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Enhancing the daily yield of single-slope solar still using a preheating water tank

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تعزيز العائد اليومي من الطاقة الشمسية أحادية المنحدر باستخدام خزان مياه التسخين المسبق

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Abstract

Single slope solar still is one of the most popular water purifiers. This paper investigated heat transfer processes that occur inside the solar still numerically and experimentally In addition, attempts to improve productivity have been studied. Comsol Multiphysics software (v5.5) was used to develop a 3D mathematical model to examine the considered developments. Four different heating tank designs (sphere, half sphere, con, and rectangular) were compared as an optimization step. The studies have also considered the volume of the tank to choose to best one among the proposed volumes. The experimental study included the manufacturing of a water heating tank and its integration with a solar still. An improvement of (35%) was obtained when designing a halfsphere tank with a volume of 2.5 times that of a conventional solar still (CSS).

الخلاصة

لا تزال الطاقة الشمسية المنحدرة واحدة من أكثر أجهزة تنقية المياه شيوعًا. بحثت هذه الورقة في عمليات انتقال الحرارة التي تحدث داخل الشمس بشكل رقمي وتجريبي بالإضافة إلى دراسة محاولات تحسين الإنتاجية. تم استخدام برنامج Comsol Multiphysics (v5.5) لتطوير نموذج رياضي ثلاثي الأبعاد لفحص التطورات المدروسة. تمت مقارنة أربعة تصاميم مختلفة لخزان التسخين (كرة ، نصف كروي ، مخروطي ، ومستطيل) كخطوة تحسين. أخذت الدراسات أيضًا في الاعتبار حجم الخزان لاختيار الأفضل من بين الأحجام المقترحة. اشتملت الدراسة التجريبية على تصنيع خزان تسخين المياه وتكامله مع جهاز التقطير الشمسي. تم الحصول على تحسن بنسبة (35٪) عند تصميم خزان نصف كروي بحجم 2.5 مرة من جهاز التقطير الشمسي التقليدي (CSS).

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

الكلمات المفتاحية: وحدة التقطير الشمسي المنحدر الفردي ، الطاقة الشمسية ، *Comsol*، التسخين المسبق

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Introduction

Water is an essential element for all living creatures on the earth. Over time, fears of water scarcity have emerged due to population growth as well as various economic and human activities. The United Nations has published that 50% of the Earth's population may suffer from water shortage by 2030 [1]. Global efforts were directed to enhance the water conservation awareness of the communities [2], Several researchers focus on eliminating these fears through developing new purification devices or enhancing existing systems. Also, fossil fuel diminishing fears rising huge awareness and interest in reliable environmentally friendly sources [3], [4]. One of the environmentally friendly purification devices is a solar desalination system. Therefore, studies are currently directed to improving the productivity of the solar distillation device because it is a distillation device that does not consume energy and is economically suitable.

Deniz 2016 utilized a flat plate solar collector to pre-heat the water entering the solar still and got a 48% improvement in productivity [5]. A heat exchanger was used to heat the water and it was combined with the solar still [6]. Also, a fan was used to improve the performance of the solar still. An improvement percentage of 5% and 10% was obtained by using the heat exchanger only and by using the heat exchanger and the fan together, respectively. Al-Harahsheh et al. 2018 highlighted the significance of using a heat exchanger immersed in the basin water to improve productivity as well as adopting other techniques such as (PCM) and glass cover cooling as possible improvements [7]. The best productivity recorded was 4.3 l/m^2. Kabeel et al. 2019 considered the integration of a parabolic solar dish, and two parabolic solar dishes with a heat exchanger to elevate the daily yield of solar still in comparison to that of the conventional solar distiller [8]. The daily yield of solar still integrated with one parabolic solar dish and two of them was reported as 8.8 kg/m^2.day and 13.63 kg/m^2.day, respectively. This highlight a noticeable improvement compared to that of conventional one which was 1.85 kg/m^2.day.
Abu Arabi et al. 2020 theoretically studied the effect of water preheating by flat panel solar collectors on the daily yield of solar still [9]. It was found that the cumulative production is 5000 ml/m^2. day in the case of preheating the water, while the cumulative production of the conventional solar still (CSS) is 2500 ml/m^2/day.

