American Journal of Energy Research, 2025, Vol. 13, No. 2, 65-71
Available online at http://pubs.sciepub.com/ajer/13/2/2
Published by Science and Education Publishing
DOI:10.12691/ajer-13-2-2

Numerical Study of A Distiller

TRAORE Damus Abdoul Aziz[1,*], DIANDA Boureima[2], INAME Allassane[1], BAMOGO Kombassé[1], OUEDRAOGO Maneg-Sanga Pélagie Rosina[1]

[1]Renewable Thermal Energy Laboratory, University Joseph KI-ZERBO, Ouagadougou, Burkina Faso
[2]Research Institute of Applied Sciences and Technologies, National Center for Scientific and Technological Research, Ouagadougou, Burkina Faso
*Corresponding author: traoredamus35@gmail.com

Received June 01, 2025; Revised July 01, 2025; Accepted July 08, 2025

Abstract This work consists of the numerical study of a double-slope solar still coupled with a parabolic trough concentrator. The numerical study, using the fourth-order Runge Kutta method, allowed us to better understand the temperature changes of the still's various elements, namely the outer glass, the inner glass, the water, and the absorber as well as the changes in the still's operating characteristics, such as productivity, performance and the overall and internal efficiency of the device. April 17 was chosen as the simulation day using Matlab software. On this day, the absorber reached a maximum temperature of 112°C, and the maximum productivity was 3.9610 kg/m²h under a maximum irradiance of 925 W/m² for a still whose absorption surface area is less than 1 m².

Keywords: *distiller, concentration, productivity, efficiency, performance*

Cite This Article: TRAORE Damus Abdoul Aziz, DIANDA Boureima, INAME Allassane, BAMOGO Kombassé, and OUEDRAOGO Maneg-Sanga Pélagie Rosina, "Numerical Study of A Distiller." *American Journal of Energy Research*, vol. 13, no. 2 (2025): 65-71. doi: 10.12691/ajer-13-2-2.

1. Introduction

The need for drinking and industrial water is growing more and more worldwide. This crisis is mainly due to the increase in the world population and the distribution of water across the globe. Indeed, according to a UN report, nearly 2 billion people in 48 countries will have difficulty finding water in 2050. The Earth's surface is covered by 70% water, 98% of which is in the form of brackish water and 2% in the form of drinking water, 90% of which is embedded in glaciers. To address this shortage of drinking water, many researchers have become interested in seawater and brackish water desalination techniques. These techniques are classified into two types: thermal and membrane desalination. These desalination techniques are certainly effective, but they are very energy-intensive To solve this energy problem, researchers have been interested in using solar energy to desalinate brackish water. It is in this sense that we will witness the birth of several types of solar distillers in order to produce drinking water. There are two types of solar distillers, namely passive and active solar distillers. Active solar distillers are distillers coupled to an external heat source while passive distillers are not coupled to any heat source [1] Single or double slope solar distillers are the most designed and studied because of their simplicity to realize. Unfortunately, their performances are not high enough. In order to improve their performances, they are coupled to concentrator generally parabolic . Work in the literature includes that of T. Arunkumar et al [2] who conducted an experimental study of a single-slope solar still coupled with a parabolic reflector. The shape of the basin was modified so that it was bemispherical. In order to improve the productivity of the stills, they poured cold Fea onto the glass and added paraffin wax to the basin Gorjian et al [3] conducted an experimental study of a solar still coupled with a parabolic disk operating in force mode. The operating time of the still is seven hours. ZM. Omara et al [4] designed and tested another still coupled with a parabolic solar concentrator and a single-slope passive solar still. The results obtained indicate that the average daily production of distilled water is significantly higher than that of the passive still. Kalpesh Medi et al [5] conducted an experimental study of a spherical solar still coupled with a parabolic concentrator. The device is equipped with solar tracking to increase its productivity. Anil Kumar et al [6] conducted an experimental study on a single-slope still coupled with a parabolic cylinder concentrator. The distiller is connected to the condenser by two PVC cores. The reports show that the productivity of fresh water has been improved compared to the patlahmanx distiller. *Elashmawy et al* [7] placed a cylindrical, parabolic concentrator under a nabulary solar distiller. They filled the tank with water in the first experiment, then removed the coating in the second experiment, and added a parabolic concentrator as a heat source in the case of the third experiment. The system proposed by Manchanda et al [8] is multifunctional. It consists of a distillate and a drying chamber under which the parabolic concentrators are placed. The results obtained were satisfactory. Hossein Amiri et al [9] designed and experimentally studied a new autonomous desalination system, consisting of a parabolic trough collector placed under a double-slope solar still. In their study, an unstable theoretical model was developed using the energy equations. The model was used to calculate the productivity and temperatures of the absorber, salt water, and glass cover. The results obtained using the theoretical model were compared with the experimental results, and good agreement was observed between them. Most of the literature focuses on experimental methods. The objective of our work is to propose a numerical model to determine the performance of a double-slope solar still equipped with a parabolic trough concentrator.

