Frontiers in Heat and Mass Transfer (FHMT), 17, 22 (2021)
DOI: 10.5098/hmt.17.22

Global Digital Central
ISSN: 2151-8629

Frontiers in Heat and Mass Transfer

Available at www.ThermalFluidsCentral.org

NUMERICALLY INVESTIGATING THE EFFECTS OF FEED WATER PREHEATING TANK DESIGN ON THE PERFORMANCE OF SINGLE SLOPE SOLAR STILL

Zahraa A. Faisal*, Hassanain Ghani Hameed, Dhafer Manea H. Al-Shamkhee

Engineering Technical College Al-Najaf, Al-Furat Al-Awsat Technical University, Al-Najaf, 54001 Iraq

ABSTRACT

One of the common water desalination apparatuses in freshwater regimes is Single Slope Solar Still (SSSS). This paper numerically investigated the heat transfer processes that took place inside the still. Also, implementing an optimization process to explore the best sustainable feed water preheating tank design. Comsol Software package (v 5.4) was utilized to develop and validate the 3D Mathematical model. The investigation included comparing four different tank designs namely are sphere, half-sphere, cone, and flat plate. In addition, the influence of altering the volume of the tank has been considered. The study revealed that the half-sphere design with a volume of 2.5 times the productivity of Conventional SSSS accompanied the highest recorded water temperature and productivity. The efficiency of the SSSS was enhanced by 27% in contrast to that without preheating.

Keywords: *Single slope solar still, Solar energy, Comsol, Preheating,*

1. INTRODUCTION

In recent years there are global fears from the increased pollution of the freshwater sources on earth (Kabeel *et al.*, 2019). As the worldwide population is growing year by year the demand for fresh water is increasing. This demand is mainly influenced not only by population growth but also climate change, energy security policies urbanization, and various human activities. It has been predicted that around 50% of the global population on earth might suffer from water insufficiency by the year 2030 (The United Nations, 2020). Several international humanitarian agencies have focused on elevating water conservation awareness through the implementation and regulation of water policies, such agencies the United Nation Development Program (UNDP), World Water Council (WWC), World Health Organization (WHO), etc. (Joshi and Tiwari, 2018). This highlights that access to freshwater is a serious problem.

One such approach to overcome such crises of water is adopting solar distillation that has been widely considered as a potential water production technique. The concept of Solar still as a cheap and easy freshwater production method was established in the 16 century (Al-Shamkhee and Abed, 2016). Several researchers have demonstrated the capabilities of Single slope solar still (SSSS) as a solar energy harnessing device (Kabeel, Omara and Essa, 2014; Hammed, Ahmed H. Ali and Dulaimi, 2018; Nazari, Safarzadeh and Bahiraei, 2019; Manoj Kumar *et al.*, 2021).

Nevertheless, in SSSS incident solar radiation elevates the temperature of basin water generating water vapor. The produced vapor shall be elevated by nature and condensate on the inner surface of the inclined glass cover producing freshwater that will be collected on a predesigned lower channel (Abd Elbar and Hassan, 2020). However, the disadvantage of such a system is the low daily production rate. The production rate is directly related to the temperature difference between the basin water and the condensation surface (glass cover). Many Scientists have explored theoretically and experimentally these processes and demonstrated various methods to enhance the production rate of SSSS. Preheating basin water is one of the common and less expensive methods to increase water temperature and temperature difference simultaneously.

Bani-Hani et al. 2017 experimentally inspected the significance of indirect heating of feed brackish water on the daily yield of SSSS (Bani-Hani *et al.*, 2017). They have proposed an oil heat exchanger system preheating a saline water storage tank, also they have applied an airflow to the glass cover to widening the temperature difference between Glass and basin water. Their studies illustrated an improvement of daily yield up to 3%, 5%, and 10% as the system coupled with a cooling fan, oil-based preheating, and both, respectively.

An immersed heat exchanger in the basin water was proposed to enhance the daily production rate. Al-Harahsheh et al. 2018 explored this technique besides adding phase change material (PCM) and glass cover cooling (Al-harahsheh *et al.*, 2018). The immersed heat exchanger used to circulate preheated water that is thermally treated in an external solar collector. Their experimental result revealed a noticeable improvement in the daily yield of SSSS as integrated with both PCM and Solar collector. They indicated that the production rate is a function of circulation flow rate since it influences the thermal exchange between circulated and basin water. The best-recorded productivity was 4.3 L/day /m^2. Sathyamurthy et al. 2014 examined the implication of adding PCM on the daily output of the solar still. theier study highlited an increment of 35% as result of adding PCM only, where recored productivity was 4.5L/m^{2}day and 3.5L/m^{2}day for with and without PCM..

Jaafar et al. (2020) considered the integration of SSSS with flat plate solar collector and iron wick material to improve the daily productivity of SSSS (Jaafar, Hameed and Hussein, 2020). Their experimental studies exhibited an improvement of about 48% as the solar collector heating preheating feed water, whereas the integration of wick material furtherly boosted the daily yield up to 86.65%. Similarly, Abu-Arabi et al. 2020 theoretically inspected the implication of a flat plate solar collector as a

* Corresponding author. Email: zahraa.abbas@student.atu.edu.iq

basin water feed water preheater (Abu-Arabi *et al.*, 2020). Their results indicated that the daily productivity of the proposed design was 5000 ml/day, while the production rate of a conventional SSSS was 2500 ml /day for 1 m^2 of the basin area. Sathyamurthy et al. 2017 presented a comprehensive review study on various solar collectors integrating with Solar still. Depending on the published literature, there was not optimal feed water preheating tank design.

In the present study, a 3D model is developed to predict average water temperatures and daily productivity of SSSS. Comsol Software package 5.5 was utilized to build this model. Besides investigating various preheating tank designs and applying an optimization process to define the optimal design/material depending on the climatic conditions, parameters and solar radiation intensities of Al-Najaf city in Iraq (32° 1' 38.55" N / 44° 19'59.22" E).

2. NUMERICAL ANALYSIS

The studied single slope solar still consists of an insulated Polystyrene box with a trapezoid side creating an enclosure with an inclined glass top cover and a black painted flat galvanized plate. A side cross-section view of the investigated still as well as the thermal energy balance is provided in figure 1.

