lg} Heat loss coefficient from glass cover to ambient ($W/m^2.°C$).

$f(t) = [A_c.F_R.(\alpha.\tau)_c.I'(t) + (\alpha_w+\alpha_g.h'+\alpha_b.h).I(t).A_s + U'_L.T_a] / [m_w.C_w]$.

$U_{lb} = h_w.h_b / h_w + h_b$.

$U_{lg} = h_{lw}.h_{lg} / h_{lw}(\cos\beta_s) + h_{lg}$.

$h = h_w / (h_w + h_b)$.

$h' = h_{lw} / (h_{lw} + h_{lg})$.

In order to obtain an approximate solution of Equation (6), the following assumptions have been made:

1. The time interval of Δt $(0 < t < \Delta t)$ is small.
2. For a given time interval, the average value of solar insolations ($I(t)$ & $I'(t)$) and ambient temperature (T_a) has been taken into account.
3. (a) is constant during the time interval (Δt).
4. $f(t)$ can be considered as $f(t)'$.

The internal heat transfer coefficient (h_{lw}) can be evaluated at known values of initial water and glass temperatures at $t = 0$, $T_{w|t=0} = T_{w0}$ and $T_{g|t=0} = T_{g0}$.

The solution of Equation (6) can be written as:

$T_w = [f(t)'/a].[1 - \exp(-at)] + [T_{w0}.\exp(-at)]$.

and the average value of T_w will be:

$\text{Ŧ}_w = \int_{0-t} T_w\, dt$.

Ŧ Average temperature (°C).

$\text{Ŧ}_w = [f(t)'/a].[1 - \{1-\exp(-a.\Delta t)/(a.\Delta t)\}] + [T_{w0}.\{1-\exp(-a.\Delta t)/(a.\Delta t)\}]$.

Δt Time interval (s).

Substituting the value of T_w in Equation (4) to get the value of the glass cover temperature which acts as the initial temperature for the next set of computations and so forth for 24th.

The rate of evaporative heat loss for both solar stills is given by:

$q'_{ew} = h_{ew}.(T_w - T_g)$.

q'_{ew} Evaporative heat transfer rate from water to glass surface (W/m^2).

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

$m'_{ew} = h_{ew}.(T_w - T_g).(3600) / £$.

m'_{ew} Productivity of solar still ($kg/m^2.h$).

£ Latent heat of vaporization (J/kg).

Where (£) is the latent hat of vaporization (J/Kg) and is given by the expressions (Fernandez and Chargoy, 1990):

For temperature < 70 °C, $£ = [3.1615(10^6)].[1 - 7.616(10^{-4}).T]$.

For temperature ≥ 70 °C, $£ = [2.4935(10^6)].[1 - 9.4779(10^{-4}).T + 1.3132(10^{-7}).T^2 - 4.7974(10^{-9}).T^3]$.

The average daily yield can be obtained as:

$M_w = \sum_{i=1-24} m'_{ewi}$.

The average annual yield can be obtained as:

Annual yield $= \sum_{j=1-12} M_{wj}.n_j$.

n Day of the year.

Where (nj) is the number of clear days of the month (j).

The instantaneous efficiency can be determined by:

$\eta = [q'_{ew} / A_s.I(t)].[100] = [h_{ew}.(T_w - T_g) / I(t)].[100]$.

The daily efficiency can be determined by:

$\eta = [\sum m'_{ew}.A_s.£ / \sum A_s.I(t).3600].[100]$.

η Efficiency (%).

