

# NEW DESIGN OF A GREENHOUSE SOLAR DISTILLER COUPLED WITH PARABOLIC TROUGH AND THE ENERGY BALANCE OF THIS SYSTEM

KHALID GUISSI<sup>1</sup>, ABDELMOUMEN TABYAOU<sup>1</sup>, MOHAMED HARMOUCHI<sup>1</sup>,  
AZEDDINE MOUHSEN<sup>1</sup>, EL MOSTAFA OUALIM<sup>1</sup>, ABDELLAH BOULAL<sup>1</sup>

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**Abstract.** Distillation is one of many processes that can be used for water purification. This process consists in heating water directly by the solar radiation in a closed enclosure covered with glazing. The produced vapor, which condenses on the colder glazing and slightly inclined, east collects in gutters. The principle is very simple, reliable and does not require any maintenance. But its output is relatively weak, 4 to 6 liters/day. In this research we have developed a new design of a greenhouse solar distiller with parabolic trough in order to increase the performance of the distiller and subsequently obtaining a important distillate flow.

**Keywords:** Design; greenhouse; solar distiller; parabolic trough; heat balance

## 1. INTRODUCTION

The solar distillation systems are mainly classified as passive solar still and active solar still [1]. The numerous parameters are affecting the performance of the still such as water depth in the basin, material of the basin, wind velocity, solar radiation, ambient temperature and inclination angle. In a passive solar still, the solar radiation is received directly by the basin water and is the only source of energy for raising the water temperature [2]. High efficiency active solar still pushed us further research in the field of solar concentrators to design a new active solar still. Here, an extra thermal energy is supplied to the basin through parabolic trough to increase the evaporation rate and in turn improve its productivity.

## 2. SOLAR CONCENTRATION SYSTEMS

A parabola is the locus of a point that moves so that its distances from a fixed line and a fixed point are equal. The curve of the parabola is shown in Fig. 1.

The equation of the parabola is [3] :

$$y^2 = 4fx \quad (m) \quad (1)$$

where  $f$  is focal length.

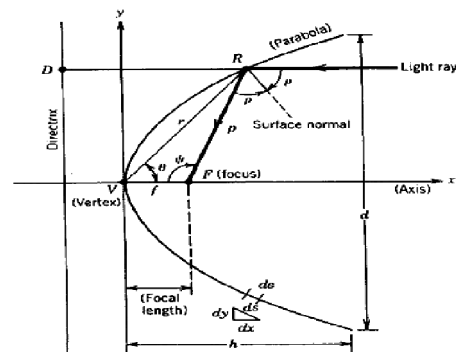


Figure 1. Parabola [3].

<sup>1</sup> Hassan 1st Univ, Settat, Radiation and matter laboratory, Morocco. E-mail: [elguissi@yahoo.fr](mailto:elguissi@yahoo.fr).

Solar concentrators use a truncated portion of the parabola curve, defined in terms of the rim angle  $\psi_{rim}$  or the ratio of the focal length to aperture diameter  $f/d$ .

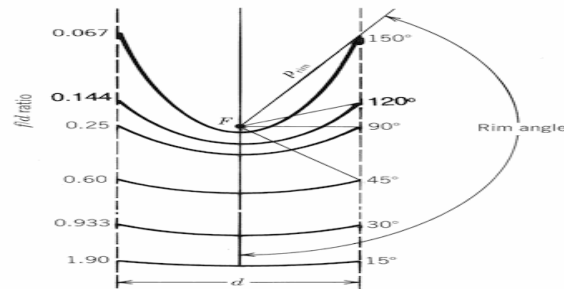


Figure 2. Segments of a parabola having a common focus  $f$  and the same aperture diameter [3].