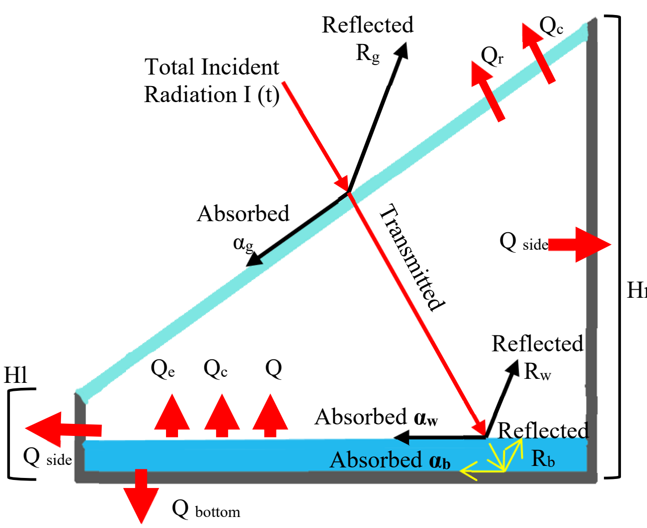


Fig. 1 The fractions of incident radiation

Before thermal analysis of the studied case, it is vital to have a comprehensive understanding of the mass and heat transfer that take place inside the still enclosure. The incident solar radiation on the glass cover is partially absorbed and partially reflected, while the remained radiation transmitted through the glass to the still enclosure. Similarly, phenomena can be observed as the penetrated rays interact with the basin water. The transmitted radiation through the water shall reach the black painted plate inducing similar reactions. However, the absorbed energy by the lower plate is partially transferred to the sides and lower surfaces of the enclosure through conduction, while the remained amount of energy is conducted to the basin water. The basin water is evaporated as a result of this conduction as well as the absorption of the incident radiation. The generated vapor shall elevate then interact with the lower surface of the glass cover. The induced energy by the evaporation process is partially transferred to the glass cover. However, Comsol Software analysis, in this case, is governed by Navier stokes equations. These equations represent Energy, Mass, Momentum conservation equations. The energy conservation equation is valid for solid surfaces (glass cover and basin plate), water and moist air, while Mass, Momentum conservation equations are valid for water and moist air regimes. Also, the concentration equation is valid for moist air. These equations can be presented as follows (Kalogirou, 2005; Torchia-Núñez, Cervantes-de-Gortari and Porta-Gándara, 2014; Faisal and Hameed, 2021, COMSOL, 2021):

Energy Conservation Equation

$$\rho C_P \frac{\partial T}{\partial t} + \rho C_P u.\nabla Tc = \nabla.(k\nabla T) + Q \tag{1}$$

Mass Conservation Equation (Continouity Equation)

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho u) = 0 \tag{2}$$

Momentum Conservation Equations (The Navair Stokes equation).

$$\rho\left(\frac{\partial u}{\partial t} + u.\nabla u\right) = -\nabla P + \nabla.\left(\mu(\nabla u + (\nabla u)^T)\right) + F \tag{3}$$

Concentration Equation

$$\frac{\partial c}{\partial t} + \nabla cu = D_{ab}(\nabla^2 c) \tag{4}$$

The hourly productivity (Ph) of pure water can be calculated as:

$$Ph = \frac{(-3600 \times Dab)}{L}\int_0^x \frac{dc}{dy}|water\ dx \tag{5}$$

And the daily productivity (Pd) can be obtained from the following:

$$Pd = \sum_{24} hr\ Ph \tag{6}$$

The daily efficiency of the solar still can be obtained from the following equation:

$$\eta_d = \frac{Pd\ Lw,av}{(Ap\sum I)\Delta t} \times 100\% \tag{7}$$

Dab: is Mass diffusivity of vapor.

$\frac{dc}{dy}$: is the variation of vapor concentration as a function of particles position along the y-axis.

Lw,av : the latent heat average value required to evaporate the water during an entire day.

Δt is a time interval to measure the period of solar radiation.

Furthermore, mathematical representation of each part of SSSS can be presented as indicated in the following sections (Kalogirou, 2005; Torchia-Núñez, Cervantes-de-Gortari and Porta-Gándara, 2014; Faisal and Hameed, 2021):

2.1 Glass Cover

The top glass cover represents the aperture of solar still where solar radiation is permeation through to activate the desalination process. Also, it shall keep the maximum possible amount of heat within the enclosure. Nevertheless, the energy balance equation of glass cover can be summarized as follows:

$$m_g\, c_p\left(\frac{dT_g}{dt}\right) = A_g \acute{\alpha}_g I + A_w h_{wg}(T_w - T_g) - A_g h_{rgs}(T_g - T_s) - A_g h_{cga}(T_g - T_a) \tag{83}$$

Where:-

$$\acute{\alpha}_g = (1 - R_g)\alpha_g \tag{4}$$

$$h_{wg} = h_{rwg} + h_{cwg} + h_{ewg} \tag{10}$$

DOI: 10.5098/hmt.17.22
ISSN: 2151-8629

The h_{wg} is the summation radiation (h_{rwg}), convection (h_{cwg}) heat coefficient, and evaporation heat coefficient (h_{ewg}) between water and glass. These governing energy equations are as follows:

$$h_{rwg} = \frac{\varepsilon_{eff}\sigma(T_w^4 - T_g^4)}{T_w - T_g} \quad (5)$$

$$\varepsilon_{eff} = \frac{1}{\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1} \quad (6)$$

