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Optimization of the Inclination Angle of a Capillary Film Solar Still to Enhance the Productivity in South Algeria

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ABSTRACT
The fresh water production finds all its justification in the Algerian south. The majority of water of underground origin is brackish and unsuitable for human consumption, This water is characterized by a salinity which exceeds the world health organization standards lower or equalizes 0.5 g/l, Solar distillation can considered not only as an economic solution which respect environment , but a real alternative to the energy resources of origin fossils.

This study objective is the theoretical optimization of the inclination angle of a distiller with a capillary film in the site of Adrar in the great Algerian south, for this , we worked out an equations system of the total assessments which control this distiller operation , these equations solved by the Runge-Kutta-Fehlberg 4(5) integration method. The results of the digital simulation highlight the inclination angle effect on this distiller production, a detailed study on the daily, monthly and annual variation of the inclination optimum angle showed that a value of 38° represents the best optimum angle for a distiller with a capillary film directed in the full south for this site.

Keywords - Capillary film, Inclination angle, Numerical simulation, Optimization, Solar distillation.

Nomenclatures

A	*Area*	m^2
Cp	*Specific heat*	*J/kg°C*
d	*Distance*	*m*
D_m	*Mass diffusivity*	m^2/s
i	*inclination*	°
g	*Gravity accelerator*	m/s^2
G	*Solar radiation*	W/m^2
h	*heat transfer coefficient*	$W/m^2°C$
Le	*Lewis number*	-
Lv	*Vaporization latent heat*	*J/kg*
m	*Mass*	*kg*
$\dot{m}$	*Mass flow rate of brine*	*kg/s*
$\dot{m}d$	*Distillate mass flow*	*kg/s*
$\dot{m}_{Out}$	*Outgoing concentrated brine mass flux*	*kg/s*
Nu	*Nusselt Number*	-
Sc	*Schmidt number*	-
Sh	*Sherwood number*	-
t	*Time*	*s*
T	*Temperature*	*°C*
V	*Wind Velocity*	*m/s*
p	*Water vapor pressure*	*N/m2*

	Greek symbols	
α	*Absoptivity*	-
ρ	*Density*	*Kg/m^3*
ε_{eff}	*Effective emissivity*	-
ε	*Thickness*	*m*
σ	*Stefan Boltzmann Constant*	*W/m^2°C^4*
λ	*Thermal conductivity*	*W/m°C*
τ	*Transmissivity*	-
	Subscripts	
a	*Ambient*	
ha	*Humid air*	
da	*Dry air*	
c	*Condenser.*	
e	*Evaporator*	
v	*water vapor*	
g	*Glass*	

I. INTRODUCTION

The subsoil waters represent the principal source of drinking water in the site of Adrar; the chemical analyses results show a predominance of water of bad chemical quality on those of good quality. This water of bad quality is characterized by a higher salinity of 1 g/l exceed too far away the standards established by the world health organization. Meanwhile this region has the one of the most significant solar layers of the world, with more 3000 hours of sunning per year The daily average energy received per horizontal unit of area on this territory is evaluated 5.75kwh [1], it is available in abundance; it is thus presented as being an energy of replacement. Nevertheless, desalination requires energy whose cost intervenes for a great part in that of water. It appears a priori interesting to consider the solar energy use in the desalination process of this water.

Several types of solar distillers configurations with a capillary film were built and tested throughout the world, since work of R. and C Ouahes and P. Goff, continuation by those of B Bouchekima[2];H.Tanaka S.Hikmet [3]; and more recently the work of S. Ben Jabrallah and Mr. Abidi[4], the most part of this work were devoted for the vertical distillers study , in this present study we seek to optimize the inclination angle of this distiller type in order to improve its output.