Once a specific portion of the parabolic curve has been selected, the height of the curve  $h$  may be defined as the maximum distance from the vertex to a line drawn across the aperture of the parabola [3].

$$h = \frac{d^2}{16f} \quad (\text{m}) \quad (2)$$

Another property of the parabola that may be of use in understanding solar concentrator design is the arc length  $S$  [3] :

$$s = \left( \frac{d}{2} \sqrt{\frac{(4h)^2}{d^2} + 1} \right) + 2f \ln \left( \frac{4h}{d} + \sqrt{\frac{4h}{d} + 1} \right) \quad (3)$$

For a parabolic trough of length  $L$ , the reflective surface area  $A_{rs}$  is:

$$A_{rs} = L \cdot S \quad (\text{m}^2) \quad (4)$$

### 3. DESIGN OF A GREENHOUSE SOLAR DISTILLER COUPLED WITH PARABOLIC TROUGH

The Parabolic trough concentrates the sunlight on the tube filled with water and placed at the focus of this sensor, this fluid circulates under the thermosiphon effect and transfers the heat to water basin (Natural circulation mode).

The greenhouse solar still is built by ordinary glass and a steel basin. The parabolic trough is fabricate by stainless steel sheet and polished to have a high reflectivity. The system is equipped with a solar tracker on two axes in azimuth and elevation. To as the parabolic trough assembly rotates the piston will be compressed and the water coming out of the hopper to reach the basin through the plastic pipe with holes at the top. Rotation of the assembly in the other direction will cause the relaxation of the piston and thereafter the suction wastewater for filling the tank through the filter.

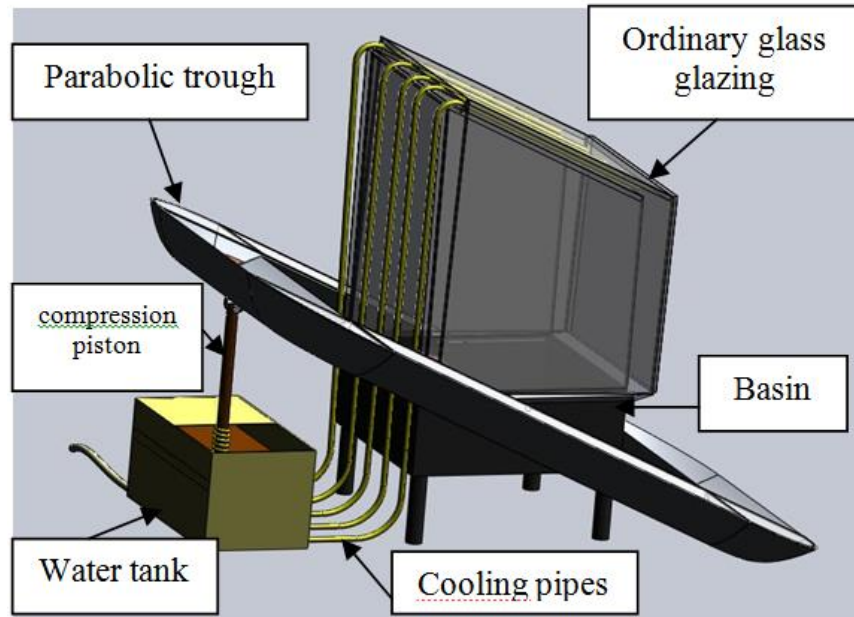


Figure 3. New Design of a Greenhouse Solar Distiller Coupled With Parabolic Trough.

#### 4. THEORETICAL ANALYSIS OF A GREEN HOUSE SOLAR DISTILLER COUPLED WITH PARABOLIC TROUGH

The heat transfer in solar still is mainly classified into internal and external heat transfer. The details of various heat transfers that take place in our solar still are shown in Fig. 5.