Whereas, the convection heat coefficient is defined as

$$h_{cwg} = 0.884[T_w - T_g + \frac{(P_w - P_g)T_w}{268900 - P_w}]^{\frac{1}{3}} \quad (13)$$

$$P_w = exp\left[25.317 - \frac{5144}{T_w}\right] \quad (14)$$

$$P_g = exp\left[25.317 - \frac{5144}{T_g}\right] \quad (75)$$

While coefficient of water evaporation is given by

$$h_{ewg} = 0.016273 h_{cw}\frac{P_w - P_g}{T_w - T_g} \quad (86)$$

The coefficients of convection and radiation from glass to ambient is expressed as:

$$h_{rgs} = \frac{\varepsilon_g\sigma(T_g^4 - T_{sky}^4)}{T_g - T_a} \quad (97)$$

$$h_{cga} = 2.8 + 3V \qquad if\ V \leq 5 \quad (1810)$$

$$h_{cga} = 2.8 + 3.8V \qquad if\ V > 5 \quad (1911)$$

$$T_{sky} = 0.0552\, T_a^{1.5} \quad (2012)$$

2.2 Basin Water Thermal Balance Equation

The energy balance equation of basin water is almost the same as that of the glass cover and as follows:

$$m_w C_{pw}\left(\frac{dT_w}{dt}\right) = A_w \acute{\alpha}_w I + A_w h_{cbw}(T_b - T_w) - A_w h_{wg}(T_w - T_g) - A_w U_{ins,w}(T_w - T_a) \quad (131)$$

$$\acute{\alpha}_w = (1 - R_g)(1 - \alpha_g)(1 - R_w)\alpha_w \quad (142)$$

2.3 Absorber plate thermal balance equation

The exchange of energy between plate and basin water is expressed as follows:

$$m_b c_{pb}\left(\frac{dT_b}{dt}\right) = A_b \acute{\alpha}_b I - A_b h_{cwb}(T_b - T_w) - A_b U_{ins,w}(T_b - T_a) \quad (153)$$

$$\acute{\alpha}_b = (1 - R_g)(1 - \alpha_g)(1 - R_w)(1 - \alpha_w)(1 - R_b)\alpha_b \quad (164)$$

2.4 Preheating tank thermal balance equation

$$m_{tank}\, c_p\left(\frac{dT_{tank}}{dt}\right) = A_{tank}\alpha_{tank} I - A_{tank} h_{rt_s}(T_{tank} - T_s) - A_{tank} h_{ct_a}(T_{tank} - T_a) \quad (25)$$

3. COMSOL MODELING

The Mathematical model of the case study has been developed with the aid of the Comsol Multiphysics software package. The generated model is presented in figure 2. Certain assumptions must be adopted before investigating the constructed model. These assumptions determine the physics and boundary conditions surround single slope solar still, also such assumptions may simplify the solution. The considered assumption and boundary conditions of the present study are as follows:

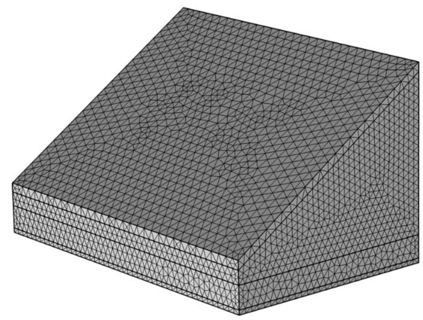


Fig. 2 Graphical representation of the developed 3D model

1. The generated model is 3D SSSS.
2. The considered heat transfer from glass and tank surfaces was convection and radiation to the surrounding boundary.
3. The flow inside the still is assumed to be laminar.
4. The influence of the condensed water film on the solar radiation that penetrates the still has been neglected.
5. Air velocity inside the still cavity is to be negligible.
6. The pipe connecting preheating tank and Solar still is insulated.
7. The base of the preheating tank is insulated.
8. There is not any leakage from the system either vapor or water
9. Evaporation and condensation rates are of equal values.
10. The level of water in the basin is constant.

Moreover, The Comsol solver utilizes the above-mentioned equations to predict the daily yield and thermal behavior of the solar still in this study. Furthermore, those equation requires set of parameters to be solvable by Comsol. The operation parameters utilized in this work are presented in table 1.

Table 1. The adopted operation parameters

Parameter	Value	Parameter	Value
Right height (Hr)	40 cm	α_b	0.9
Left height (Hl)	9 cm	α_w	0.05
Basin Length	78 cm	ε_g	0.88
Basin width	50 cm	ε_w	0.96
Glass thickness	4 mm	R_g	0.05
Lower plate thickness	2 mm	R_w	0.05
Water level	1 cm	R_b	0
Insulation Thickness	5 cm	k_{ins}	0.03
Basin area	0.39 m^2	σ	5.669x10-8
Inclined angle (Based on Al-Najaf Latitude)	32.1°	L_{ev}	2454[kJ/kg]
		ρ_{water}	1000[kg/m^3]
α_g	0.05		

Furthermore, the adopted thermal parameters in this numerical investigation were as of the climatic conditions of the summer season in Al-Najaf city – Iraq on 15/7/2020. The time-dependent ambient temperatures, solar radiation, and wind speed of Al-Najaf City on the specified date are as shown in figures 3 &4. These graphs have been created based on the collected data by a Davis weather station installed at Technical Engineering College\ AL-Najaf.

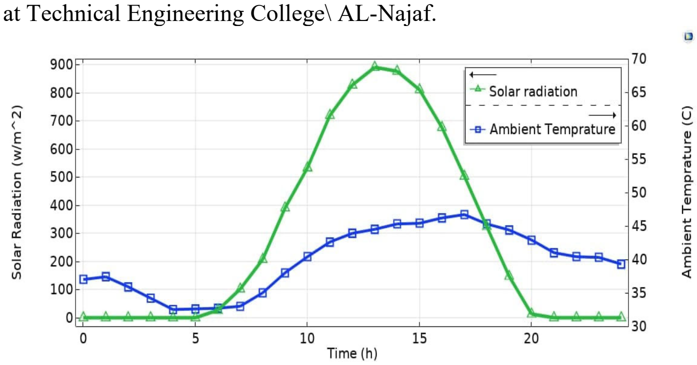


Fig. 3 Hourly solar radiation intensities and ambient temperatures of Al-Najaf (15/7/2020)

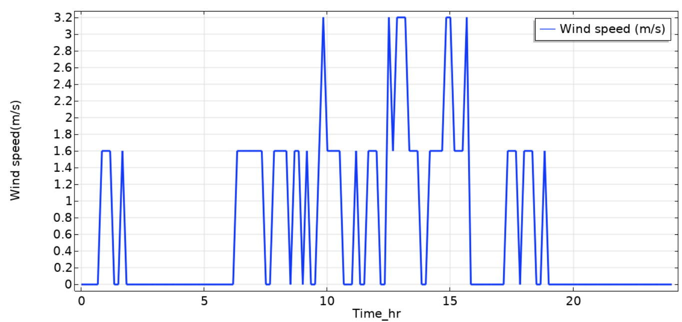


Fig. 4 Hourly wind speed velocities of Al-Najaf (15/7/2020)

4. MODEL VALIDATION

The developed 3D model has been validated compared to the experimental work reported by Elango et al. (2015) to decide whether the presented model is mathematically viable and can predict with a low margin of error the temperature of the basin water (Elango, Kannan and Kalidasa Murugavel, 2015). To implement this step, the operation and climate parameters reported by Elango et al. (2015) were collected to conduct Comsol simulation. Hence, the gained water temperatures and cumulative daily productivity resulted from the simulation are compared to those reported by Elango et al. The hourly recorded basin water temperature comparison is presented in figure 5, while the cumulative hourly productivity of the still is compared in figure 6.