2. Materials and Methods

2.1. Description and Operation of the Device

The device studied is a high-temperature active solar still. It consists of a:

■ Double-slope solar still

The still consists of a double-slope glazing and a tank containing the water to be distilled. The glazing consists of two identical clear panes 4 mm thick. The tank containing the water to be distilled is made of stainless steel and the bottom is painted black. Gutters are installed at the tank level to collect the distillate.

■ Parabolic trough concentrator

The concentrator is a parabolic trough collector with a focal length of 35 cm. Sheets of aluminum were cut and riveted to the support, thus forming the reflective surface. The concentrator has a manual tracking system that allows us to better focus the solar rays on the bottom of the tank.

The distiller is powered by the solar energy from the parabolic trough concentrator, which aims to concentrate the sun's rays incident on its exposure surface at the focus where the absorber is placed (the bottom of the distiller). Thus, in addition to the solar energy transmitted through the glazing, the water also receives energy from the concentrator. The water contained in the distiller's tank sees its temperature rise rapidly and evaporates. This vapor, in contact with the glazing, condenses. The water is then collected in gutters.

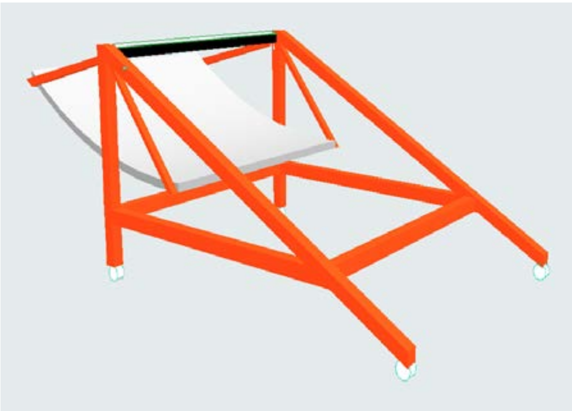

Figure 1. Diagram of the device studied

2.2. Heat Balances at the Levels of the Different Elements of the Device

We established simplifying assumptions, established the heat balances at the levels of the different elements of the device, and solved these equations using the fourth-order Runge Kutta method.

2.2.1. Assumptions

In our study, taking into account the geometry of our device, we formulated the following assumptions:

- Heat transfer is unidirectional
- The temperature of each component is uniform
- The physical properties of the materials are constant

2.2.2. Heat Balance

• At the Level of the Outer Pane

The outer pane exchanges heat by convection, by radiation with the external environment, and by conduction with the inner pane. The heat balance equation for the outer pane is:

$$\frac{M_v C_{pv}}{2A_V}\frac{dT_{vex}}{dt} + h_{RVA}\left(T_{vex} - T_a\right) + h_{CVA}\left(T_{vex} - T_a\right) - h_{cv}\left(T_{vin} - T_{vex}\right) - I_v = 0 \quad (1)$$

Avec:

$$h_{CVA} = 5,7 + 3,8V \quad (2)$$

h_{CVA} is the convection transfer coefficient between glass and ambiant .

$$h_{RVA} = \varepsilon_v \sigma\left[(T_{vex}{}^2 + T_c{}^2)(T_{vex} + T_c)\right] \quad (3)$$

h_{RVA} is the radiation transfer coefficient between glass and ambiant

$$h_{cv} = \frac{\lambda_v}{e_v} \quad (4)$$

h_{cv} is the conduction transfer coefficient in the glass

$$I_v = \alpha_V I_G \quad (5)$$

I_v is the solar power absorbed by the glass.