II. SYSTEM DESCRIPTION

The device is made of glass cover (1) and two metal plates laid out face to face and inclined of a certain angle. The first plate front face is painted in black (2), Water to be distilled, runs out slowly using a fabric (3), on the other side; this fabric is suitable to form a capillary water film. This justifies the name given to the device (distiller with capillary film) [2]. The produced water vapor leaves fabric and will condense in contact with the second plate (4). Distilled water and the residue are recovered by collectors. The heat insulation of the unit is ensured by a trunk out of wooden (5), Fig.1 shows the general diagram of functioning, the distillation unit:

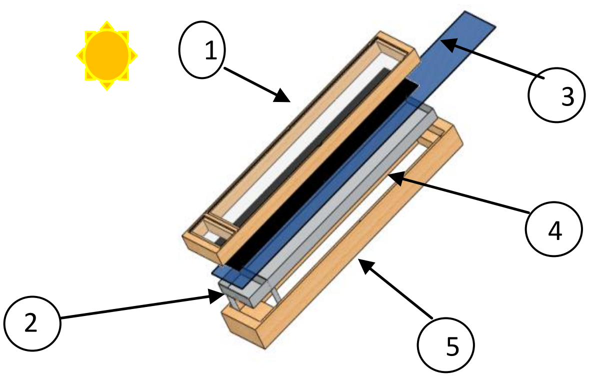


Fig1. System of a distiller with capillary film

III. Modeling and Numerical Resolution of the System

The modeling is made on the basis of heat balances and mass on the level of each part of the system, it is necessary to know the various coefficients of heat exchange and mass of the heat-transferring surfaces.

To obtain the heat balance the distiller is divided into three levels:

3.1 On the level of glass

$$(mCp)_g \frac{dT_g}{dt} = Q_{r(e-g)} + Q_{c(e-g)} - Q_{r(g-a)} - Q_{c(g-a)} + A_g \alpha_g G \quad (1)$$

$$\frac{dT_g}{dt} = \left(\frac{1}{\rho\varepsilon Cp}\right)_g \begin{bmatrix} -\left[\left(h_{r(e-g)} + h_{c(e-g)}\right) + h_{r(g-a)} + h_{c(g-a)}\right]T_g + \\ \left(h_{r(e-1)} + h_{c(e-g)}\right)T_e + h_{r(g-a)}T_{sky} + h_{c(g-a)}T_a + \alpha_g G \end{bmatrix} \quad (2)$$

G: It is the total radiation estimated by the Capderou numerical model in case of clear sky [1].

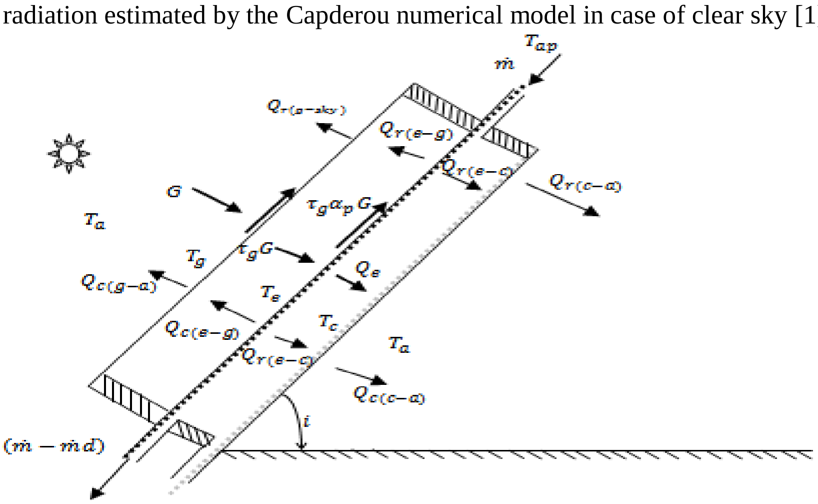


Fig 2. Thermal processes of the capillary film solar still

It is obvious that the ambient temperature T_a plays a significant role in a distillation process; we propose to calculate it using the following formula of Parton and Logan [5]:

$$T_a = (T_{amax} - T_{amin}) \sin\left[\frac{(t-(T_{sr}-0.17))\pi}{(T_{sr}-T_{ss}+3.6)}\right] + T_{amin} \quad (3)$$

The sky temperature is estimated by a simple relation according to ambient temperature [6, 7].