The overall error percentage is estimated as not exceeding 4% and 6% for productivity and basin water temperature respectively.

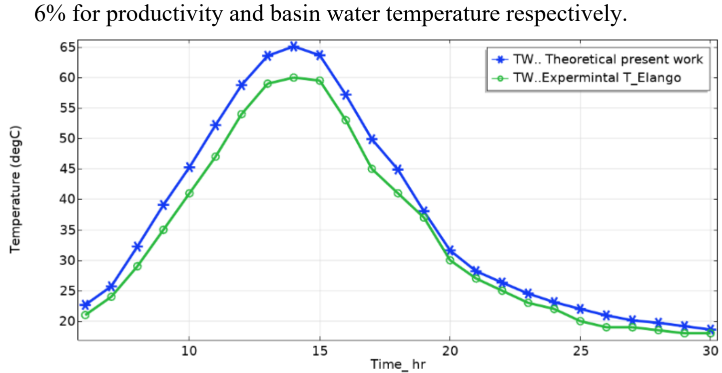


Fig. 5 Model validation through comparing hourly water temperatures

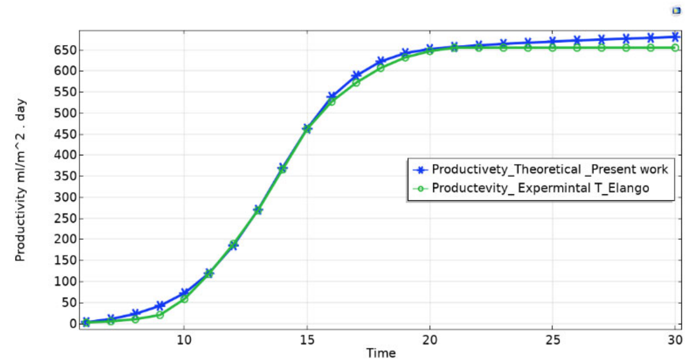


Fig. 6 Model validation based on cumulative daily productivity

5. PREHEATING TANKS

The current study explored various designs of preheating storage tanks and their respective influence on the daily productivity as well as the overall glass, basin water, and basin plate temperatures. The considered designs were namely sphere, half sphere, cone, flat plate storage tank. These specific tank shapes were chosen for their respective simple design and ease of fabrication The investigated volume of these tanks was 2.5 times the total daily amount of the produced water by a conventional solar still this to reconsider later. This is to cover the required daily feeding of water to the basin. Figure 7 shows the considered designs of preheating storage tanks. Also, different material has been considered as the shell material of the tanks including glass, steel, aluminum, and cast iron.

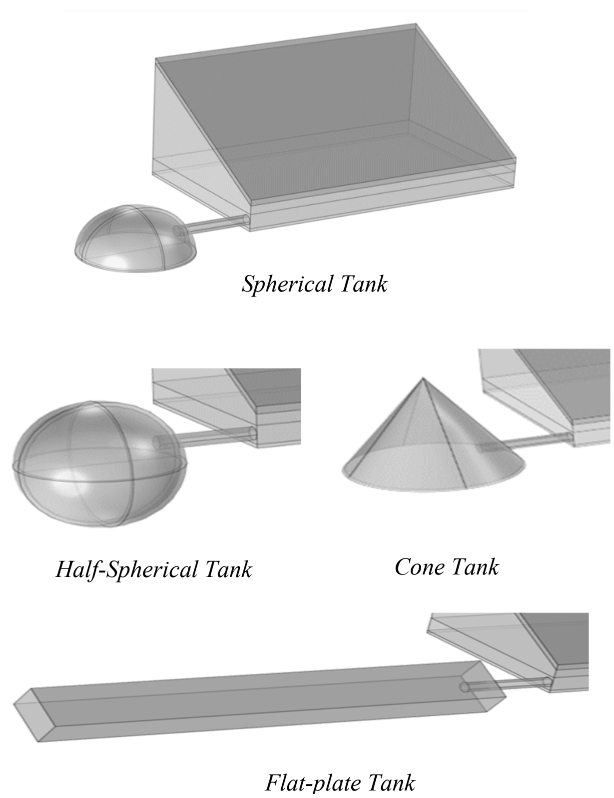


Fig. 7 The Examined preheating tank designs

6. RESULTS AND DISCUSSION

The result of the various studied models and configurations in this investigation are presented and discussed in this section. The water depth in the basin is widely considered as one of the highly important factors that directly influence the daily yield of solar stills in general. Thus before digging deep into the details of the design considerations, the daily yield dependency of CSS on the water depth has been conducted. The estimated results are provided in figure 8.

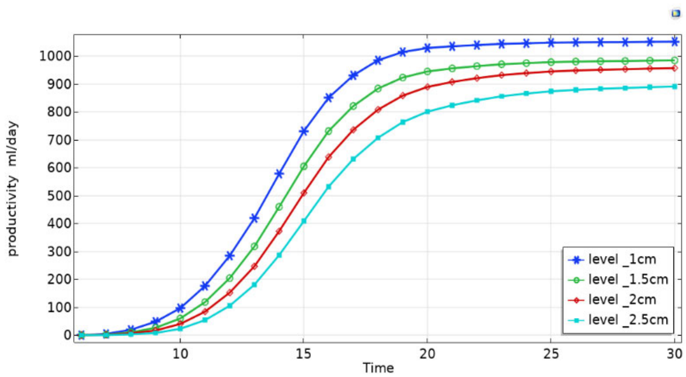


Fig. 8 Cumulative water productivity as a function of basin water level

It can be seen that as the water depth increases the collected or produced amount of water is reduced. The best-collected amount of water was reported as the water depth keep to 1 cm, which quite sounds with the reported experimental literature. This can be argued to the reduction in thermal capacity of water as the level is reduced.