• At the inner pane

The inner pane exchanges heat by radiation, by convection with the water, by evaporation, and by conduction with the outer pane. The heat balance expression is:

$$\frac{M_v C_{pv}}{2A_V}\frac{dT_{vin}}{dt} + h_C\left(T_{vin} - T_{vex}\right) - h_{REV}\left(T_E - T_V\right) - h_{CVE}\left(T_E - T_{vin}\right) - h_{EV}\left(T_E - T_{Vin}\right) - I_v = 0 \quad (6)$$

With:

$$h_{REV} = \varepsilon_{eff}\sigma\left[(T_{eau}{}^2 + T_{vin}{}^2)(T_{eau} + T_{vin})\right] \quad (7)$$

h_{REV} is the radiation transfer coefficient between the glass and the water.

Using the Dunkle model [10], we have:

$$h_{CVE}=0,884[(T_E-T_v+\frac{(P_E-P_V)(T_E+273,15)}{298,910^3-P_E})]^{(1/3)} \quad (8)$$

In the case of our distiller, the glazing is inclined at an angle β.

$$h_{CVE}=0,884[(T_E-T_v+\frac{(P_E-P_V)(T_E+273,15)}{298,910^3-P_E})(\frac{1+\cos\beta}{2})]^{(1/3)} \quad (9)$$

h_{CVE} is the convection transfer coefficient.

$$h_{EV}=16,273.10^{-3}h_{CVE}\left(\frac{P_E-P_v}{T_E-T_v}\right) \quad (10)$$

h_{EV} the evaporation transfer coefficient.

$$P=exp\ (25,317-\frac{5144}{T+273}) \quad (11)$$

For the partial pressure of vapor there are several relationships for determining the partial pressure of vapor, but in our study we used the relationship of Fernandez and Chargoy [11], which is the simplest and most widely used.

• At the absorber

The absorber exchanges heat by convection with the water and with the surrounding environment. In addition to these exchanges, it absorbs a solar flux from the concentrator. The equation translating the heat balance is:

$$\frac{M_{abs}C_{pabs}}{A_{abs}}\frac{dT_{abs}}{dt}+h_{abs}\left(T_{abs}-T_E\right)+h_{CVA}\left(T_{abs}-T_a\right)-I_{abs}=0 \quad (12)$$

With:

$$h_{abs}=\frac{N_u\lambda_f}{L} \quad (13)$$

h_{abs} is the convection transfer coefficient between the absorber and the water

N_u the Nusselt number is determined as a function of the Graschof number G_r and Prandtl number P_r.

If $G_r\le 10^5$ then $N_u=1$ (14)

If $10^5<G_r<2\,10^7$ then $N_u=0.54\left(G_rP_r\right)^{0.25}$ (15)

If $G_r>2\,10^7$ then $N_u=0.14\left(G_rP_r\right)^{0.33}$ (16)

I_{abs} the solar power absorbed by the absorber

$$I_{abs}=\alpha_{abs}\rho C_g I_D \quad (17)$$

I_D : The direct radiation

α_{abs} : The absorption coefficient of the absorber

ρ : The reflexion coefficient

•Thermal balance of the water mass

The water transfers heat to the glass by radiation and not convection. It collects heat from the heater on the part of the absorber. The thermal balance of the water is:

$$\frac{M_ECp_E}{A_E}\frac{dT_E}{dt}+h_{REV}\left(T_E-T_V\right)+h_{CVE}\left(T_E-T_{vin}\right)+h_{EV}\left(T_E-T_{Vin}\right)-h_{abs}\left(T_{abs}-T_E\right)-I_E=0 \quad (18)$$

$$I_E=\alpha_E(\tau_vI_v+\tau_{abs}I_{abs}) \quad (19)$$

I_E : the solar power absorbed by the water

2.2.3. Theoretical Expressions of Performance

• Productivity

The productivity of a distiller or the flow rate of distilled water is defined as its yield. It is the quantity of water produced per unit area per day. It is determined by the following relationship:

$$md=3600\frac{Q_{ev}}{L_V} \quad (20)$$

Where Q_{ev} and L_V are respectively the heat flow transferred by evaporation and the heat vaporization of the water.