RESULTS AND DISCUSSION

A computer program have been prepared using Microsoft Excel 2002 spreadsheets software for the solution of the energy balance equations for the SDA, the input to program include climatic, design and operational parameters were used to calculate the productivity and efficiency for the SDA. The design parameters for the computer program are: $A_s = A_b = A_w = 0.5\ m^2$, $m_w = (A_b.d_w.\rho)$, $d_w = 0.015\text{-}0.06\ m$,

C_w = 3898 J/kg, ρ = 1024 kg/m^3, α_w = 0.97, α_g = 0.03, τ_g = 0.92, ε_g = 0.95, ε_w = 0.94, β_s = 10-15°, h_w = 100 W/m^2.°C, h_b = 0.8 W/m^2.°C, A_c = 1 m^2, m = 37 kg/h, β_c = 25-35°, F' = 0.8, U_L = 8 W/m^2.°C, α_c = 0.97, $(\alpha\tau)_c$ = 0.89, ω = 15°/h, I_{sc} – 1367 W/m^2.

The mean day July (17 July 2003) as an example of summer season, was taken as an example to clear the effect of all studied parameters. This day is the mean day of July, which represents the mean value of solar insolation during the month (El-Sayed et al., 1994).

The measurements of solar radiation, ambient air temperature and wind speed of 17 July 2003 are presented in Figures (5) and (6).

The effect of FPSC inclination on the SDA daily productivity for different SSBSS glass cover inclinations is shown in Figure (7). The effect of SSBSS glass cover inclination on the SDA daily productivity for different FPSC inclination is shown in Figure (8). Both the two Figures are clear evident that the productivity of the SDA is maximum at SSBSS inclination angle (β_s) = 12° and FPSC inclination angle (β_c) = 30°.

The effect of basin water depth on the SDA daily productivity for SSBSS inclination angle (β_s) = 12° and FPSC inclination angle (β_c) = 30° is shown in Figure (9). It could be concluded that the SDA productiviety is maximum at a water depth 0.015 m, which is the lowest depth can be reached. Also it could be noticed from that the SDA productivity decreases with increase of water depth due to the storage effect. A relation was concouluded from this curve:

SDA daily productivity = $2146.7(d_w)^2 - 265.44(d_w) + 13.619$.

The theoretical and experimental hourly variation of daily productivity (accumulative) for the SDA and the SSBSS daily productivity is shown in Figure (10). From this curve there is a good agreement between theoretical and experimental results for accumulative SDA daily productivity, also the SDA daily productivity is double of that of the SSBSS (traditional type).

The hourly variation of the basin water temperature (T_w), glass cover temperature (T_g) of the SDA, total, evaporative, convective and radiative heat transfer coefficients of 17 July 2003 is shown in Figure (11). It was observed that radiative and convective heat