In this study, a 3D model was built using Comsol Software package 5.5 to predict average water temperatures, and daily productivity, as well as examining several preheating tank designs to determine the optimal design. The weather condition of Al-Najaf City, Iraq was adopted in this investigation with the location of (32°1'38.55"N / 44°19'59.22"E). The work also experimentally investigated the proposed integration of preheating tank with the single slope solar still.

Numerical analysis

The investigated single slope solar module is designed as a box with a trapezoidal side view, the enclosure is made of insulated Polystyrene with glass covering the top side top the still, while a matt-black painted galvanized plate is placed at the bottom of the basin. A Side view of the single slope solar still is demonstrated in figure 1.

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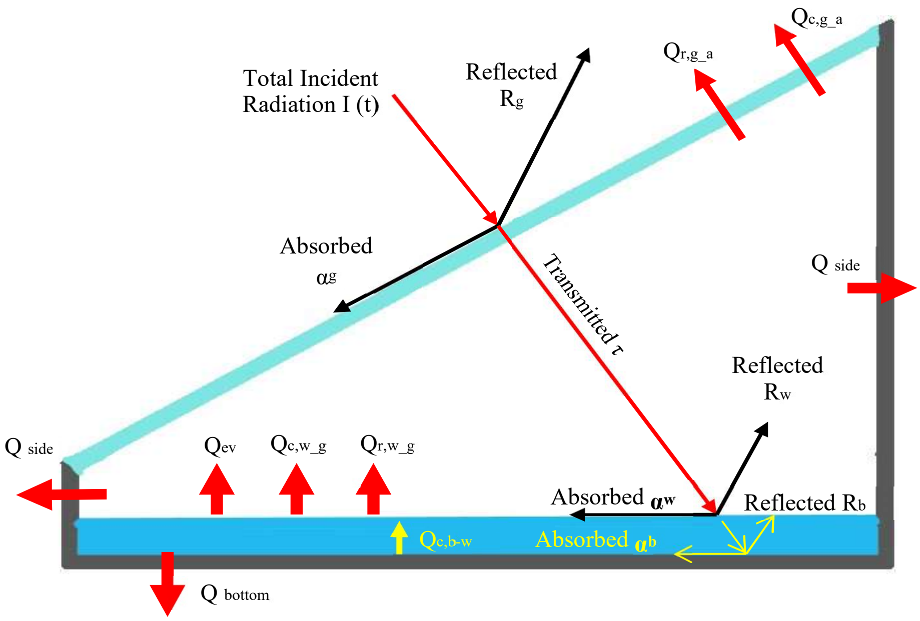

Figure 1. Energy distribution of the Single Slope Solar Still

Figure 1 also highlighted the energy distribution of the incident radiation/ energy across various layers as it penetrates the regimes of solar still. It is important to develop a comprehensive understanding of heat and mass through various regimes of solar still. The glass cover is exposed to direct sunray. However, the incident rays are divided due to various effects, where it is partially penetrating, partially reflected, and partially absorbed by the glass cover. The penetrated radiation shows a similar reaction once interacted with the surface of basin water. Also, the basin plate shall interact with the penetrated rays through the water, where the rays are either absorbed by the plate or reflected into the water but there will be no penetration of rays by nature. Part of the absorbed energy is transferred from the galvanized plate to the enclosure by convection and hence dissipated to the outside and can be considered as energy. While the reflected rays from the plate elevate the water temperature and help evaporates it through free convection. As water vapor is generated, it rises and collided with the inner surface of the glass cover. As a result of the temperature difference between the glass surfaces vapor condensates on the inner surface of the glass. Owing to the inclined angle of the glass cover the coordinated water shall slide towards the lower edge where a collecting channel directs the collected water to a vessel. In addition, as the vapor interacts with the glass cover energy losses may occur through the transfer of heat by convection and radiation to the outside environment.

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In this case, we use the Navier-Stoke (momentum conservation), the continuity, energy conservation, and concentration equations [10]–[12]:

Energy Conservation Equation

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

Mass Conservation Equation (Continuity Equation)

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

Momentum Conservation Equations (The Navair Stokes equation).

