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NUMERICAL SIMULATION OF RECEIVER TUBE FOR PARABOLIC TROUGH COLLECTOR WITH SINGLE SOLAR STILL

Hawraa Fadhel[1], Qahtan A Abed[2], Dhafer M Hachim[3]
[1]*Department Of Technical Power Mechanics, Technical Engineeringcollege / Najaf, Al-Furat Al-Awsat Technical University (ATU), Najaf, Iraq*
[2]*Technical Institute / Al-Rumaitha, Al-Furat Al-Awsat Technical University (ATU), Najaf, Iraq*
[3]*Department Of Technical Power Mechanics, Technical Engineeringcollege / Najaf, Al-Furat Al-Awsat Technical University (ATU), Najaf, Iraq*
[1]*hawraa.fadhel@student.atu.edu.iq*

ABSTRACT

A numerical simulation study was carried out to model the absorption pipe of the parabolic trough collector with the single-slope solar still. Simulations were carried out in the comsol 5.4 g program to obtain the best design of the solar still and to improve the yield of the distilled water. The number of heat exchanger tubes changed inside the solar still 6,8,10,12 tubes. The diameter of the heat exchanger tubes (0.5 cm, 1 cm, 1.5 cm) was also changed. The results showed that when increasing the number of tubes inside the heat exchanger, the best temperatures were obtained. When the number of 12 tubes, the highest temperature of the water inside the solar still is obtained at 93.597ºC, and the highest temperature of the surface of the inner glass of the solar still is 72.791ºC at 1:07 pm. As it turns out, as the diameter of the heat exchanger tubes increases, the temperature of the water inside the single solar still increases, 99.93ºC. And the surface of the inner glass of the solar distiller was 79.991ºC at 1:06 pm. The work was done on February 18, 2021 in AL-Najaf City-Iraq (32° 1 'N/44° 19' E)

Keywords: Parabolic trough collector, solar still, fresh water.