$$T_{sky} = 0.0552(T_a + 273.15)^{1.5} - 273.15 \quad (4)$$

The irradiative heat transfer coefficients evaluated as:

$$\begin{cases} h_{r(g-a)} = \epsilon_g \sigma \left[\left(T_g + 273.15\right)^2 + \left(T_{sky} + 273.15\right)^2\right]\left(T_g + T_{sky} + +546.30\right) \\ h_{r(e-g)} = \epsilon_{eff} \sigma \left[(T_e + 273.15)^2 + \left(T_g + 273.15\right)^2\right]\left(T_e + T_g + +546.30\right) \\ \epsilon_{eff} = \left[\frac{1}{\epsilon_g} + \frac{1}{\epsilon_e} - 1\right]^{-1} \end{cases} \quad (5)$$

$$h_{c(g-a)} = \begin{cases} 2.8 + 3V, & V \leq 5ms^{-1} \\ 6.15V^{0.8} & ,V > 5ms^{-1} \end{cases} \quad (6)$$

The convection coefficient is estimated using correlation of Hollandes:

$$\begin{cases} h_{c(e-g)} = \frac{\lambda_{da}}{d_{e-g}}\left[1 + 1.44\left(\frac{|X|+X}{2}\right)\left[1 - \frac{1708(\sin 1.8i)^{1.6}}{Ra}\right] + \left(\frac{|Y|+Y}{2}\right)\right] \\ X = 1 - \frac{1708}{Ra\cos i} \qquad ; Y = \left[\left(\frac{Ra\cos i\cos i}{5830}\right)^{1/3} - 1\right] \end{cases} \tag{7}$$

3.2 On the level of the absorber –evaporator

$$(mCp)_e \frac{dT_e}{dt} = -Q_{r(e-g)} - Q_{c(e-g)} - Q_{r(e-c)} - Q_{c(e-c)} - \dot{m}d \times Lv + (\dot{m} - \dot{m}d)Cp(T_e - T_a) + (\dot{m}Cp)_w\left(T_e - T_{ap}\right) + A_e\tau_g\alpha_e G \tag{8}$$

$$\frac{dT_e}{dt} = \left(\frac{1}{\rho\varepsilon Cp}\right)_e \left[\left(h_{r(e-g)} + h_{c(e-g)}\right)T_g - \left[\begin{pmatrix} h_{r(e-g)} + h_{c(e-g)} + \\ h_{c(e-c)} + h_{r(e-c)} \end{pmatrix} + \\ (2\dot{m} - \dot{m}d)Cp_w A_e^{-1}\right] T_e - A_e^{-1}\begin{pmatrix} (\dot{m} - \dot{m}d)Cp_w T_a - \\ \dot{m}Cp_w T_{ap} + \dot{m}d \times Lv \end{pmatrix} + \tau g\alpha eG \right] \tag{9}$$

The convection heat transfer coefficient ($h_{c(e-c)}$) can be written as:

$$h_{c(e-c)} = \frac{\lambda_{ha}}{d_{e-c}}\left[1 + \left[0.197Ra^{0.25}\left(\frac{d_{e-c}}{L_1}\right)^{-\frac{1}{9}} - 1\right]\sin i\right] \tag{10}$$

3.3 On the level of the condenser

$$(mCp)_c \frac{dT_c}{dt} = Q_{r(e-c)} + Q_{c(e-c)} + \dot{m}d_1 \times Lv - Q_{r(c-a)} - Q_{c(c-a)} \tag{11}$$

$$\frac{dT_c}{dt} = \left(\frac{1}{\rho\varepsilon Cp}\right)_c \left[\left(h_{r(e-c)} + h_{c(e-c)}\right)T_e - \begin{bmatrix} h_{r(e-c)} + h_{c(e-c)} + \\ h_{r(c-a)} + h_{c(c-a)} \end{bmatrix} T_c + md_1 \times LvA_c^{-1} + \left(h_{r(c-a)} + h_{c(c-a)}\right)T_a\right] \tag{12}$$