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

Concentration Equation

$$\frac{\partial c}{\partial t} + \nabla c u = Dab(\nabla^2 c) \quad (4)$$

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

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

An\d the daily productivity (Pd) can be obtained from the following:

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

Dab: is the Mass diffusivity of vapor.

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

Comsol modeling

The model was built using Comsol Multiphysics with the dimensions shown in Table 1. The created geometry of the solar still with generated mesh is shown in figure 2. The governing equation is solved for these nodes to predict the mathematical behavior of the solar still. However, certain assumptions must be taken into account to determine the boundary and physical conditions governing the system. Also, such assumption can simplify the analysis.

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Table 1. The adopted operation parameters

Parameter	Value	Parameter	Value
Right height (Hr)	40 cm	αb	0.9
Left height (Hl)	9 cm	αw	0.05
Basin Length	78 cm	εg	0.88
Basin width	50 cm	εw	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	kins	0.03
Basin area	0.39 m^2	σ	5.669x10-8
Inclined angle (Based on AlNajaf Latitude)	32.1°	L_{ev}	2454[kJ/kg]
		ρwater	1000[kg/m^3]
αg	0.05		

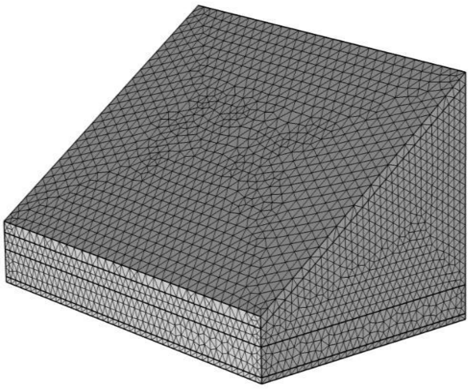

Figure. 2 Graphical representation of the developed 3D model The following assumptions were considered in this study:

1. The created model is 3D
2. Heat transfer from tank and glass surfaces was radiation and convection to the adjacent boundary.
3. The flow within the still is anticipated to be laminar.
4. The impact of the condensed water film on the solar radiation which enters the still was neglected.
5. Air velocity within the still enclosure was negligible.
6. The pipe link between the Solar still and the preheating tank is insulated.
7. The preheating tank base is insulated.

8. The system is not having any vapor or water leakage.
9. Condensation and evaporation rates are considered to be equal in value.
10. Water level is constant within the basin.

The weather condition of Al-Najaf city that has been considered was for the date of (1/5/2020), where radiation, temperature, and wind speed were measured to adopt in this investigation.

Preheating tanks

In the current study, several forms of pre-heating water tank designs were investigated to determine the optimal design. The studies considered the influence of tank design on preheating basin water and their effect on daily productivity and glass and water temperatures. The designs considered in this study were (sphere, half sphere, cone, and rectangle). The volume of the proposed tanks was considered to be double the volume of the produced amount of water by the conventional solar still in one day. This volume was reinvestigated after choosing the optimal design among the proposed tanks. The material of the tank was considered to be aluminum for several reasons, mainly relative high thermal conductivity, low price, and ease of forming. Figure (3) shows the studied designs for manufacturing aluminum tanks.