I. INTRODUCTION

Energy is one of the most dangerous problems in the world. A high-performance solar collector is required to deliver elevated temperatures with good efficiency. The Solar Parabolic Trough Collector was able to acquire systems with light structures and low-cost technologies for the application of process heat up to 400°C (solar PTC). These systems can generate temperatures between 50 and 400°C efficiently [1]. Valladares et al [2] A numerical analysis of the optical, thermal and fluid dynamic behavior of a single-pass solar PTC was proposed and the research was expanded by replacing the absorber with a concentric circular heat exchanger counter-flow (double-pass). Hachicha et al [3] A visual model for computation was developed to show the distribution of irregular solar flux around the receiver. This model is based on the finite-size method and ray-tracing techniques, taking into account the position of the sun. The results received showed good compliance with the experimental and analytical results. Many previous works have been carried out on different solar still types to improve their productivity and thermal efficiency [4], [5]. The parabolic trough collector is currently concentrated solar systems are closely employed as one of the various solar energy converters [6]. A new optical efficiency analytical model and an updated integration algorithm to simulate the performance of a vacuum tube receiver parabolic trough collector (PTC) have been suggested and implemented by Weidong et al [7].The system's optical efficiency was simulated by the algorithm of numerical integration . Taking into account the lack of costs, the annual yield was often simulated. Ananthsornaraj et al. [8] Three-dimensional numerical modeling of the future of the parabola is carried out by coupling the Monte Carlo ray tracing method (MCRT) with the finite volume method (FVM), to investigate the flux distribution irregularities on the outside of the receiver. About Bilal et al [9] Under transient climate conditions, the thermal output of a solar parabolic trough has been numerically analyzed by the Collector (PTC). For the thermal efficiency of the PTC, the receiver tube length and the geometry of the heat transfer fluid (HTF) were simulated. They noticed that the overall thermal efficiency of the solar collector reached during the summer was nearly 76 per cent.. Jamel et al. [10] The experimentally studied the effect of integrating the parabolic trough complex supported by a spherical layer filled with glass with the flat plate collector and the traditional slope solar distillation action, and the results showed that the maximum rate of fresh water production for solar energy with the parabolic collector and the flat plate collector and the heat storage medium is 2.775 kg/m^2/day during the winter and 6.036 kg/m^2 during the summer. Ali [11] The efficiency of a single solar system was tested experimentally, modeling five solar trailers with a pool depth of 0.5 × 0.5 m. Tilted to 20°, 31°, 45° and 50° were the basin lids. The results showed that fresh water productivity increased when the angle of inclination was reduced from 50 to 20°, where the highest efficiency was 495 mL/day at a 20° angle. Muntadher et al. [12] A numerical analysis concerning the study of single-slope solar still efficiency using various PCM masses with and without. The numerical solution was conducted using COMSOL 5.3 software and the findings were contrasted with previous tests and found that there was a strong agreement. The findings also found that the use of 1 kg of PCM is the optimum amount of change. Huang et al. [13] Receiver tube numerical simulations were examined with and without helical fins, as the protrusions work to create a fully-formed turbulent flow and heat transfer in the inner tunnel. The results show that the receiving tubes with dimples have a great improvement in heat transfer efficiency for the suggested design. In this paper, work was done to obtain the best design of the solar still with the receiving tube of the parabolic trough collector, where the number of heat exchanger tubes and the diameter of the tube were changed. Zeinab et al. [14] conducted an experimental and theoretical study of a solar powered desalination system in Cairo, Egypt. The device includes a solar equivalent basin with a receiving tube and a heat exchanger. As the oil inside the heat exchanger is heated up, the path of sunlight through direct solar radiation and the solar concentrator. Salt water is heated by the oil inside the heat exchanger and by solar radiation, and the results showed an increase in fresh water productivity of 18%. Mehmet Canalp Kulahli, et al.[15] introduced a new parabolic reflector for a Parabolic Trough Collector (PTC). The reflector has a variable focal length in the longitudinal direction while keeping a fixed focal line.The flow rate optimization study resulted in a 0.21 % increase in thermal efficiency and a 0.63 % increase in net energy gain as a result of the parametric studies. Mohamed M. Khairat, et al.[16] worked on a heat exchanger serpentine with an under basin phase change material (PCM) and an evacuated tube on the focusing axis of a parabolic trough (PTC). The daily productivity for the conventional solar still and oil as a working fluid at flow rates of 1.5, 1.0, and 0.5 L/min, and nano-oil as a working fluid at a flow rate of 0.5 L/min, respectively, was 3.182, 4.67, 6.21, 8.79, and 11.14 L/m2/day.. Hossein Amiri, et al[17] The work on a novel independent desalination system that consists of a parabolic trough collector with solar still, The solar system generates 0.961 L of freshwater per day in the summer, which is 55% more than the yield of the fixed parabolic trough collector in the winter. In the summer, the parabolic trough collector with tracking systems would yield 1.266 L per day.

The purpose of the work is to check the design of the solar still .To get the best design, we will work with the COMSOL 5.4 simulator by changing the number and diameter of the heat exchanger tubes inside the solar chopping block, so that good heat transfer is obtained as the number and diameter of the tubes increase, and thus the water temperature remains. Inside the solar energy is increasing, so I will make a good improvement in the yield of distilled water. As the new point in this work is choosing the best number of heat exchanger tubes for the investigated model from among (6,8,10,12) tubes. Which gives the highest temperatures. A simulation was also carried out to choose the best diameter among three models (1.5 cm, 1 cm and 0.5 cm). To obtain better temperatures to increase the evaporation process inside the solar still.