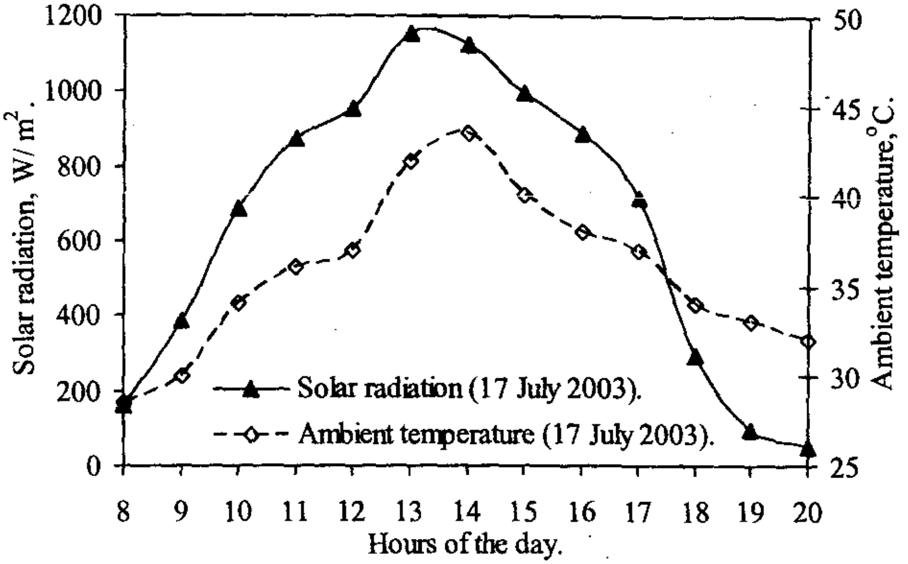

Fig. 5: Solar radiation and ambient temperature measurements

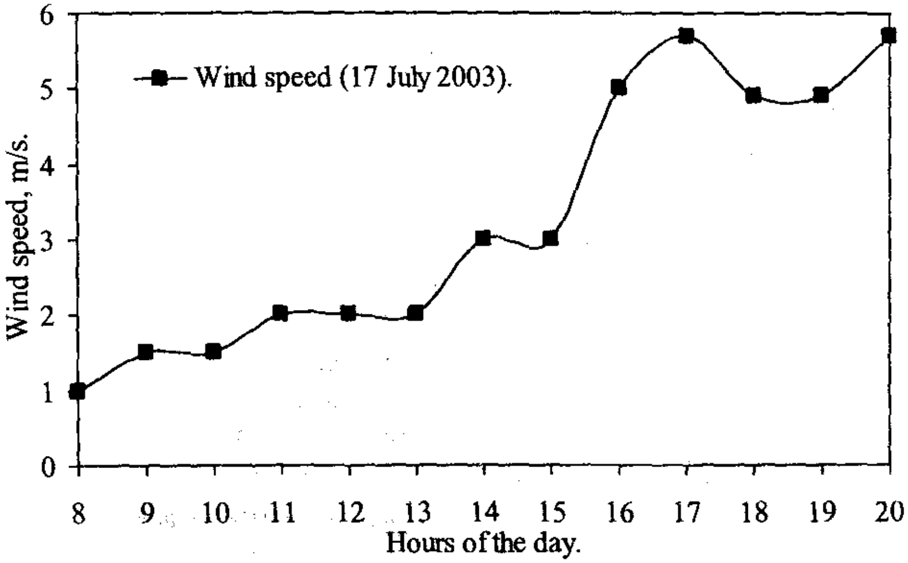

Fig. 6: Wind speed measurements (17 July 2003)