The mass balance is simple to write, since we have the flow conservation, the brackish water flow is the flows sum of distilled water and the brine at the outlet:

$$\dot{m}_{Out} = \dot{m} - \dot{m}d \tag{13}$$

We base on the analogy existing between the thermal and mass transfer, we admit that [8]:

$$\frac{Nu}{Pr^n} = \frac{Sh}{Sc^n} \qquad \text{Knowing that} \qquad \frac{h_{c(e-c)}\left(d_{(e-c)}/\lambda_{ha}\right)}{Pr^n} = \frac{h_m\left(d_{(e-c)}/D_m\right)}{Sc^n} \tag{14}$$

Let us consider that the ratio *Pr/Sc* is the Lewis number who expresses also the relationship between the mass diffusivity on the thermal diffusivity, the mass convection coefficient is thus worth:

$$h_m = \frac{h_{c(e-c)}}{\rho_{ha}Cp_{ha}Le^{1-n}} \tag{15}$$

The heat and matter transfers obey the analogy of Chilton–Colburn *n=1/3*, mass flux per unit of area is given by:

$$\dot{m}d = h_m\left((\rho_v)_e - (\rho_v)_c\right) \tag{16}$$

$$\dot{m}d = h_{c(e,c)}\frac{1}{Cp_{ah}Le^{2/3}}\frac{(\rho_v)_e - (\rho_v)_c}{\rho_{ah}} \tag{17}$$

$$\dot{m}d = \frac{31.672Nu.\lambda_{ah}}{d_{e-c}} \cdot \frac{(T_e + T_c + 546.3)}{[2572.082 - 38.672p_e]Cp_{ha}Le^{0.67}} \cdot \left(\frac{p_e}{T_e + 273.15} - \frac{p_c}{T_c + 273.15}\right) \tag{18}$$

Equations describing the phenomena of thermal transfer (2), (9) and (12, in the distiller are ordinary differential equations of first order, A Runge-Kutta-Fehlberg 4(5) integration method was choose to solve the obtained mathematical model. The step of discretization of time is variable. Convergence is regarded as obtained when relative error is lower 10^{-4}[9].

IV. RESULTS AND DISCUSSIONS

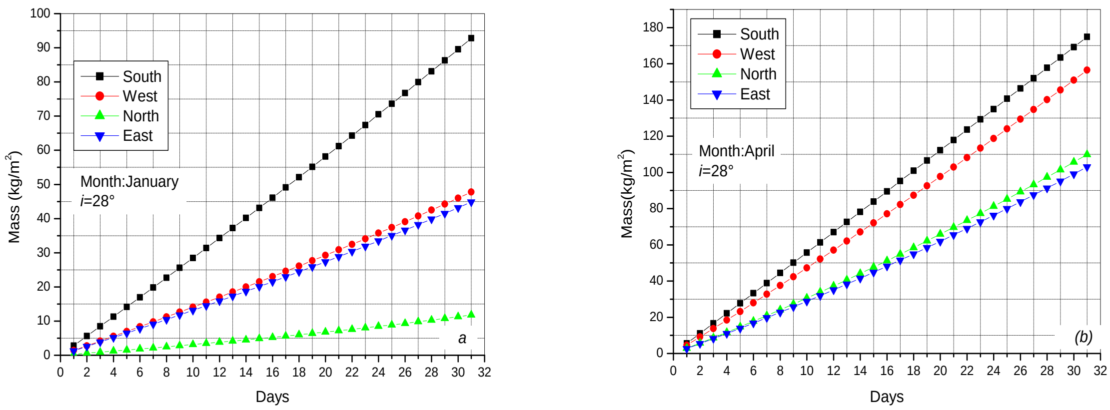
Calculations are carried out at Adrar of which geographical coordinates, at a latitude of 27°.53 North, at a longitude of 0°.17 East and at an altitude of 264m[1], as from an initial moment "$t_0=t_{sr}$" (of sunrise) for each component of the distillers, at an initial temperature, the rate of feed by the brine is constant fixed at 1.152kg/h its temperature is taken equal to with T_a, the wind speed is considered constant and taken at1.5 m/s