II. COMSOL NUMERICAL SIMULATION

2.1. Physical method used

In order to investigate the performance of theTSS a three-dimensional simulation model wasimproved using COMSOL Multiphysics. A numerical simulation was performed in the COMSOL Version 5.4 program. The complete three-dimensional solar system consisting of a receiving tube for a parabolic trough collector with an inner diameter of 16 mm and a length of 140 cm of copper material has been implemented by this simulation. The receiver tube is connected to various 12 tubes, connected to all components of the solar still system, as shown in Figure.1. The length of the solar still is 61cm, and its width is 38cm. The thickness of the water inside the solar still is 0.5 cm. The main geometrical properties of the solar parabolic trough and single solar still are presented in table 1. Water was used as a working fluid, there properties are shown in Table .2. and figure. 2 . flowchart to explain the details of the selected approach.

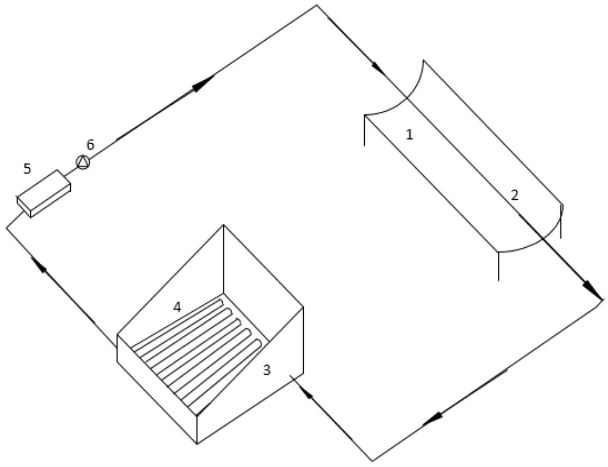

Figure 1. Sketch shown modified system, 1 parabolic trough collector, 2 receiver tube, 3 single solar still, 4 fluid serpentines, 5 fluid tank, 6 pumps.

Table 1. Real dimensions of the parabolic trough collector & single solar still

Parameter	**Value**
Aperture width for parabolic trough collector	80 [cm]
Trough length	140 [cm]
Aperture area	1.12 [m^2]
Concentration ratio	13.091[-]
Inner diameter of receiver tube	16 [mm]
Outer diameter of receiver tube	19 [mm]
Width of single solar still	38 [cm]
Length of single solar still	61[cm]
Rim angle	90°

Table 2. Properties of fluid (water) at 20°C

Properties	**Value**
Specific heat (C_P)	4182 J/kg.°C
Thermal conductivity(K)	0.6W/m.K
Density(ρ)	998.3kg/m^3
Prandtl (P_r)	7

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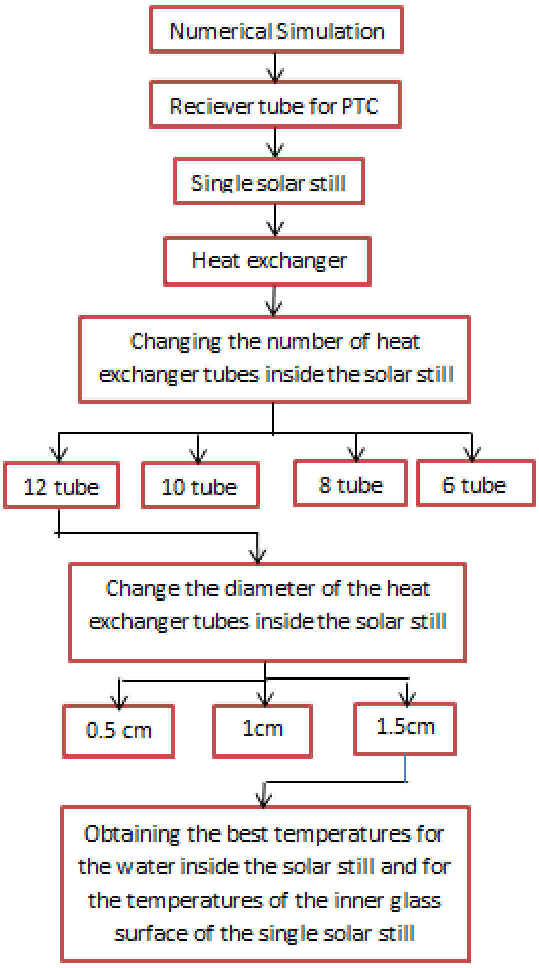