The heat flow exchanged by evaporation is given by the relationship:

$$Q_{EV}=h_{EV}\left(T_E-T_{Vin}\right) \quad (21)$$

• The overall efficiency

It shows the performance of the distiller in relation to the energy absorbed by the water. It is defined as the ratio of the quantity of water produced to the amount of sunlight on the distiller.

$$n_{globale}=\frac{Q_{EV}}{Av.I_g+A_{abs}.C_g.I_D} \quad (22)$$

• Internal efficiency

This second efficiency shows the performance of the distiller in relation to the energy absorbed by the water.

$$n_{interne}=\frac{Q_{EV}}{I_E} \quad (23)$$

• Exergy Efficiency

Exergy efficiency is defined as the ratio of output exergy to input exergy. In the case of our device, the output exergy is the evaporation exergy, and the input exergy is the solar exergy. The expression for exergy efficiency is given by the following equation:

$$n_{exer}=\frac{Exer\_ev}{Exer\_sun} \quad (24)$$

Exer sun is the solar szergetic flux falling on the solar still.

Exer ev is the gastgstic evaporation flux

• The performance factor

In order to characterize the operation of a solar still,

Stacunanathan et al [12] defined a gross performance factor (GPF) and an hourly performance factor (HPF). These two factors are a function of the distillate flow rate and the amount of energy entered into the still.
At a given time of day, the performance factor FP can be given by the relationship:

$$FP = \frac{md}{I_E} \tag{25}$$

3. Results and Discussion

The solved equations are used for the simulations. The results of these simulations are presented in the form of curves and discussed in this section.

A typical April day in the city of Ouagadougou under a clear sky is used for the simulations.

3.1. Sunshine

Figure 2 shows the variation in direct, diffuse and global solar radiation on the chosen day

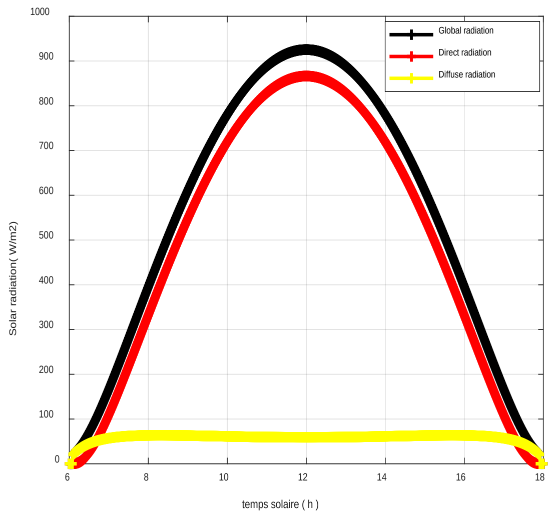

Figure 2. Evolution of direct, diffuse, and global solar radiation

These curves evolve in a bell shape. The different radiations increase between 6 a.m and 12 p.m they reach their maximum value at noon and decrease after 12 p.m. for minimum values at sunset. The maximum radiation values are 925.24 W/m², 836.504 W/m², and 59.14 W/m², respectively, for global, direct, and diffuse radiation. The direct radiation responsible for solar concentration is quite significant.

3.2. Temperatures of the Different Components

Figure 3 represents the evolution of the temperatures of the outer pane, the inner pane, the water and the absorber.

These temperature curves have a bell-shaped evolution. The temperatures increase as the sunshine increases. They increase slowly from the first hours of 6 a.m to 8 a.m then quickly to reach their maximum value at 3 p.m then a drop in temperature is observed after 3 p.m. We note that the temperature of the absorber is the highest. This is explained by the fact that the power absorbed by the latter is very high. Indeed, it receives a concentrated solar flux from the parabolic trough concentrator and a heat flux transmitted by the glazing The absorber temperature changes significantly, reaching a maximum of 112°C at 3 p.m then begins to decrease.

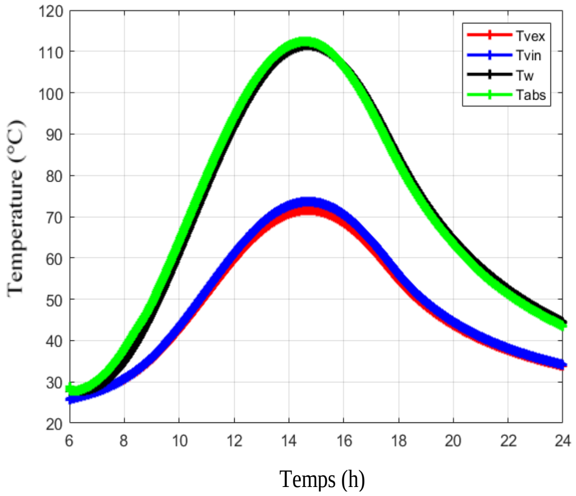

Figure 3. Evolution of Temperatures of the different components

The water has a temperature very close to that of the absorber. This can be explained by the fact that the water is directly heated by the bottom of the tank. It gradually increases until reaching a maximum temperature of 110°C at 3 p.m then begins to decrease. This water temperature is higher than that obtained by Hossein Amiri et al. in their work.