##### A. ENERGY BALANCE OF SOLAR DISTILLER

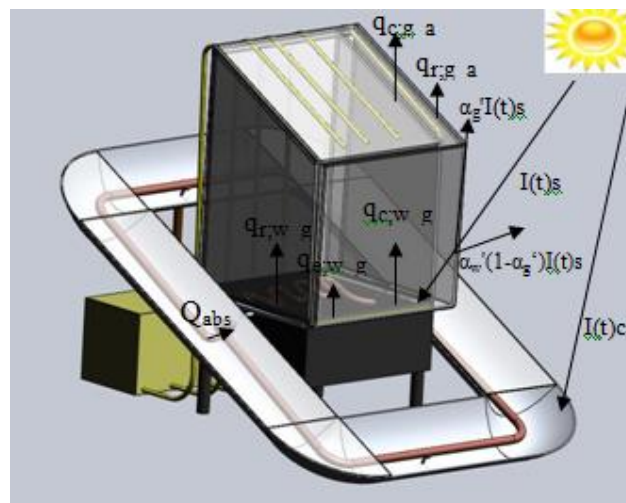


Figure 4. Energy flow diagram of solar still.

The rate of radiative heat transfer between water to glass is given by [4]:

$$q_{r,w-g} = h_{r,w-g} (T_w - T_{gi}) \quad (5)$$

Where:

$h_{r,w-g}$  : Radiative heat transfer coefficient from water to glass cover ( $W/m^2\text{ }^\circ\text{C}$ )

$T_w$  : Water temperature ( $^\circ\text{C}$ )

$T_g$  : Inner surface glass covers temperature ( $^\circ\text{C}$ )

The radiative heat transfer coefficient between water to glass is given as:

$$h_{r,w-g} = \varepsilon_{eff} \sigma \left( \frac{(T_w + 273)^2 + (T_{gi} + 273)^2}{T_w + T_{gi} + 546} \right) \quad (6)$$

The effective emittance between water to glass cover is presented as :

$$\varepsilon_{eff} = \left[ \frac{1}{1/\varepsilon_g + 1/\varepsilon_w - 1} \right] \quad (7)$$

$\sigma$ : Stefan Boltzman constant

$\varepsilon_g$  : Glass emittance

$\varepsilon_w$  : Water emittance

The rate of convective heat transfer between water to glass is given by:

$$q_{c,w-g} = h_{c,w-g} (T_w - T_{gi}) \quad (8)$$

where:  $H_{c,w-g}$ : Convective heat transfer coefficient from water to glass cover ( $W/m^2\text{ }^\circ\text{C}$ ).

The convective heat transfer coefficient depends on the temperature difference between evaporating and condensing surface, physical properties of fluid, flow characteristic and condensing cover geometry [4].

$$h_{c,w-g} = \frac{K_v}{\chi_v} C (Gr \times Pr)^n \quad (9)$$

where:

$K_v$ : Thermal conductivity of humid air ( $W/m\text{ }^\circ\text{C}$ )

$\chi_v$ : Mean characteristic length of solar still between evaporation and condensation surface (m)

$n$ : Constant in Nusselt number expression

$C$  : Constant in Nusselt number expression

$Pr$ : Prandtl number

$Gr$ : Grashof number

The unknown constants 'C' and 'n' will be calculated by linear regression analysis using experimental data. From the experimental study, Kumar and Tiwari proposed that value of 'C' and 'n' was 0.0278 and 0.3513, respectively [4].

The general equation for the rate of evaporative heat transfer between water to glass is given by:

$$q_{e,w-g} = h_{e;w-g} (T_w - T_{gi}) \quad (10)$$

$h_{e;w-g}$  : Evaporative heat transfer coefficient from water to glass cover ( $W/m^2\text{ }^\circ\text{C}$ )

$$h_{e,w-g} = \frac{0,016}{2} h_{c;w-g} (P_w - P_{gi}) \quad (11)$$

$P_{gi}$ : Partial vapour pressure at inner surface glass temperature ( $N/m^2$ )

$P_w$ : Partial vapour pressure at water temperature ( $N/m^2$ )

The convective heat transfer between basin to water is given by:

$$q_w = h_w (T_b - T_w) \quad (12)$$

$h_w$ : Convective heat transfer coefficient from basin liner to water ( $W/m^2\text{ }^\circ\text{C}$ )

$T_b$ : Basin temperature ( $^\circ\text{C}$ )