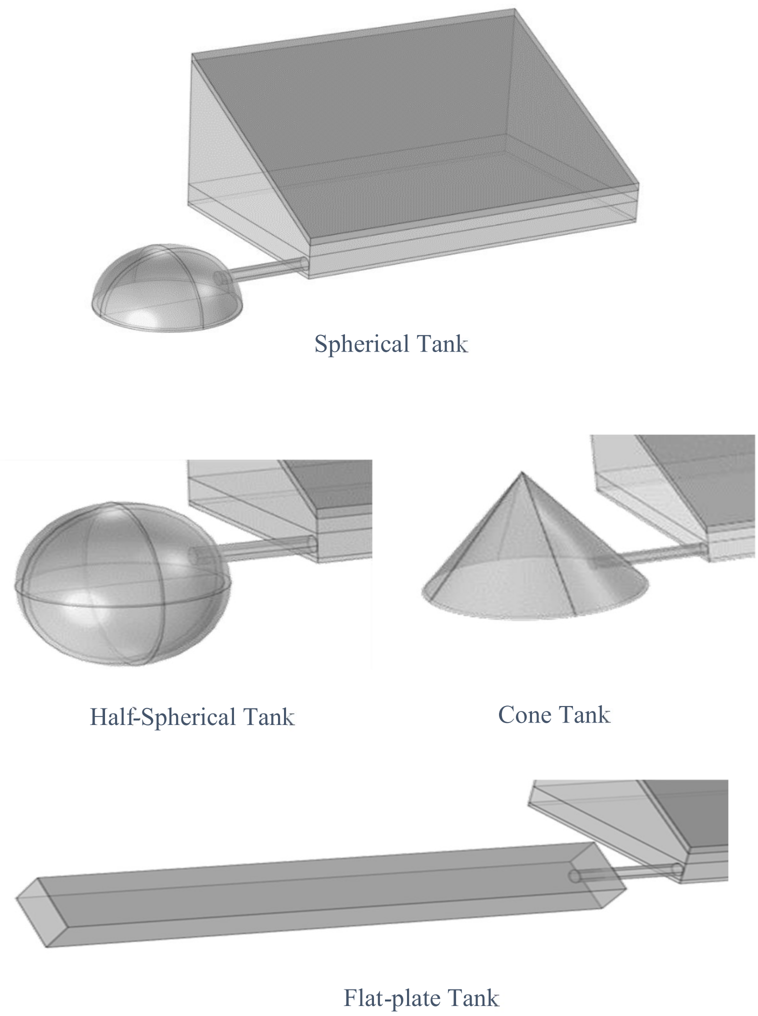

Fig. 3 The Examined preheating tank designs

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Experimental Set-up

The fabricated solar still was made by converting an insulated Polystyrene box into a trapezoidal shape from the side. Figure 4 shows the fabricated solar still with an inclined angle of 32.1˚ this is based on the Latitude of AL-Najaf City. Two solar still were designed similarly to each other in layout but one was conventional without any add-ons and the other integrated with a preheating tank. To prevent vapor leakage from the top side adhesive sealant were inserted between the inclined edges and the glass cover as shown in figure 5.

Figure Error! No text of specified style in document.The SSSS

Figure 5 Adhesive sealant rubber material

Moreover, the preheating tank was fabricated from aluminum as a half-sphere with the size of 2.5 the volume of the amount of produced water from conventional solar still (2.5v). This is based on the optimization process. Figure 6 provides a front view of the solar stills in action.

Modified Still CSS

Figure 6 Experimental Models

Experimental procedure

The first step of the operation is to feed water to the basin and maintain its level at 1 cm height above the absorber plate. To maintain the water level inverted bottle mechanism was adopted where water cannot be fed unless the water level retrieves below the feeding orifice that is located 1 cm above the base, it is a sort of auto-feeding mechanism. This mechanism works based on the difference in hydraulic pressure between a solar still and a feeding tank, where the air is needed in the tank to feed water. Hence penetrating air bubbles through the orifice shall reach the tank and the tank swap it with water feeding. The solar radiation rises the basin water temperature and thus evaporates water. As the evaporation process is initiated the water level is retrieved and the feeding process establish simultaneously. Also, the vapor moves toward the glass cover where it shall condensate, this process shall continue until something changes, such as night time, or runout of basin water.

Results and discussion

The theoretical investigation of the proposed tank shaped showed a noticeable results. This can be highlighted through examining the daily productivity and basin water temperatures. Figures 7 provides the basin water temperature measured hourly of solar still integration with various preheating tanks design and conventional solar still adopted in this analysis. Whereas, figure 8 illustrated the anticipated hourly productivity of each combination.

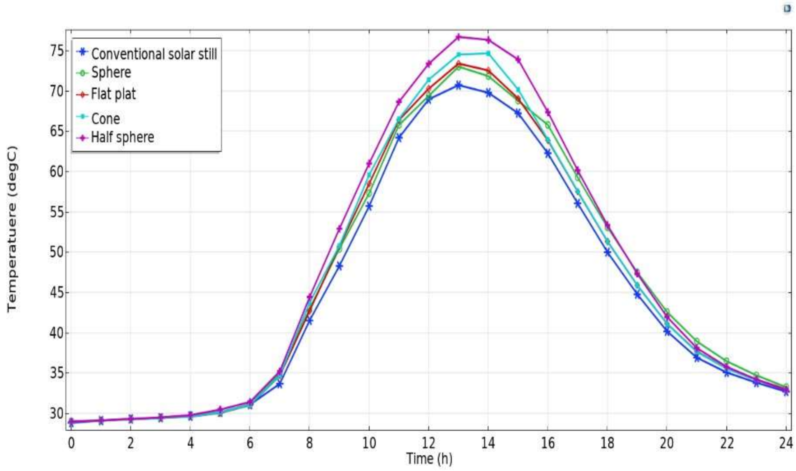

Figure 7. Hourly basin water temperature of CSS and SSSS integrated with Preheating Tank (1/5/2020)