The temperature changes of the outer and inner panes are similar. The temperature of the inner pane is slightly higher than that of the outer pane due to the greater thermal input. These two temperatures remain low compared to those of the absorber and the water.

3.3. Productivity

Figure 4 shows the change in the productivity of our distiller, which is the quantity of distilled water produced.

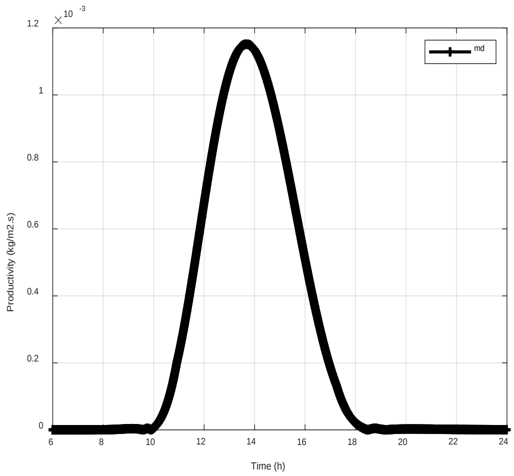

Figure 4. Productivity variation

Figure 4 shows productivity that changes very slowly, with values practically zero during the early morning hours due to low sunlight, then increases.

It increases rapidly with sunshine, reaching its maximum around 2 p.m. It begins to decrease rapidly, reaching a value of almost 1,000 around 6 p.m due to the decrease in sunshine. A maximum productivity of 1.110 kg/m² or 3.96 kg/m² h is obtained for an absorption surface of 0.078 m². This productivity is higher than the productivity of conventional stills and that of certain active solar stills. A. Dellou et al [13] obtained a maximum productivity of 0.55 kg/m³ h with a passive double-slope still. R. Menina [14] et al obtained a maximum productivity of 0.45 kg/m² h with a still coupled with a flat collector.

3.4. Overall Efficiency

Overall efficiency is one parameter that characterizes the operation of a distiller. Figure 5 shows the evolution of overall efficiency.

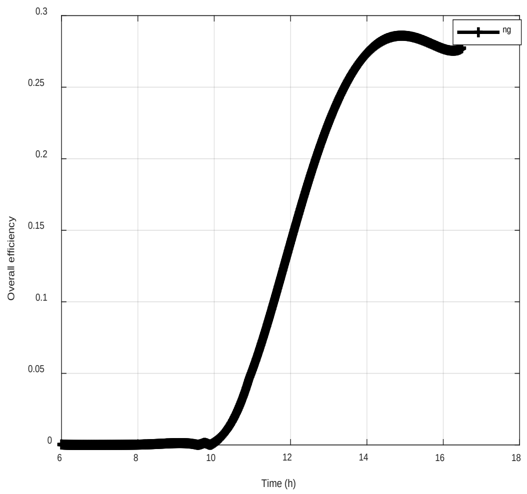

Figure 5. Variation in overall efficiency

The overall efficiency is almost zero between Sh and 10 a.m, then it increases rapidly from 10 a.m to 2 p.m, reaching a maximum value of 28.69% around 3 p.m After 3 p.m a slight decrease is observed, then it increases again after 4 p.m. We note that it evolves according to the quantity of heat evaporated the more this increases the more the efficiency increases, which explains its increase between 10 a.m and 3 p.m because at these times the amount of heat used for evaporation is very high. After 3 p.m this amount of heat decreases which explains its slight decrease. Its increase after 4 p.m is due to the fact that at these times the amount of heat evaporated is greater than the sunlight falling on the distiller.

3.5. Internal Efficiency

Figure 6 shows the evolution of the distiller's internal efficiency.

Its evolution is similar to that of the overall efficiency, but it is higher than the overall efficiency. It begins its evolution at 10 a.m and then increases quite rapidly to reach its maximum value which is 5.14 at 3 p.m then begins to decrease after 3 p.m. Its rapid increase between 10 a.m. and 3 p.m is explained by the fact that the amount of heat evaporated is very high at these times. The decrease in efficiency after 3 p.m is due to the fact that the amount of heat evaporated decreases after 3 p.m. The internal efficiency of our device is much higher than the internal efficiencies of conventional systems.