Direct expression for total loss heat transfer coefficient from glass cover to ambient in terms of wind speed  $v$  [4].

$$q_{t,g-a} = 5.7 + 3.8v \quad (W/m^2) \quad (13)$$

The heat is transferred from water in the basin to the atmosphere through insulation and subsequently by convection and radiation from the side and bottom surface of the basin

$$q_b = h_b (T_b - T_a) \quad (14)$$

$q_b$  : Rate of heat transfer from basin liner to ambient ( $W/m^2$ )

$h_b$ : Overall heat transfer coefficient from basin liner to ambient through bottom insulation

The energy balance equation of inner surface of glass cover is:

$$\alpha'_g I(t)_s + q_{r;w-g} + q_{c;w-g} + q_{e;w-g} = \frac{K_g}{L_g} (T_{gi} - T_{go}) \quad (15)$$

$I(t)_s$ : Intensity of global solar radiation over the surface of solar still ( $W/m^2$ )

$\alpha'_g$ : Fraction of energy absorbed by glass

$K_g$ : Thermal conductivity of glass cover ( $W/m\text{ }^\circ\text{C}$ )

$L_g$ : Thickness of insulation glass cover (m)

$T_{go}$ : Outer surface glass covers temperature ( $^\circ\text{C}$ ) Inner surface of glass cover

By simplifying and substituting equations, inner surface of glass temperature is written as follows :

$$T_{gi} = \frac{\alpha'_g I(t)_s + h_{t,w-g} T_w + (K_g / L_g) T_{go}}{h_{t,w-g} + (K_g / L_g)} \quad (16)$$

$h_{t,w-g}$ : The rate of total heat transfer of water to glass

The rate of energy absorbed and the rate of energy conected from the basin liner is equal to the rate of energy stored and rate of energy transferred to the glass cover .

$$\alpha'_w (1 - \alpha'_g) I(t)_s + q_w + Q_u = M_w C_w \frac{dt_w}{dt} + q_{r,w-g} + q_{c,w-g} + q_{e,w-g} \quad (17)$$

$q_w$ : Rate of convective heat transfer from basin liner to water ( $W/m^2$ )

$\alpha'_w$ : Fraction of energy absorbed by water

$Q_u$ : Thermal energy supplied to the water from concentrator

$C_w$ : specific heat of water in solar still ( $J/kg \text{ } ^\circ C$ )

$M_w$  : mass of water in the basin (kg)

Since applied the black paint on the copper tube, we can neglect these optical losses.

From absorber tube surface to fluid we have [5] :

$$Q_{absorbed} - Q_{therm .loss} = Q_u \quad (18)$$

$$h_{t-f} \pi . D_t . L . (T_t - T_f) - Q_{thermloss} = Q_u \quad (19)$$

$Q_{absorbed}$  : Solar radiation absorbed by tube receiver

$Q_{therm loss}$  : Thermal losses of tube receiver

$D_t$  : Diameter of the tube

$h_{t-f}$ : convective heat coefficient (tube-water)

$L$ : Length of tube

$T_t$ : Tube temperature

$T_f$ : fluid temperature

### B. SOLAR IRRADIATION REFLECTED FROM THE PARABOLIC TROUGH AND SUPPLIED TO SOLAR STILL

The equation for the absorbed solar radiation is [5] :

$$Q_{absorbed} = D_r . A_s . \cos(\theta) . M_{Ref} \quad (20)$$

$D_r$  : Direct radiation ( $W/m^2$ )

$A_s$  : Reflective surface area

$\theta$  : Angle of incidence (deg)

$M_{Ref}$  : Materiels reflectivity

The Direct radiation is given by [6]:

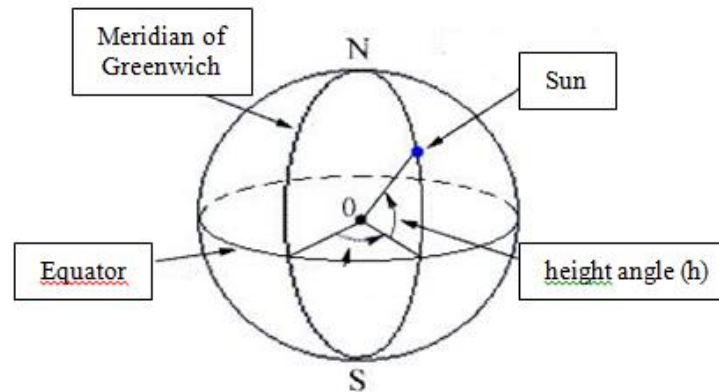
$$D_r = a . \sin(h) . \exp\left(\frac{-1}{c . \sin(h + 2)}\right) \quad (21)$$

**Table 1. Values of the constants a,b,c[6]**

SKY	a	b	c
PURE	1300	87	6
AVERAGE	1230	125	4
POLUTTED	1200	187	2.5

$h$  : height angle

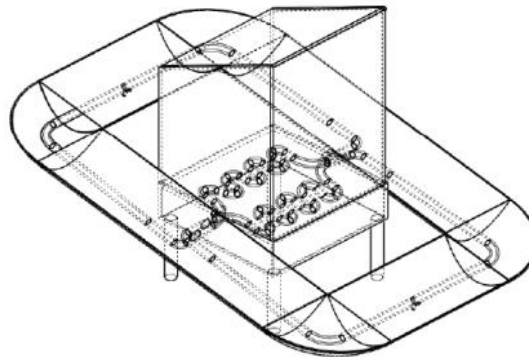
$h$  is the angle between the horizon and a line from the site toward the centre of the sun

**Figure 5. Horizontal coordinates [6].**

The reflective surface area ( $A_s$ ) is:

$$A_s = 2.L_1.S + 2.L_2.S + \pi.S^2 \quad (22)$$

$$A_s = 2.S.(L_1 + L_2 + \pi.\frac{S}{2}) \quad (23)$$

**Figure 6. Dimensions of Parabolic trough.**

The angle of incidence ( $\theta$ ) represents the angle between the beam radiation on a surface and the plane normal to that surface. The angle of incidence will vary over the course of the day (as well as throughout the year) and will heavily influence the performance of the collector [7].

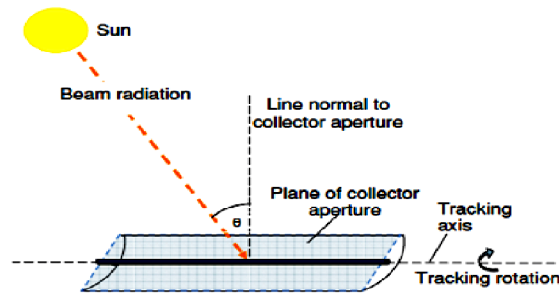


Figure 7. Angle of incidence in parabolic trough collector [7].

$$\cos(\theta) = \sqrt{\cos^2(\theta_z) + \cos^2(\delta) \cdot \sin^2(\omega)} \quad (24)$$

$$\cos(\theta_z) = \cos(\phi) \cdot \cos(\phi) \cdot \cos(\omega) + \sin(\phi) \cdot \sin(\phi) \quad (25)$$

where:

$\delta$  = declination angle

$\Phi$  = latitude location

$\omega$  = the hour angle [deg]

Stainless steel is a material which can be interesting to use as solar reflector material even if its optical properties are inferior to silver and aluminium. The reason for selecting stainless steel is that it is inherently resistant to ageing and that it is mechanically stronger than silver and aluminium. Stainless Steel perfectly polished would be expected to reflect approximately 70 % of light. [8]

## 5. CONSTRUCTION AND TESTING OF THE DISTILLER



Figure 8. Greenhouse Solar Distiller Coupled With Parabolic Trough.

Project cost is approximately 5500 dh (500 Euro)

We performed temperature measurements with HOBO sensors in different positions on the copper tube to ensure the concentration of the rays on the tube.