The study involved examining several tank shell materials to decide the most appropriate one. The simulations have shown that Aluminum (AL) among other tested materials has the best potential since integrating CSS with a tank fabricated from (AL) produced a higher quantity of water as shown in figure 9. The noticeable differences can be attributed to the variation in thermal conductivity of these materials, where AL has the higher thermal conductivity among the others.

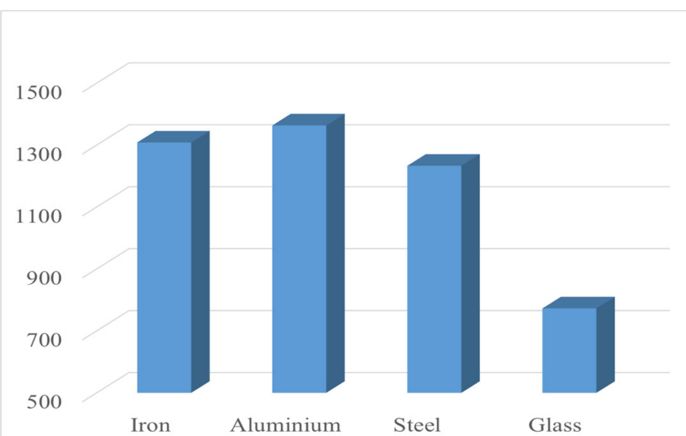


Fig. 9 The cumulative daily productivity as a function of preheating tank material as of half-sphere design

Nevertheless, having decided the material of the tank, numerical simulations can be conducted to explore the impact of adopting certain designs of integrated preheating feed tanks. Figure 10 summarizes the gained cumulative daily productivity of these configurations as well as the CSS. These graphical results demonstrated that the half-spherical sort of tanks has the potential to boost the daily productivity of CSS up to 27%. These results were estimated as the volume of the tanks was set to 2.5 times the amount of the produced water by CSS.

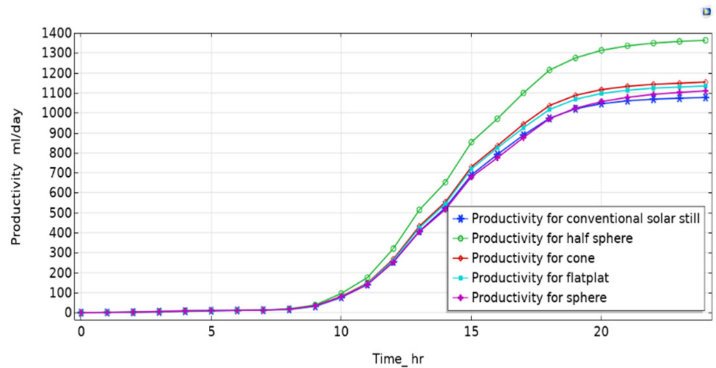


Fig. 10 Daily productivity of various the preheating tank designs

Furthermore, the volume of the tank might be one of the factors influencing the cumulative daily yield of Single slope solar still. Hence, the authors explore different volumes proportional to the daily productivity of CSS as 1.5, 2, 2.5, 3 times the produced amount of water (v). It can be seen in figure 11 that the best volume of half-sphere tanks is 2.5v in contrast to other volumes. This can be attributed to the thermal capacity of water which is directly proportional to the volume of water inside the preheating tank. Where a bigger water volume can be a heat sink that requires a longer solar irradiation period to elevate its temperature, while a smaller volume can easily lose thermal energy to the surrounding. Table 2 illustrated the daily cumulative water productivity of the different investigated configurations.

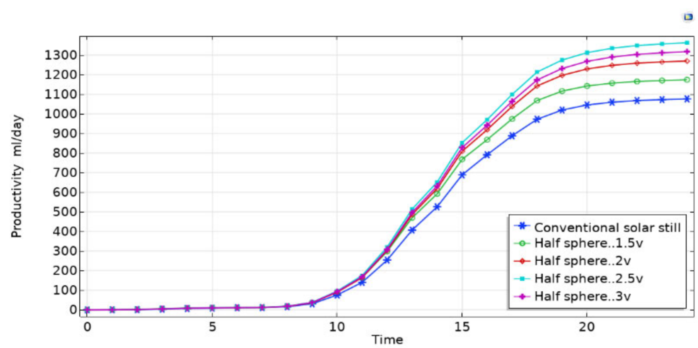
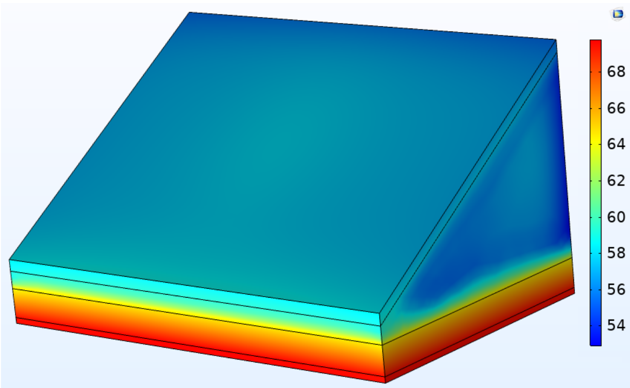


Fig. 11 Compression of daily productivity based on the preheating tank size (volume)

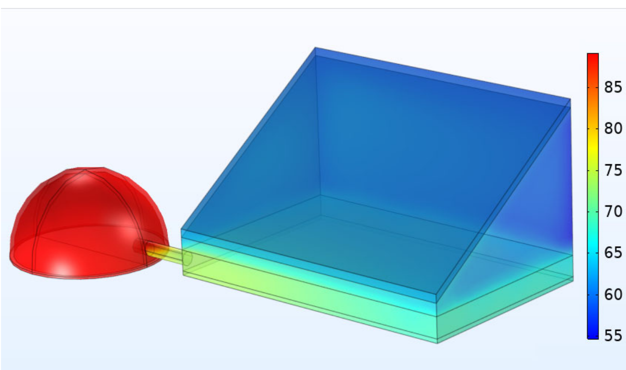
Table 2. the estimated daily productivity of various experiment of this work

Tank design	Daily productivity ml/.day	The volume of half sphere	Daily productivity ml/.day
Half sphere	1363.391	1.5v	1174.625
Cone	1153.947	2v	1270.247
Flat plate	1134.248	2.5v	1363.391
Sphere	1109.739	3v	1318.182
CSS	1076.814	**(v) is the volume of produced water from CSS**	
Note: these values for a cross-section area of 0.39 m^2			

Figure 12 demonstrates the temperatures distribution on the different surfaces of the CSS and preheated solar still. The integration of a half-sphere feed tank with the still has boosted the temperature of still layers where the temperature ranges between (55-68 °C) and (54-90°C) of CSS and preheated solar still, respectively. A closer look into the surface of the water in both cases to examine surfaces temperatures can provide better proof of the potentials of preheating technique. It has been noticed that the half-sphere tank has the highest temperature about 85 thus influencing and increasing the lowest temperature of the integrated still. Alternatively, the highest temperature in the case of CSS was observed as basin water temperature which is remained low due to the fed water reduced the water temperature upon entry.