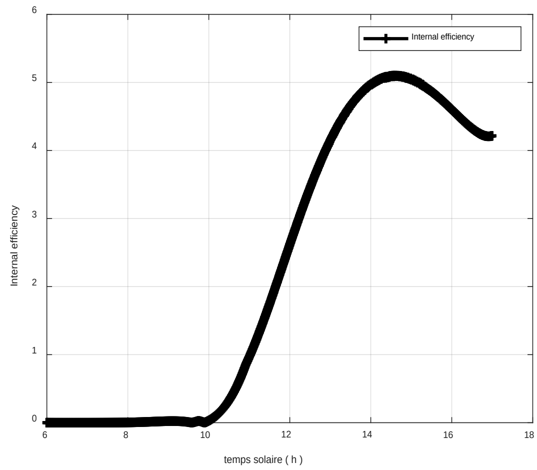

Figure 6. Variation in internal efficiency

3.6. Exergy Efficiency

Figure 7 shows the evolution of the distiller's exergy efficiency.

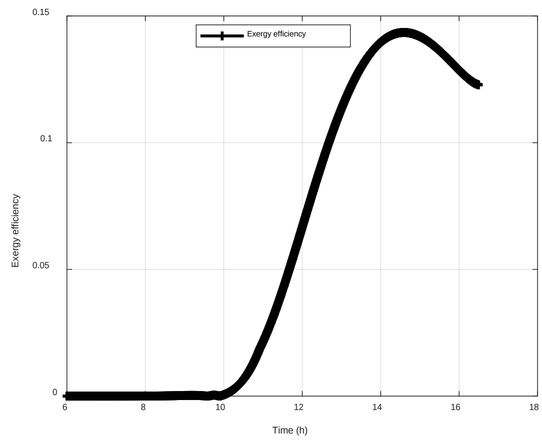

Figure 7. Evolution of the distiller's exergy efficiency

Its evolution is similar to that of overall efficiency and internal efficiency but it remains lower than the other two efficiencies. A maximum value of 15% is observed at 3 p.m

The energy efficiency of our distiller is significantly higher than that of conventional distillers. Rajaseenivasan et al. [15] obtained an exergy efficiency of 1.031% for a passive double-slope solar distiller. Kumar and Fiwari [16] obtained a daily exergy efficiency that varies between 0.4% and 0.5% for a single-slope distiller. In order to improve the performance of their distiller, they coupled it to a flat-plate solar collector, where they obtained 2.4% and 1.16% respectively, for the single-slope and double-slope distillers, all coupled to a flat-plate collector.

3.7. The Performance Factor of the Distiller

Figure 8 shows the evolution of the performance factor of our device.

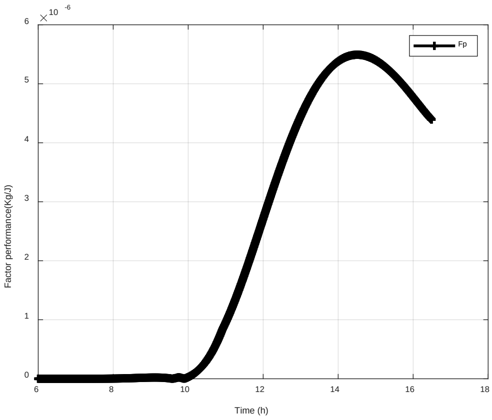

Figure 8. Variation of the distiller's performance factor

Its evolution is similar to that of the efficiencies. It is a function of productivity. It is zero between 6 a.m. and 10 a.m. This is due to the fact that at these times productivity is zero. It begins its evolution from 10 a.m and increases between 10 a.m and 2:30 p.m. to reach a maximum of 5.49 106 kg/J then decreases rapidly to reach a value of 4.39 105 kg/J before 6 p.m.

4. Conclusion

The numerical model of the device we proposed in this work allows us to theoretically predict the thermal behavior of a concentrating solar still. We obtained a maximum temperature of 112°C at the absorber, a productivity of 0.0012 kg/m².s, an overall efficiency of 28.69%, and an internal efficiency of 5.14. Analysis of the results shows that the concentrator allows the absorber temperature to increase, which would cause an increase in water temperature, an improvement in productivity, internal efficiency, exergy efficiency, and the performance factor. However, the overall efficiency of the still is lower than that of conventional stills. We can conclude from these results that our device is more efficient than conventional stills and some active stills. In the rest of our work, we will proceed with the construction of the device and the experimental study to validate the numerical model.