Test conditions:

Ambient temperature displayed on the thermometer 35 °c in the sun.

Humidity: 50%

Manual rotation of the assembly and fixing in 3 positions



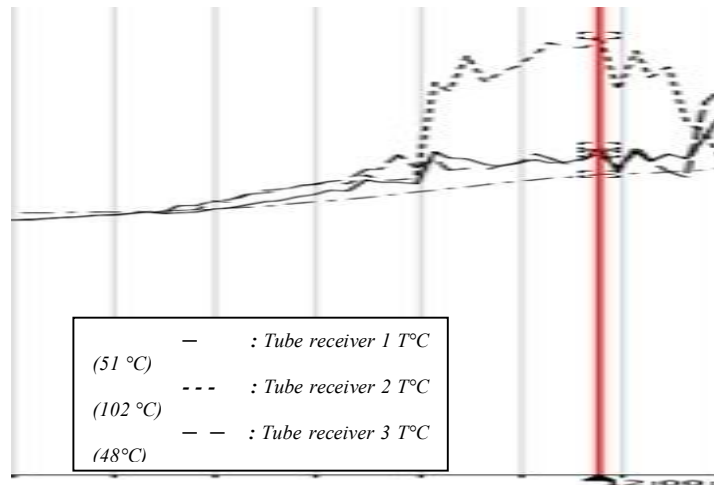


Figure 9. Time-temperature curves.

**HOBOWare Pro**

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#	Time, GMT+00:00	Temp, °C	Temp, °C	Temp, °C	Temp, °C
146	31/08/14 09:58:16 AM	43,133	87,518	42,624	34,598
147	31/08/14 10:08:16 AM	44,534	93,004	47,190	35,448
148	31/08/14 10:18:16 AM	43,223	98,382	45,342	36,039
149	31/08/14 10:28:16 AM	43,465	96,042	42,475	36,661
150	31/08/14 10:38:16 AM	45,499	96,042	45,154	37,233
151	31/08/14 10:48:16 AM	47,287	101,674	51,031	37,811

Figure 10. Temperature measurements made by sensors HOBO.

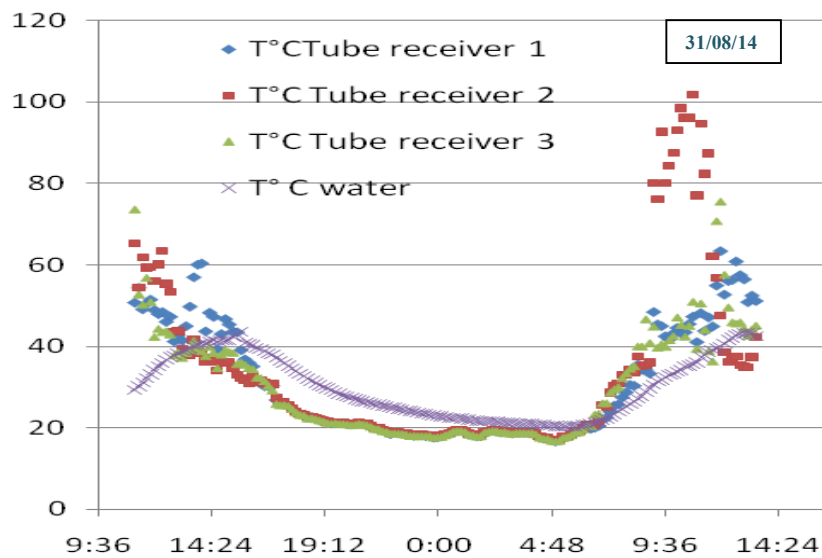


Figure 11. Time-temperature curves .

## 6. CONCLUSIONS

The results obtained after the first test at an ambient temperature of 35 ° C shows that the system can give satisfactory results in higher ambient temperature.

To increase the efficiency of our distiller we have equipped our system with a solar tracker on two axes, to minimize the incidence angle and have good concentration throughout the day. We are currently performing tests on our solar tracker and results will be published in an upcoming article.

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