Figure 2. flowchart of the selected approach to work

2.2. Mesh implementation

A close-up of the mesh resolution of the parabolic trough collector with a single solar still is presented in figure 3. In the second stage of the COMSOL numerical simulation, a3-D mesh type has been created for this simulation. The mesh quality immediately influences the simulation result. Therefore ,a number of networks are examined to find accurate solutions. This grid is improved near the walls with heat exchanger pipes and salt water. The mesh type was uniform over the water pipe domain but near solar still walls where the network mesh was extremely big (see figure. 3).

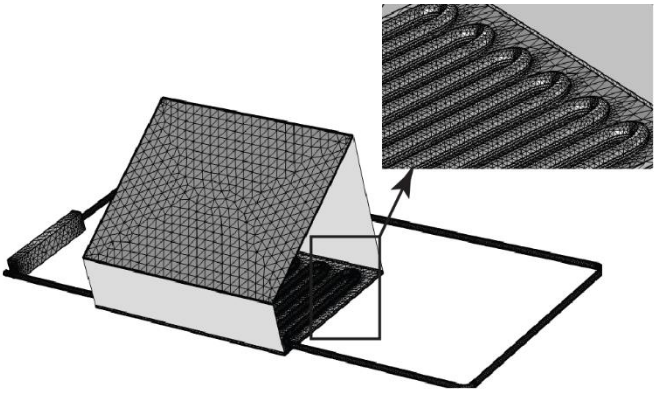

Figure 3. Mesh distribution in the system with different numbers of elements.

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III. MATHEMATICAL MODEL

The model consists of the following sets of equations Continuity, three dimensional flow unsteady[19].

$$\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}+\frac{\partial \rho w}{\partial z}+\frac{\partial \rho}{\partial t}=0 \qquad (1)$$

where u flow velocity in x direction (m/s), v flow velocity in y direction (m/s), w flow velocity in z direction (m/s), and ρ the density of steam (kg/m^3).

The Momentum Equations of water flow in three dimensional unsteady as flowing:

In x-direction[20]

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial \rho}{\partial x}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \qquad (2)$$

In y-direction

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial \rho}{\partial y}+v\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \qquad (3)$$

In z-direction

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial \rho}{\partial z}+v\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \qquad (4)$$

The energy equation for the water flow in three dimensional unsteady as flowing:

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right) \qquad (5)$$

where P the pressure of water flow and α the thermal diffusivity.

Initial & Boundary Conditions

Initial Conditions (I.C)

At time t = 0

$$u(x, y, z, 0)=v(x, y, z, 0)=w(x, y, z, 0)=0$$

$$P(x, y, z, 0)=0$$

$$T(x, y, z, 0)=22.8°C$$

Boundary Conditions (B.C):

Concentration tube.

The wall of concentration tube, has from one halve of tube to concentration solar irradiation as following: -

$$Q_b = G \times C.R. \times \alpha \tag{6}$$

while the other halve of concentration tube subjected to convection to ambient as following equation:

$$Q_{out} = h_{out}\left(T_{tube} - T_{amb}\right) \tag{7}$$

$$h_{out} = 5.7 + 3.8V_{out} \tag{8}$$

where Q_b and Q_{out} are the rate of heat transfer to the receiver tube and the ambient, G is the solar irradiation (W/m^2), $C.R.$ is a concentration ratio, T_{tube} and T_{amb} are temperatures of receiver tube and ambient (°C), V_{out} is wind speed (m/s) and h_{out} is the convective heat transfer coefficient (W/m^2.°C).