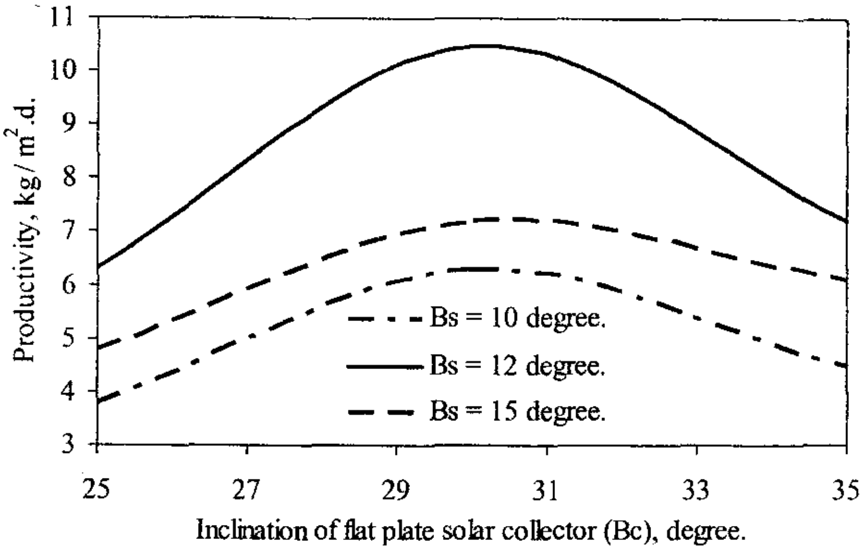

Fig. 7: The effect of FPSC inclination on the SDA daily productivity

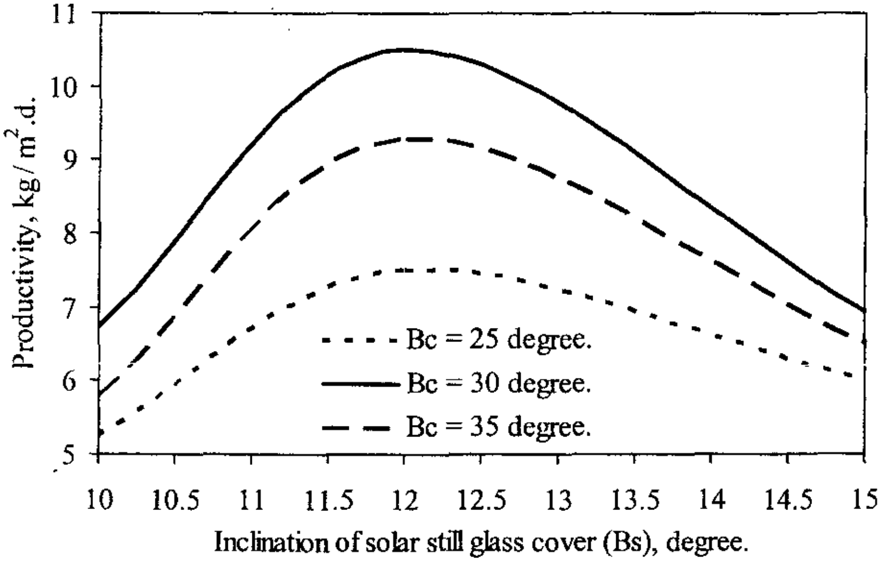

Fig.8: The effect of SSBSS glass cover inclination on the SDA daily productivity

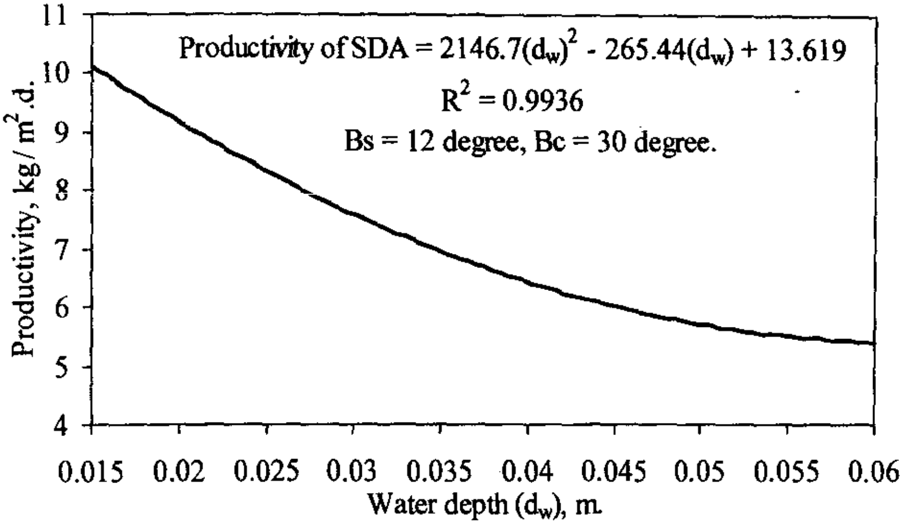

Fig.9: The effect of basin water depth on the SDA daily productivity ($\beta_s = 12°$, $\beta_c = 30°$)