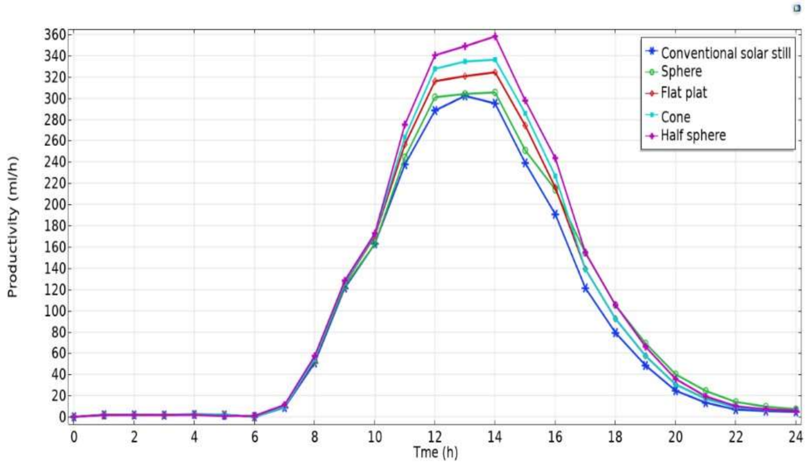

Figure 8 The hourly production rate of CSS and SSSS integrated with various preheating tanks (1/5/2020)

It can be seen that the integration of preheating tank enhanced the hourly yield of single slope solar still. Simultaneously, the design of the half-sphere tank has shown the best performance possible among the considered tank shapes. The cumulative production of the solar still with a half-sphere tank was recorded as 2.638 L/day, whereas, the CSS produces an amount of 2.2 L/day. This can be argued the surface exposure to the sun rays could be more in contrast to other shapes, also the surface contact between water and the surface exposed to rays is more as well.

The other consideration in the theoretical analysis is the volume of that half-sphere tank. The analysis considered 4 different volumes, which compared to the amount of produced water in the case of conventional solar still. The volumes are 1.5 v, 2 v, 2.5 v, and 3 v times the amount of produced water from conventional solar still. Figures 9, and 10 provides the predicted hourly basin water temperature and hourly yield of this case studies, respectively.

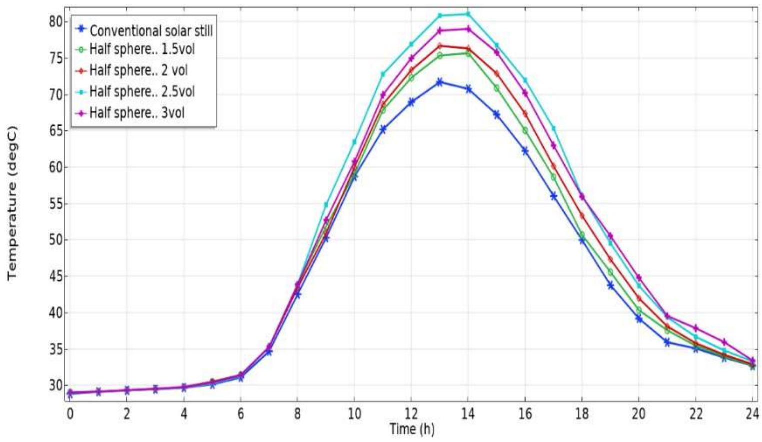

Figure Error! No text of specified style in document.**9.** Hourly basin water temperatures of CSS and SSSS integrated with half-sphere Preheating tanks of (1.5 vol, 2 vol, 2.5 vol, and 3 vol). (1/5/2020)