Water domine of solar still

Heat absorbed by water

$$R_w = G \times \tau_w \times A_b \tag{9}$$

Evaporation from water surface

$$Q_{ew} = h_{ew}\left(T_{wb} - T_{gi}\right) \tag{10}$$

Heat convection from water surface

$$Q_{wc} = h_{cwb}\left(T_{wb} - T_i\right) \tag{11}$$

Heat radiation from water surface

$$Q_{wr} = h_{rw}\left(T_{wb} - T_{gi}\right) \tag{12}$$

where R_w and Q_{ew} are the rate of heat absorbed and evaporated from water (W/m^2), Q_{wc} and Q_{wr} are the rate of heat transfer from water surface by convection and radiation (W/m^2), G is the solar irradiation (W/m^2), h_{ew}, h_{cwb} and h_{rw} are Evaporative, convective and radiative heat transfer coefficients from the water surface (W/m^2.°C), T_{wb} and T_{gi} are temperatures of water surface and inner glass (°C).

Trough domine of solar still

Heat absorbed by trough

$$R_T = G \times \tau_t \times A_b \tag{13}$$

Heat loss to ambient by convection

$$Q_{tha} = \left(\frac{k_{ins}}{t_{ins}}\right)\left(T_b - T_{amb}\right) \tag{14}$$

Glass domine of solar still

Heat absorbed by glass

$$R_g = G \times \tau_g \times A_g \tag{15}$$

Condensation in inner glass.

$$Q_{cdha} = h_{ew}\left(T_{wb} - T_{gi}\right) \tag{16}$$

Heat convection between inner glass and moisture air

$$Q_{cha} = h_{cwb}\left(T_i - T_{gi}\right) \tag{17}$$

Heat radiation between inner glass and water surface.

$$Q_{rw} = h_{rw}\left(T_{wb} - T_{gi}\right) \tag{18}$$

Heat convection between outer glass surface and ambient

$$Q_{cc} = h_{cga}\left(T_{go} - T_{amb}\right) \tag{19}$$

Heat radiation between outer glass surface and ambient

$$Q_{rgs} = 0.9 \times \sigma \times A_g\left(T_{go}^4 - T_{sky}^4\right) \tag{20}$$

$$T_{sky} = 0.0552 \times T_{amb} \tag{21}$$

where R_g and Q_{cdha} are the rate of heat absorbed and condensate by glass (W/m^2), Q_{cha} and Q_{rw} are the rate of heat transfer from inner glass surface by convection and radiation (W/m^2), Q_{cc} and Q_{rgs} are the rate of heat transfer from outer glass surface by convection and radiation (W/m^2), T_{go} and T_{sky} are temperatures of outer glass surface and sky (℃).

The boundary condition for fluid flow in the closed loop system using pump to circulation the water between the concentration tube of parabolic trough collector and the coil tube inside the solar still as shown in fig.1. Where the governing equation used for pump in the system as following:

$$\left[\rho u.n\right]_-^+ = 0 \tag{22}$$

$$\left[\rho - n^T\ kn + \rho\left(u.n\right)^2\right]_-^+ = \Delta p_{pc} \tag{23}$$

$$\Delta p_{pc} = f\left(P_{np}, V_{o,pd}\right) \tag{24}$$

where u is velocity field, n is normal component of flow field P_{np} is static pressure of pump as function of the volumetric flow rate pump, $V_{o,pd}$ is water flow rate, P_{pc} is pressure difference between inlet and outlet of pump.

In our study have been implemented the following values; $P_{np} = 100\ Pa$ and $V_{o,pd} = 2.01 \times 10^{-7}\ m^3/s$.

IV. RESULTS AND DISCUSSION

To validate the COMSOL simulation model the same real boundary conditions were implemented in previous work [21]. The temperature at the water surface during four periods of the day has been compared. The validation is presented in figure 4. It can be comprehended that the COMSOL simulation results are in agreement with the experimentally measured results [21]. The relative main errors were 4%. Therefore, the simulation model can be employed to analyse the impacts of different parameters.