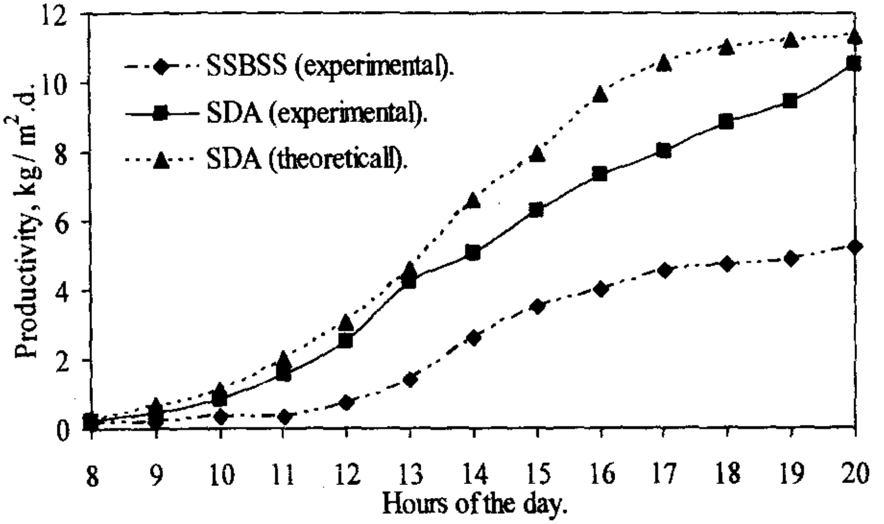

Fig. 10: The theoretical and experimental hourly variation of the SDA daily productivity (July 2003)

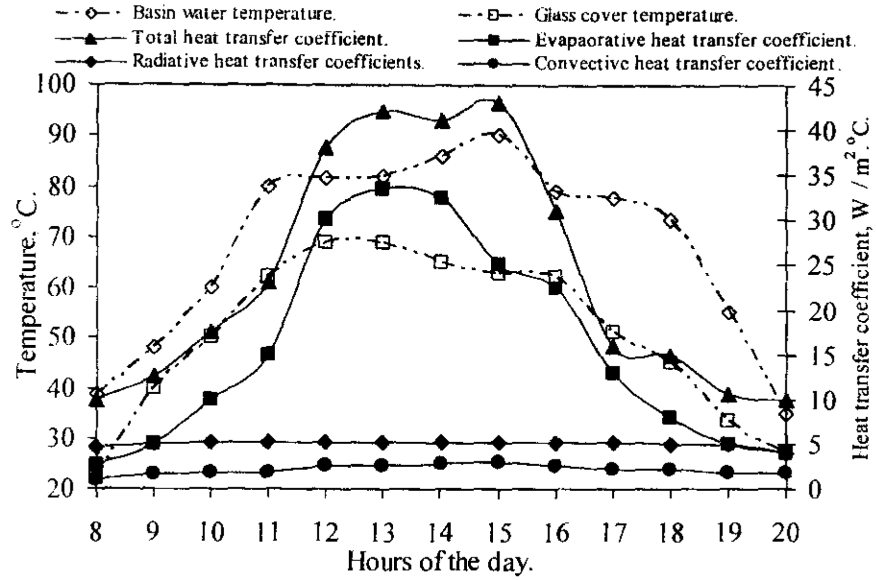

Fig. 11: The hourly variation of the basin water temperature, glass cover temperature, total, evaporative, convective and radiative heat transfer coefficients of the SDA (July 2003).

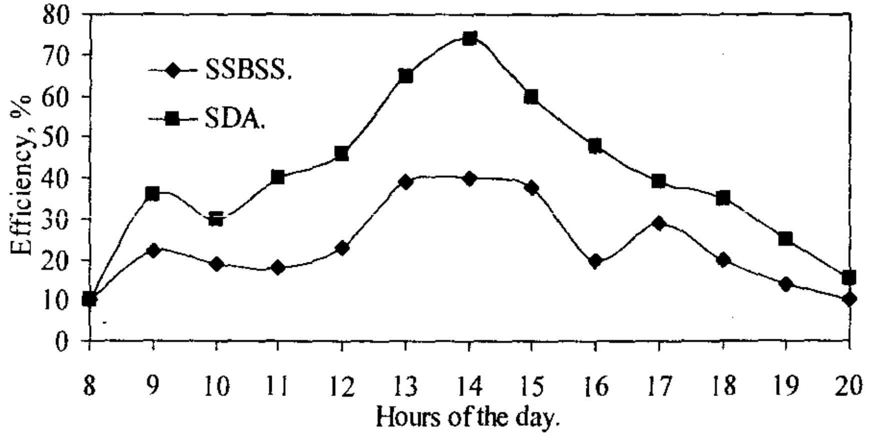

Fig. 12: The hourly variation of the efficiency (July 2003)

transfer coefficients do not vary greatly comparing to evaporative heat transfer coefficient, that indicated strong dependence of evaporative heat transfer coefficient (h_{ew}) on the operation basin water temperature (T_w).