Nomenclature

A Glass Surface Area (m^2)
C_p Specific Heat ($J/kg°C$)
C_g Geometric Concentration Coefficient
e_v Glass Thickness (m)
$Exer$ Exergy (W/m^2)
Fp Performance Factor ($J/kg°C$)
G_r Grashof Number
h Heat Transfer Coefficient (W/m^2C)
I Absorbed Solar Power (W/m^2)
I Global Radiation (W/m^2)
L Length (m)
L_V Specific Heat of Vaporization (J/kg)
M Mass (kg)
md Mass Flow Rate (kg/m2h)
P Partial Vapor Pressure (P_a)
P_r Prandtl Number
Q Heat Flux (W)
T Temperature ($°C$)
t Time (S)
V Wind Speed (m/s)

Abréviation

a ambient
abs absorber
CVA glass-ambient convection
CVE glass-water convection
D direct
d diffuse
E water
EV evaporation
f fluid
g global
RVE glass-water radiation
RVA glass-ambient radiation
vex exterior glass
vin interior glass

Greek Letters

α Absorption coefficient
β Tilt angle
ε Emissivity
λ Thermal conductivity $(W/m°C)$
η Efficiency
σ Blozman constant
ρ Reflection coefficient
τ Transmission coefficient

References

[1] S.A.Kalogirou, Solar Energy Engineering: *Processes and Systems,Academic Press*, 2013.

[2] T.Arunkumar , D.Denkenberger, R.Velraj, Experimental study on a parabolic concentrator assisted solar desalting system, *Energy Conversion and Management* 105 ,665-674, 2015.

[3] Gorjian S, Ghobadian B, Hashjin TT, Banakar A Experimental performance evaluation of a stand-alone point-focus parabolic solar still. *Desalination* 352 ,1–17, 2014.

[4] Z.M. Omar, M.A. Eltawil, Hybrid of solar dish concentrator, new boiler and simple solar collector for brackish water desalination, *Desalination*, 326,62–68, 2013.

[5] Kalpesh V. Modi, Kuldeep H. Nayi, Sonu S. Sharma,Influence of water mass on the performance of spherical basin solar still integrated with parabolic reflector, Groundwater for *Sustainable Development*, 2019.

[6] Anil Kumar, Savita Vyas, Dan Nchelatebe Nkwetta, Experimental study of single slope solar still coupled with parabolic trough collector, *Materials Science for Energy Technologies*, 2020.

[7] Elashmawy, M., An experimental investigation of a parabolic concentrator solar tracking system integrated with a tubular solar still. *Desalination*, 411, 1–8, 2017.

[8] Himanshu Manchanda, Mahesh Kumar Performance Analysis of single basin solar distillation cum drying unit with parabolic reflector. *Desalination* 416 ,1-9, 2017.

[9] Hossein Amiri , Mohammad Aminy , Marzieh Lotfi , Behzad Jafarbeglo , Energy and exergy analysis of a new solar still composed of parabolic trough collector with built-in solar still, *Renewable Energy*, 163,465-479, 2021.

[10] R.V. DUNKLE, Solar water distillation, The Roof Type Still and a multiple diffusion Still, *Commonwealth scientific and industrial research organization, Victoria, Australia*,, 895-902 edition 1961.

[11] Tiwari.G.N. Energy: Fundamentals, Design, Modelling and Application. *Alpha science, England,* 2006.

[12] Satcunathan Hansen, An investigation of some of the parameters involved in solardistillation, *Sol. Energy* 14, 353-363, 1973.

[13] A.Deliou, Experimental study of the characteristics of a still solar still with a sintering effect, *Renewable Energie* ,109-118, 2008.

[14] R.Menina, Etude Expérimentale de l'Effet du Préchauffage sur la Productivite d'un Distillateur Solaire (Type: Hot - Box), *Rev. Energ. Ren.: Journées de Thermique* ,145-150, 2001.

[15] Rajaseenivasan, T., Murugavel, K.K., Theoretical and experimental investigation on double basin double slope solar still. *Desalination* 319, 25–32, 2013.

[16] Kumar, S., Tiwari, A., An experimental study of hybrid photovoltaic thermal (PV/T) active solar still. *Int. J. Energy Res*. 32, 847–58, 2008.