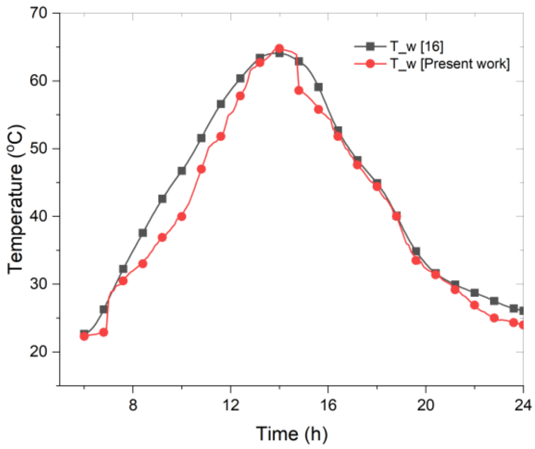

Figure 4. Comparison of COMSOL simulation water temperature with real experimental test [21].

A numerical study was carried out in two stages. The first stage is the change in the number of tubes inside the solar still. So 6,8,10, and 12 tubes were tested. The second stage changes the diameter of the pipes inside the solar still. All these stages were performed in a simulation program COMSOL5.4 to obtain the best design between them.

The experimental data for the weather conditions has been chosen based on a clear sky day. Figure 5 gives the variation values of solar irradiance and the ambient temperature on 2/18/2021 in the city of Najaf / Iraq.. It was found through the results that solar radiation begins to increase from the time of the appearance of the sun's rays until it reaches its highest value at 1:00 pm and then begins to decrease due to the decrease in the sun's rays. We note that the ambient temperature begins to rise even after the decrease in solar radiation, because the earth stores heat and emits heat after the decrease in radiation, which leads to a rise in ambient temperatures. The real ambient temperature is also presented in the same behaviour as shown in figure 5.

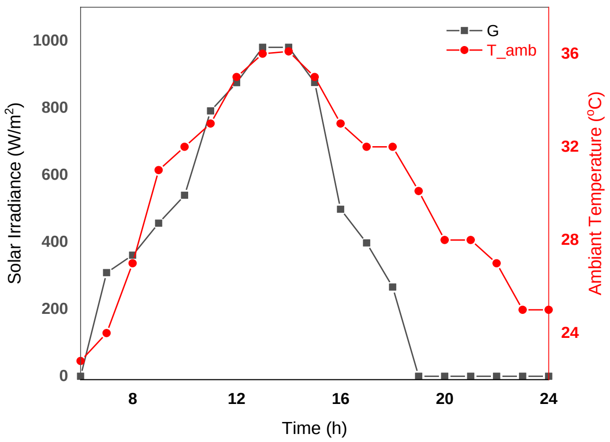

Figure 5. Hourly variations of solar irradiance and ambient temperature are implemented on the COMSOL simulation

In the first stage, when the number of tubes was increased, the tubes were tested at 6, 8, 10 and 12. It was found through the results that as the number of tubes increased, the temperatures of the water inside the single solar still increased, because the increase in the number of tubes increased the passage of hot water inside the heat exchanger that comes from the receiver tube of the PTC. The temperature of the inner glass cover also increases due to the increase in temperatures inside the single solar still. The highest temperatures of the liquids (water) and the inner glass surface of the single solar still were obtained when the number of tubes was 12 at 1:07 p.m., as shown in the figure. 6 A and B.