CSS



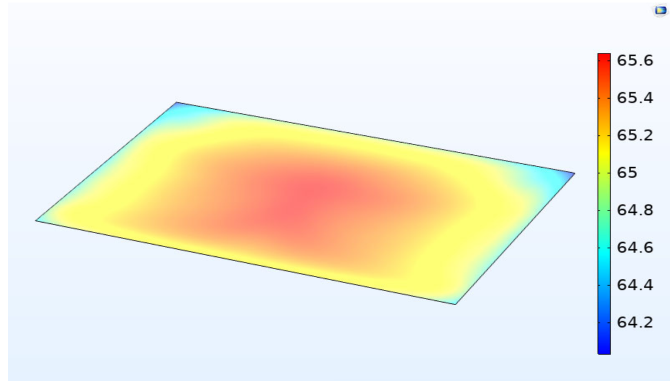
Improved SSSS

Fig. 12 Temperatures distribution through the layers of CSS and improved one

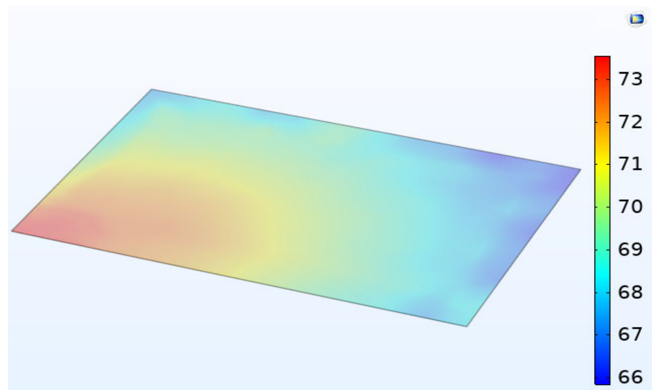
Figure 13 shows temperatures across the water surface of CSS and preheated type. The result showed a noticeable increase in the water surface temperature up to 7 °C higher if CSS is integrated with a preheating tank. It seems that the water temperature in the case of preheating is higher on the left corner than on the right, which can be argued to the point where the feeding took place. Although the produced amount of water has been increased, where the estimated cumulative daily productivity of single slope solar still integrated with half-sphere preheating tank is 1363.391 ml/.day for the basin area of 0.39 m^2.

Moreover, based on the basin water temperatures gained from the implemented Comsol analysis the comparison can be summarized as shown in figure14. Once again, half-sphere sort of tanks showed better-enhancing capabilities in contrast to other sorts of preheating tank designs in terms of water temperature as illustrated in figure 13.

The presented result revealed that the cumulative daily productivity of CSS has increased as it integrated with a half-sphere (AL) preheating tank. Thus the optimization process showed an efficiency enhancement of 27% as integrating CSS with the Preheating tank. Where the daily yield of CSS is 1076.814 ml/.day in contrast to the daily yield of 2.5 v half-sphere (AL) preheating tank that is 1363.391 ml/.day. Eventually, the optimal preheating tank design was the half-sphere (AL) preheating



CSS



Improved SSSS

Fig. 13 Comparison of Water surface temperatures between CSS and improved one

tank having a volume of 2.5 times the volume of the produced amount of water from CSS.

The non-uniform pressure distribution of moist air within the investigated solar stills is illustrated in figure 15. The results revealed that the vapor pressure increases in the upstream flow direction. Simultaneously, the averages of vapor pressure within the improved solar still are higher than that with CSS at the same instant.

Stream velocities of the moist air within the CSS and The improved solar still are illustrated in figure 16. The overall stream velocities increase with the addition of preheating technique in contrast to the CSS. Nevertheless, the concentration of water vapor influenced by the increase

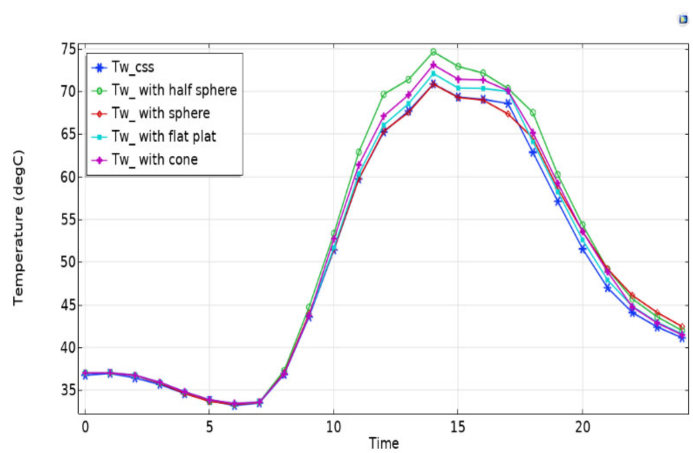
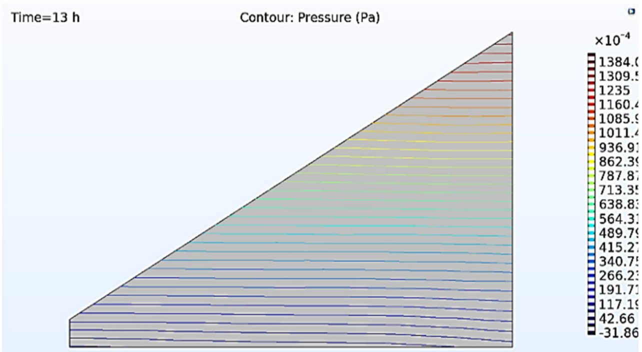