Figure (12) shows the hourly variation of daily thermal efficiency of both the SDA and the SSBSS. It is clear that the daily thermal efficiency of the SDA is 48 % and it 25 % for SSBSS, also the efficiency increases with the increase of productivity.

Conclusion

An active Solar Desalination Apparatus (SDA) was designed, manufactured and outdoor tested in Cairo, during the period of January 2002 to February 2004, to desalinate sea or brackish water in remote and arid areas in Egypt. A simple mathematical model based on analytical solution of the energy balance equations for different parts of the SDA presented. The performance of the SDA investigated both experimentally and theoretically, good agreements between experimental and theoretical results were observed. Based on the results and discussion, it was observed that for maximum daily productivity of the SDA, the optimum inclination for the FPSC is 30°, the optimum inclination of the SSBSS glass cover is 12° and the optimum water basin depth is 0.015 m. It was observed from the experimental results that the productivity of SDA is double (or more) of conventional solar still and it has a daily thermal efficiency of 0.45-0.60. The SDA produced fresh water has total dissolved solids (TDS) of 100-300 ppm from TDS of 35500-44500 ppm of seawater.

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تصميم جهاز تحلية مياه يعمل بالطاقة الشمسية

محمد قدرى عبد الوهاب[١] - محمود عبد الرحمن الشاذلى[١] -
شريف هادى طاهر[٢] - عبد الله عصمت صبره[١]

[١] قسم الهندسة الزراعية- قسم الهندسة الزراعية- كلية الزراعة- جامعة الزقازيق- مصر.

[٢] قسم الهندسة الميكانيكية - كلية الهندسة بشبرا - جامعة بنها - مصر.

تهدف هذه الدراسة تصمَيم، تصنيع، تشيغل، إختبار خارجى و تقييم أداء جهاز تحلية شمسي للعمل في المناطق البعيدة والقاحلة في مصر. و يتكوّن الجهاز من: مقطر شمسيّ حوضى ، مجمع شمسيّ مستوي ، خزّان ماء ساخن ، وكلهاً إرتبطت بأنابيب التوصيل. و تم دراسة نموذج رياضيّ مبسط يعتمد على حلّ تحليليّ لمعادلات إتزان الطاقة للجهاز طبقا للظروف المناخية لمدينة القاهرة. تم دراسة أداء الجهاز بشكل تجريبي ونظرياً و لوحظ وجود توافق جيد بين الدراسات النظريةِ والتجريبية. الإنتاجيّة الأعلى (١٠,٥ لتر/م^{٢}.يوم) يتحصل عليها عند ميل مجمع شمسى ٣٠° و ميل غطاء مقطر ١٢° و عمق الماء بالمقطر ٠,٠١٥ متراً. كما سجل أيضا أن معدل إنتاجية جهاز تحليةِ المياه الشمسي النشيط تتراوح من ضعف الى أكثر من ضعف إنتاجية المقطر الشمسى التقليدى ، كما أن الكفائة الحرارية اليومية للجهاز هى ٠,٤٨. و الماء العذب المقطر الناتج عن جهاز تحليةِ المياه الشمسيِ النشيط يكون ذو مواد صلبةَ كلية ١٠٠ - ٣٠٠ جزء فى المليون ناتجا عن ماء بحار ذو مواد صلبةَ كلية ٣٥٥٠٠ - ٤٤٥٠٠ جزء فى المليون.

الكلمات الدالة: الطاقة الشمسية، التحلية، جهاز تحلية مياه شمسي نشيط.