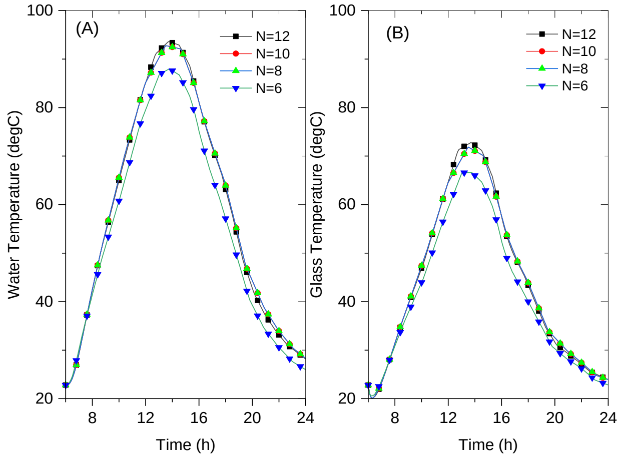

Figure 6. (A)Variations in water temperature inside the solar still .(B) Variations in the surface temperature of the inner glass of the solar still ,When changing the number of heat exchanger tubes.

In the second stage, when the diameter of the tubes for the heat exchanger inside the solar still was increased to a diameter of 0.5 cm, 1 cm, and 1.5 cm, it was found through the results that when the diameter of the pipes was increased to 1.5 cm, the temperatures of the water inside the single solar still increased because the increase in the diameter of the pipes increased the space for passage of hot water inside the heat exchanger that comes from the receiving tube of the PTC. The temperature of the inner glass cover also increases due to the increase in temperatures inside the single solar still. So, the larger the diameter of the tube, the better the average water temperature at 1:07 p.m., and the highest average temperature of the inner glass surface at 1:06 p.m. as shown in figure 7. (A and B).

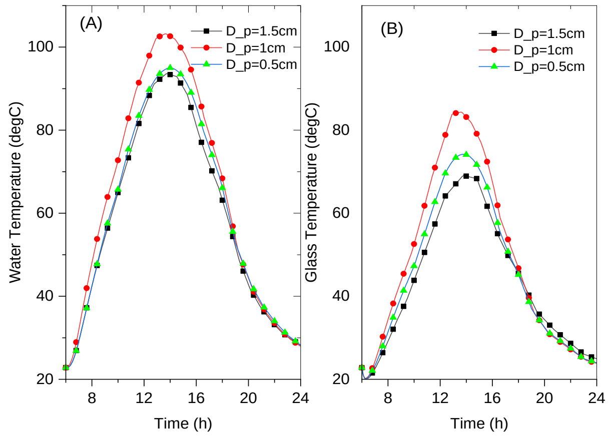

Figure 7. (A)Variations in water temperature inside the solar still (B) Variations in the surface temperature of the inner glass of the solar still, when changing the Daimeter of heat exchanger tubes.

Single slope still combined with PTC from morning (at 6 AM) was simulated over 24 hours. The results show that at 2:00 p.m. we will get the highest water temperatures inside the solar still and on the glass surface of the solar still due to the high solar radiation. Figure 8. shows the external surface temperature distribution on the