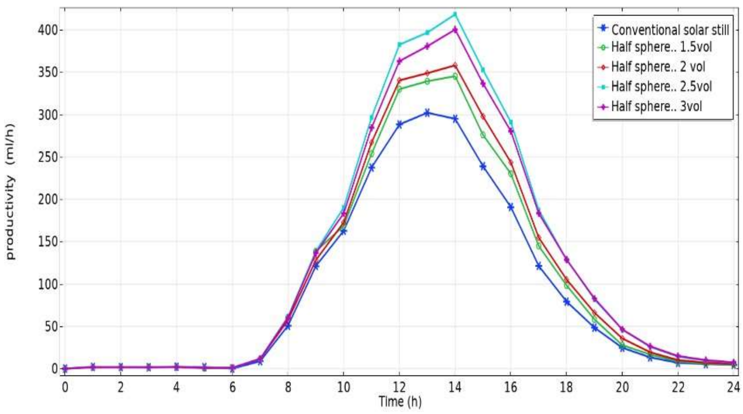

Figure 10. Hourly productivity of CSS and proposed CSS Integrated with preheating tank (1/5/2020)

The analysis results predicted that the half-sphere tank with the volume of 2.5 v once integrated with the conventional solar still produced the best daily yield among other volumes. Hence the study suggested this volume and shape as the potential one to fabricate among the others. Where the cumulative production was recorded as 3.05 L/day.

Moreover, the experimental were carried out at Al-Najaf City can be summarized and compared to those anticipated by the theoretical study. The hourly production rate of CSS and the integrated solar still with

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the preheating tanks (Improved-SSSS) is reported in figure 11. Figure 12 illustrated the temperature elevation of basin water due to integrated solar still with the 2.5 v half-sphere tank.

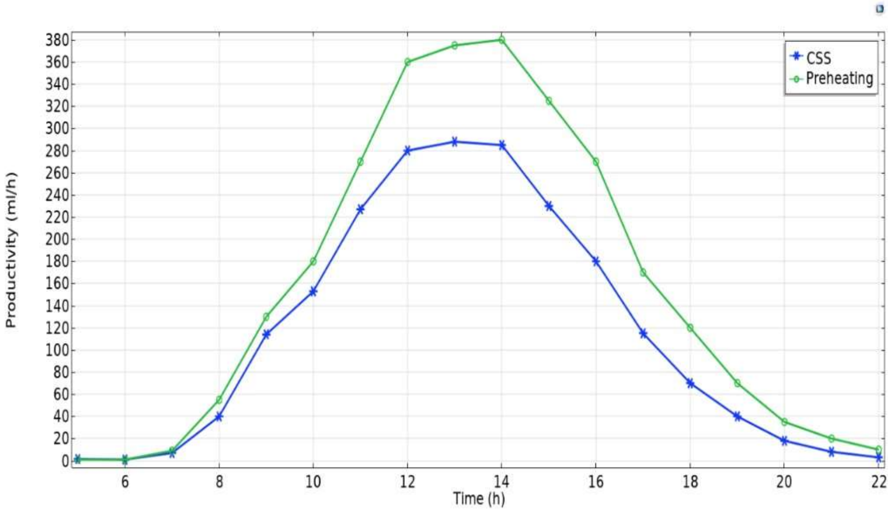

Figure 11. Hourly production rate of CSS and SSSS integrated with half-sphere Preheating tank (experimental) (4/5/2021)