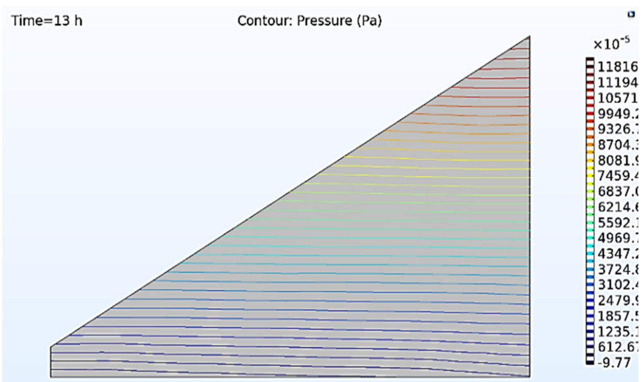
Fig. 14 The Hourly recorded water surface temperatures of the proposed designs

DOI: 10.5098/hmt.17.22
ISSN: 2151-8629

of inner temperature as illustrated in figure 17. Where the presence of preheating tank shifted up the concentration averages. Simultaneously, the influence of the preheating tank altered the distribution of stram lines based on the feeding port position.



a) Water vapor Pressure distribution within the CSS



b) Water vapor Pressure distribution within the Improved SSSS

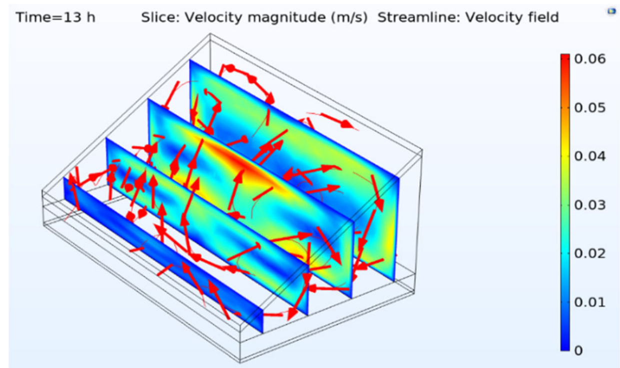
Fig. 15 Water vapor Pressure distriputoin within the CSS and the improved solar still

3. CONCLUSION

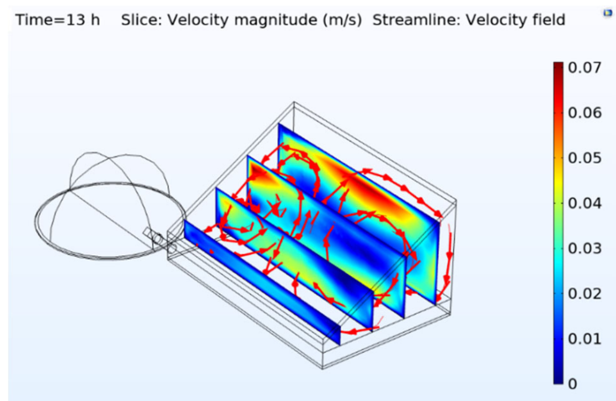
In conclusion, a mathematical model of single slope solar still has been developed and validated against experimental results from the literature. The performance of the developed model was studied and evaluated for the weather conditions of Al-Najaf City / Iraq. The daily productivity of CSS was enhanced by integrating it with a preheating tank. An optimization process has been implemented to indicate the best preheating tank design. Where several tank materials and volumes, as well as shapes, have been considered. The optimal preheating tanks were found as half-sphere preheating tank having a volume of (2.5v). The best material for fabrication among the considered materials has been estimated as Aluminum for its average thermal conductivity and the simulation results. It can be said that integrating CSS with a preheating tank has high potentials to elevate the average water temperature and increasing the temperature difference between water and glass. Thus the average evaporation and condensation rates, which directly related to daily productivity. Where the optimized result showed an efficiency enhancement of 27% and a daily yield of 1363.391 ml/.day for basin area of 0.39 m^2 as CSS integrated with the optimized tank.

NOMENCLATURE

A	Area
F	External force
Cp	Heat capacity at constant pressure.



a) Stream velocities of water vapor within the CSS



b) Stream velocities of water vapor within the Improved SSSS

Fig. 16 Stream velocities of water vapor within the CSS and the improved solar still

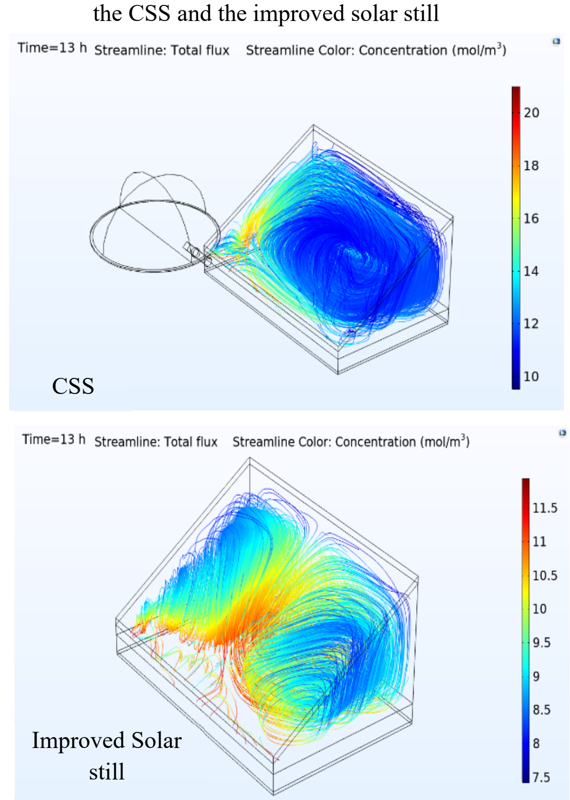


Fig. 17 The Concentration of water vapor

I	Solar radiation
m	Mass
P	Pressure
Ph	Hurly productivity
T	Temperature
t	Time
u	Velocity field
K	Thermal conductivity
h_{wg}	HTC between water and glass cover
h_{rgs}	Radiation HTC between glass cover and sky
h_{cga}	Convection HTC between glass cover and Ambient
h_{cbw}	Conduction HTC between basin plate and water
h_{rwg}	Radiation HTC between water surface and glass cover
h_{ewg}	Evaporative HTC from water to glass cover
hcwg	Convection HTC between water and glass cover
Tsky	Sky temperature
Q	Heat sources

Greek Symbols

α	Absorbency
ε	Emissivity
η	Efficiency
ρ	Density
σ	Stefan-Boltizmann's constant
R	Reflectivity
μ	Dynamic viscosity

Superscripts

a	Ambient
b	Basin
c	Convection
d	Daily
e	Evaporation
g	Glass
Ins	Insulation

Abbreviations

CSS	Convention Single Slope Solar Still
HTC	Heat transfer coefficient
SSSS	Single slope single basin solar still

REFERENCES

Abd Elbar, A. R. and Hassan, H. 2020 "An experimental work on the performance of new integration of photovoltaic panel with solar still in semi-arid climate conditions," *Renewable Energy*, 146, pp. 1429–1443. http://dx.doi.org/10.1016/j.renene.2019.07.069.