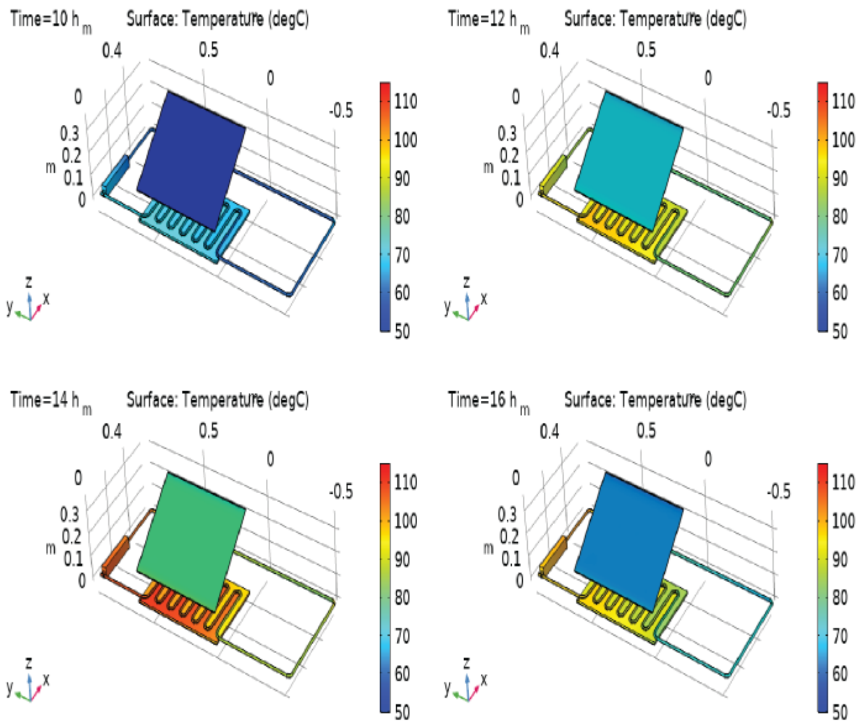

Figure 8. Temperature distribution of the system between the solar still and the receiving tube of the parabolic trough complex at 10 AM, 12 PM, 2 PM and 4 PM

V. CONCLUSION

A simulation was made by COMSOL 5.4 for a model of a parabolic trough collector with a solar still. In this work, the influence of the number of tubes entering the solar still and the diameter of these tubes were investigated under the weather conditions of Al-Najaf City-Iraq (32° 1' N/44° 19' E). From the current simulation, the following conclusions have been made:

The greater the number of heat exchanger tubes, the higher the temperature. As the highest number of heat exchanger tubes were used is 12 tube, the best results were obtained for the design inside the simgle solar still , where the highest water temperature inside the solar still reached 93.597ºC. The inner glass of the solar surface was 72.791 °C at 1:07 pm. It was concluded that the greater the diameter of the heat exchanger tube, the higher the temperature of the water inside the solar still, as well as the temperature of the glass surface of the solar still. When simulating, the largest diameter used is 1.5 cm. The highest temperatures of water are obtained at 99.93 ° C at 1:07 pm and the inner ceiling of the sun is still 79.991 ° C at 1:06 pm.

Recommendation

1. Changing the thickness of the water inside the single solar still .
2. Increase and decrease the flow rate of water to observe the change in temperature
3. Simulation of the effect of wind speed on the work of the solar still and to note the change in the increase or decrease in the productivity of distilled water.

Abbreviations

Symbol	Description
PTC	Parabolic trough collector
MCRT	Monte Carlo ray tracing method
HTF	Heat transfer fluid
FVM	Finite volume method
TSS	Tecnalogy solar still

Nomenclature

Symbol	Definition	unit
Q_b _ Q_{out}	rate of heat transfer to the receiver tube and the ambient	W/m^2
G	solar irradiation	W/m^2
$C.R.$	concentration ratio	
T_{tube} T_{amb}	temperatures of receiver tube and ambient	^oC
V_{out}	wind speed	m/s
h_{out}	convective heat transfer coefficient	$W/m^2.^oC$
R_w Q_{ew}	rate of heat absorbed and evaporated from water	W/m^2
Q_{wc} Q_{wr}	rate of heat transfer from water surface by convection and radiation	W/m^2
h_{cwb} h_{rw}	Evaporative, convective and radiative heat transfer coefficients	$W/m^2.^oC$
T_{wb} T_{gi}	temperatures of water surface and inner glass	^oC
R_g Q_{cdha}	rate of heat absorbed and condensate by glass	W/m^2
Q_{cha} Q_{rw}	rate of heat transfer from inner glass surface by convection and radiation	W/m^2
Q_{cc} Q_{rgs}	rate of heat transfer from outer glass surface by convection and radiation	W/m^2
T_{go} T_{sky}	temperatures of outer glass surface and sky	^oC
u	velocity field	m/s
P_{np}	static pressure of pump as function of the volumetric flow rate pump	
$V_{o,pd}$	water flow rate	
P_{pc}	pressure difference between inlet and outlet of pump.	

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