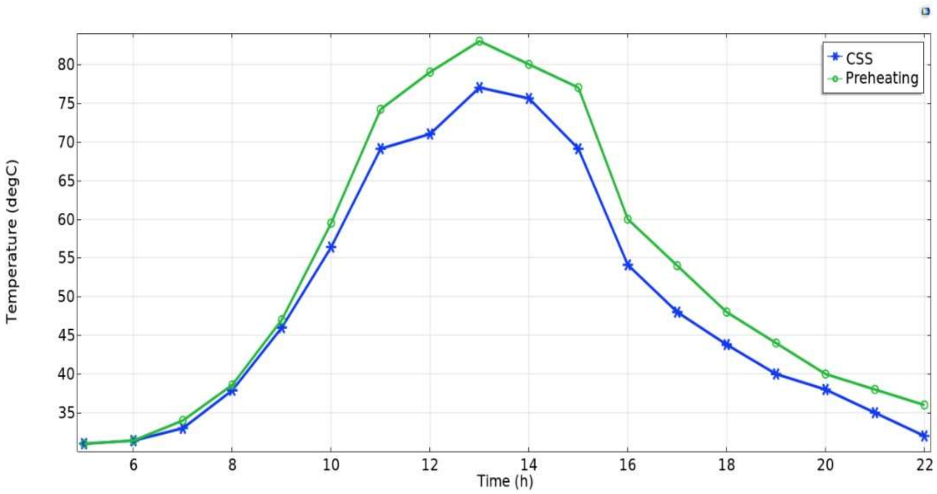

Figure 121. Basin water temperature variation with time of CSS and Improved SSSS(4/5/2021)

It can be seen that the addition of preheating tank has noticeably improved the daily yield of single slope solar still. Comparing the predicted result through Comsol analysis with the collected data from the conducted experiment have shown a remarkable agreement in the provided results. This can be demonstrated in figure 13. Whereas Figure 14 provides the solar and wind data which was utilized as an input data to gain the above predictions.

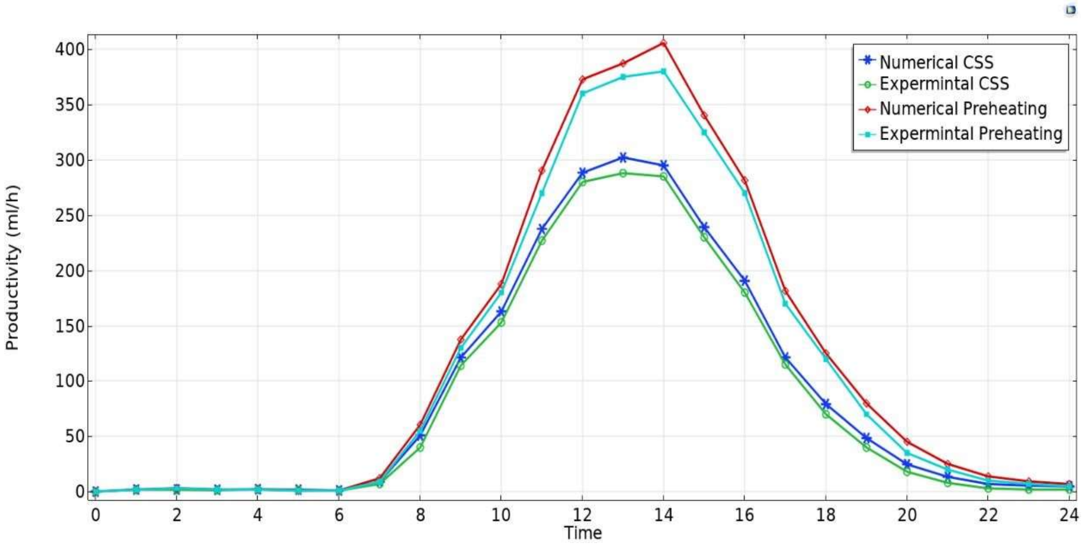

Figure 13. Comparison of numerical and experimental production rates for CSS and SSSS combined with preheating tank (4/5/2021)

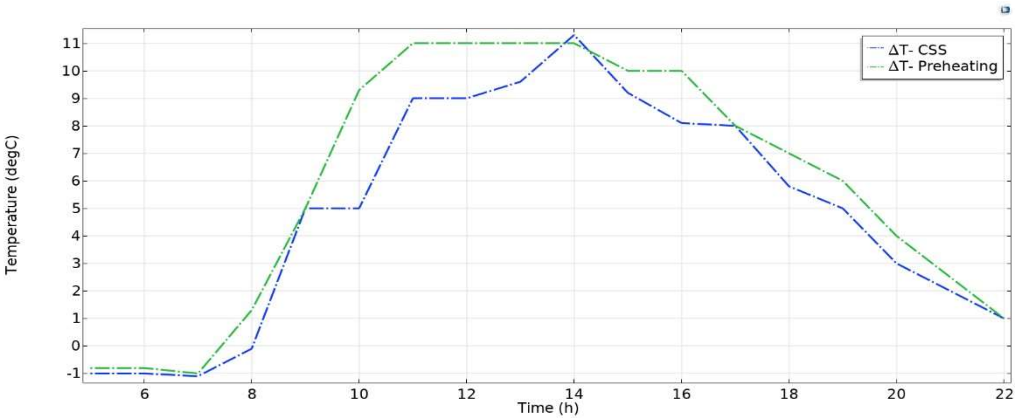

Figure14. Comparison of ΔT (between glass cover and basin water temperature) for CSS and SSSS integrated with Preheating (4/5/2021)