The thermo physical and geometrical properties of the components elements of the distiller are presented in the table below:

Table1. The thermo physical and geometrical properties

parameters	Symbol	Glass	Evap	Conden
Density	ρ	2700	7864	7864
Conductivity	λ	0.78	20	20
Mass heat capacity	Cp	840	460	460
Absoptivity	α	0.1	0.95	0.95
Transitivity	τ	0.9	0	0
Thickness	ε	0.003	0.001	0.0006
Emissivity	ϵ	0.9	0.2	0.2
Surface	A	1.00	1.00	1.00
Distance	$d_{(e-g)}$	0.05	-	-
Distance	$d_{(e-c)}$	-	0.04	-

The Fig. 3 shows monthly production variation according to different orientations, for four seasons of the year represent by the months January, April, July and October, it is clear that the orientation in the full south is the best compared to the other orientations, for example a value of 174.849 kg/month m2 for an inclination of 28° is reached, whereas this value decreases at 156.452 (W), 109.890 (N) and 103.027 (E) per standard month April. The remainder of the results are obtained we choose an orientation in the full south.



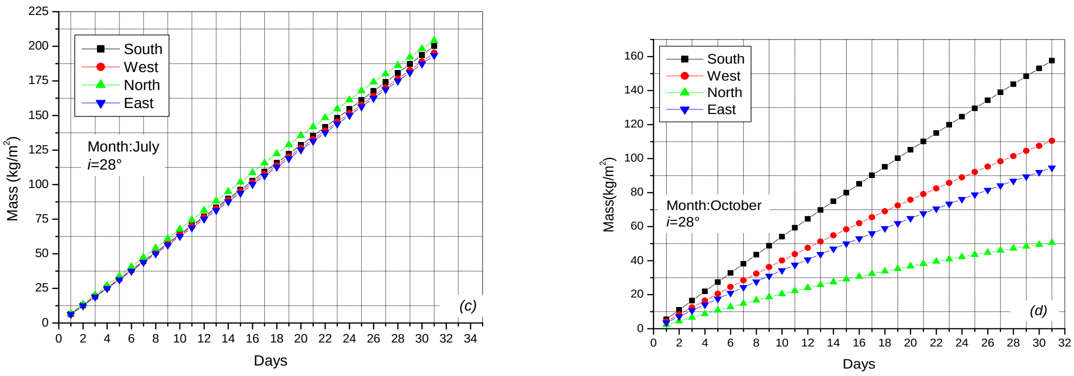


Fig3. Monthly production variation according to different orientations *(a)* January *(b)* April *(c)* July *(d)* October

The inclination angle variation according to number of days in the year is represented by the Fig. 4; we note that the optimal inclination angle is inversely proportional to the declination.

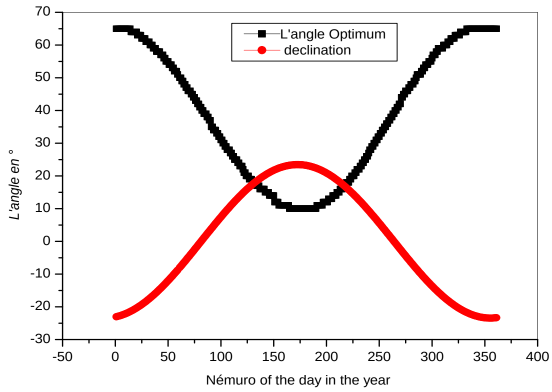


Fig 4. The optimal angle variation according to number of the days

The Fig. 5 shows linear relation between these two parameters this relationship is expressed by the correlation:

$$i_{Op} = -1.21196\delta + 38.9628 \qquad \text{With } r = 0.9983 \qquad (22)$$

The average value of the annual optimal angle is deduced on the basis of the graph Fig. 5 is evaluated at 38.60°.