Abu-Arabi, M. *et al.* 2020 "Theoretical modeling of a glass-cooled solar still incorporating PCM and coupled to flat plate solar collector," *Journal of Energy Storage*, 29(March), p. 101372. http://dx.doi.org/10.1016/j.est.2020.101372.

Al-harahsheh, M., Abu-Arabi, M., Mpousa, H., and Alzghoul, Z., 2018 "Solar desalination using solar still enhanced by external solar collector and PCM," *Applied Thermal Engineering*, 128, pp. 1030–1040. http://dx.doi.org/10.1016/j.applthermaleng.2017.09.073.

Al-Shamkhee, D. M. H. and Abed, Q. A. 2016 "Theoretical study the effect of insulation of water basin on the productivity of tubular solar still," *5th International conference on thermal equipment, renewable energy and rural development.*, (October), pp. 29–34.

Bani-Hani, E. *et al.* 2017 "Experimental Analysis of an Improved Solar Still System with Cooling Fan and Preheating Oil," *Energy Engineering: Journal of the Association of Energy Engineering*, 114(5), pp. 55–71. http://dx.doi.org/10.1080/01998595.2017.11882309.

COMSOL Multiphysics, 2021. *Fluid Flow: Conservation of Momentum, Mass, and Energy*. [online] Comsol.com. Available at: <https://www.comsol.com/multiphysics/fluid-flow-conservation-of-momentum-mass-and-energy?parent=fluid-flow-heat-transfer-and-mass-transport-> [Accessed 12 August 2021].

Elango, T., Kannan, A. and Kalidasa Murugavel, K. 2015 "Performance study on single basin single slope solar still with different water nanofluids," *Desalination*, 360, pp. 45–51. http://dx.doi.org/10.1016/j.desal.2015.01.004.

Faisal, Z. A. and Hameed, H. G. 2021 "Solar Still Productivity Improvement Techniques and Recent Advancements: Review Study," *Al-Furat Journal of Innovations in Mechanical and Sustainable Energy Engineering (FJIMSE)*, 2(February).

Hammed, G. H., Ahmed H. Ali and Dulaimi, Z. 2018 "Experimental Investigation of the Enhancement Parameters on Experimental Investigation of the Enhancement Parameters on the Performance of Single-Slope," (September), pp. 3–10. http://dx.doi.org/10.21172/1.103.24

Jaafar, Z. A., Hameed, H. G. and Hussein, R. H. 2020 "Experimental Investigation of a Single Slope Solar Still Performance- Evaporation Process Enhancement," *IOP Conference Series: Materials Science and Engineering*, 928(2). http://dx.doi.org/10.1088/1757-899X/928/2/022096.

Joshi, P. and Tiwari, G. N. 2018 "Effect of cooling condensing cover on the performance of N-identical photovoltaic thermal-compound parabolic concentrator active solar still: a comparative study," *International Journal of Energy and Environmental Engineering*, 9(4), pp. 473–498. http://dx.doi.org/10.1007/s40095-018-0276-6.

Kabeel, A. E. *et al.* 2019 "A review on different design modifications employed in inclined solar still for enhancing the productivity," *Journal of Solar Energy Engineering, Transactions of the ASME*, 141(3). http://dx.doi.org/10.1115/1.4041547.

Kabeel, A. E., Omara, Z. M. and Essa, F. A. 2014 "Enhancement of modified solar still integrated with external condenser using nanofluids: An experimental approach," *Energy Conversion and Management*, 78, pp. 493–498. http://dx.doi.org/10.1016/j.enconman.2013.11.013.

Kalogirou, S. A. 2005 "Seawater desalination using renewable energy sources," *Progress in Energy and Combustion Science*, 31(3), pp. 242–281. http://dx.doi.org/10.1016/j.pecs.2005.03.001.

Manoj Kumar, P. *et al.* 2021 "Investigating a single slope solar still with a nano-phase change material," *Materials Today: Proceedings*. http://dx.doi.org/10.1016/j.matpr.2020.12.804.

Nazari, S., Safarzadeh, H. and Bahiraei, M. 2019 "Performance improvement of a single slope solar still by employing thermoelectric cooling channel and copper oxide nanofluid: An experimental study," *Journal of Cleaner Production*, 208, pp. 1041–1052. http://dx.doi.org/10.1016/j.jclepro.2018.10.194.

Sathyamurthy, R., Nagarajan, P.K., Kennady, H.J., Ravikumar, T.S., Paulson, V., and Ahsan, A., 2014 "Enhancing the heat transfer of triangular pyramid solar still using phase change material as storage material," *Frontiers in Heat and Mass Transfer (FHMT),* 5(3). http://dx.doi.org/10.5098/hmt.5.3

Sathyamurthy, R. *et al.* 2017, "A Review of integrating solar collectors to solar still," *Renewable and Sustainable Energy Reviews*, 77, pp. 1069–1097.
http://dx.doi.org/10.1016/j.rser.2016.11.223.

The United Nations, U. 2020 *The United Nations world water development report 2019: leaving no one behind, executive summary - UNESCO Digital Library*. Available at: https://unesdoc.unesco.org/ark:/48223/pf0000367303 (Accessed: 24 December 2020).

Torchia-Núñez, J. C., Cervantes-de-Gortari, J. and Porta-Gándara, M. A. 2014 "Thermodynamics of a Shallow Solar Still," *Energy and Power Engineering*, 06(09), pp. 246–265.
http://dx.doi.org/10.4236/epe.2014.69022.