Conclusion

It can be concluded that the present work included the development of a Mathematical model with the aid of Comsol Multiphysics. This was utilized to evaluate and predict the daily yield of single slope solar still and proposed modifications. The results show that the performance of CSS can be enhance by integrating it with a preheating tank of any shape. The optimal shape was found to be the half-sphere type. Whereas the optimal volume is to be 2.5 times the anticipated produced amount by a CSS. Experimentally integrating the proposed 2.5 v half-sphere AL preheating tank with SSSS has shown similar results to those predicted numerically.

References

[1] The United Nations, "The United Nations world water development report 2019: leaving no one behind, executive summary - UNESCO Digital Library," 2020. Accessed: Dec. 24, 2020. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000367303.

[2] W. 2008 World Health Organization, "WHO Guidelines for Drinking-Water Quality," 2008. doi: 10.1248/jhs1956.35.307.

[3] H. H. Abada, A. N. Al-Shamani, and M. D. Faisal, "A grid connected PV system for a rural resident in Al-Najaf, Iraq," 2020, p. 050056, doi: 10.1063/5.0027826.

[4] M. D. Faisal, H. H. Abada, B. Albarhami, and A. N. Al-Shaman, "Grid-connected hybrid power system designed for two modern villages in Iraq," 2021, p. 080014, doi: 10.1063/5.0069160.

[5] E. Deniz, "Energy and exergy analysis of flat plate solar collector-assisted active solar distillation system," *Desalin. Water Treat.*, vol. 57, no. 51, pp. 24313–24321, Nov. 2016, doi: 10.1080/19443994.2016.1143402.

[6] E. Bani-Hani *et al.*, "Experimental Analysis of an Improved Solar Still System with Cooling Fan and Preheating Oil," *Energy Eng. J. Assoc. Energy Eng.*, vol. 114, no. 5, pp. 55–71, May 2017, doi: 10.1080/01998595.2017.11882309.

[7] M. Al-harahsheh, M. Abu-Arabi, H. Mousa, and Z. Alzghoul, "Solar desalination using solar still enhanced by external solar collector and PCM," *Appl. Therm. Eng.*, vol. 128, pp. 1030–1040, Jan. 2018, doi: 10.1016/j.applthermaleng.2017.09.073.

[8] A. E. Kabeel, M. M. Khairat Dawood, K. Ramzy, T. Nabil, B. Elnaghi, and A. elkassar, "Enhancement of single solar still integrated with solar dishes: An experimental approach," *Energy Convers. Manag.*, vol. 196, pp. 165–174, Sep. 2019, doi: 10.1016/j.enconman.2019.05.112.

[9] M. Abu-Arabi, M. Al-harahsheh, M. Ahmad, and H. Mousa, "Theoretical modeling of a glass-cooled solar still incorporating PCM and coupled to flat plate solar collector," *J. Energy Storage*, vol. 29, no. March, p. 101372, 2020, doi: 10.1016/j.est.2020.101372.

[10] S. A. Kalogirou, "Seawater desalination using renewable energy sources," *Prog. Energy Combust. Sci.*, vol. 31, no. 3, pp. 242–281, 2005, doi: 10.1016/j.pecs.2005.03.001.

[11] Z. A. Faisal and H. G. Hameed, "Solar Still Productivity Improvement Techniques and Recent Advancements: Review Study," *Al-Furat J. Innov. Mech. Sustain. Energy Eng.*, vol. 2, no. February, 2021.

[12] J. C. Torchia-Núñez, J. Cervantes-de-Gortari, and M. A. Porta-Gándara, "Thermodynamics of a Shallow Solar Still," *Energy Power Eng.*, vol. 06, no. 09, pp. 246– 265, Sep. 2014, doi: 10.4236/epe.2014.69022.