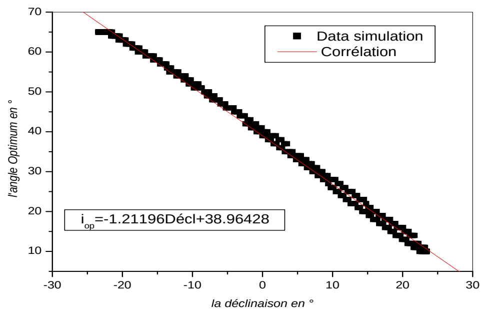


Fig 5. Optimal angle variation according to the declination variation

The study of the optimal angle monthly variation is represented by Fig.6 *(a), (b)* which show the variation of the monthly production according to the inclination angle for the two halves of the year the optimal value of this angle is given on table 2. for each month, the annual average value deduced from this same table is estimated at 38.75 °.

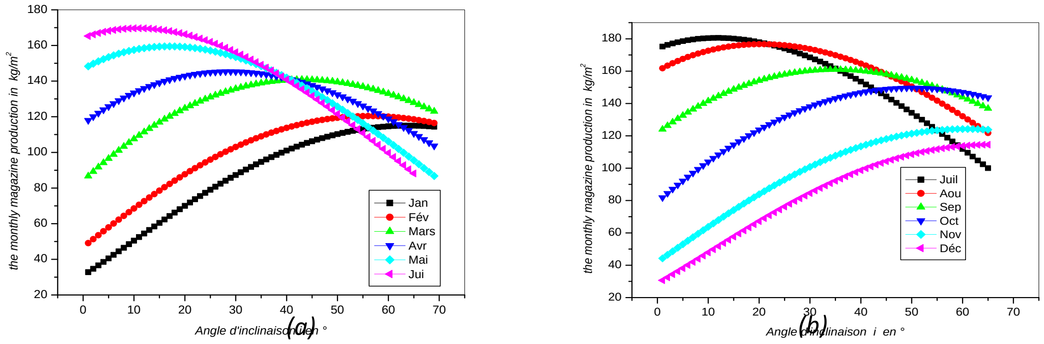


Fig 6. Monthly production variation according to the inclination angle *(a)* January-June *(b)* July-December

Finally the annual variation of the optimal inclination angle is schematized on Fig.9 which represents the annual production evaluation according to the inclination angle, the maximum value of the production is observed when the inclination angle reaches the value of 38°, and this value assures an average daily production estimated at 4.402kg/m ^{2}

Table 2. The monthly optimal inclination angle

N° Month	Jan	Feb	March	Apr	May	June	July	August	Sep	Oct	Nov	Dec	Average
i_{Op} (°)	64	56	43	29	17	11	12	21	35	50	61	66	38.75

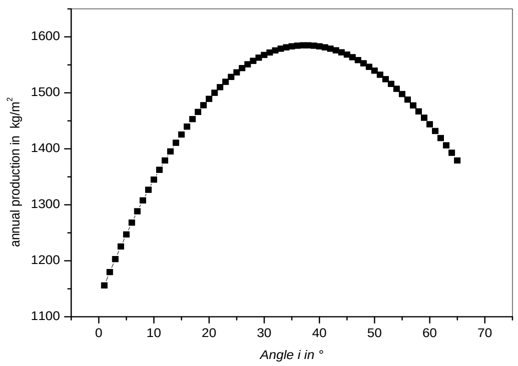


Fig 7 annual production variations according to the inclination angle

V. CONCLUSIONS

In this work, we have to build a mathematical model allowing model the functioning of a distiller with capillary film, a calculation code basing on the Runge-Kutta-Fehlberg 4(5) integration method was elaborated.

Analysis of the obtained results during the digital simulation of the model on the effect of the inclination angle of distiller applied in the site of Adrar, it allows us advance the following conclusions:

The daily variation of optimal inclination angle is inversely proportional to the declination; the average value of this angle is evaluated at 38.60°.

The study of the monthly variation of the optimal angle was making it possible to calculate the monthly average which is worth 38.75°. Finally the annual maximum production of distilled water is reached when the inclination angle is close to 38°, this value can be regarded as the optimal value of the site of Adrar, with which we can have average daily production of distilled water equal to 4.402kg/m ^{2}.

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