ORIGINAL ARTICLE

Studying Unsteady Heat and Mass Transfer Condition in a Tubular Solar Still Used for Water Harvesting Implications

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Abstract

This study presents a comprehensive unsteady-state mathematical model for analyzing heat and mass transfer processes in a tubular solar still (TSS), aimed at enhancing the accuracy of temperature predictions and freshwater productivity assessments. The model incorporates time-dependent energy balance equations for key components—including the saline water, trough, humid air, and transparent cover—while accounting for convective, evaporative, radiative, and condensative heat transfer mechanisms. Assumptions such as uniform water temperature, negligible vapor leakage, saturated vapor near the water surface, and minimal solar absorption by humid air are employed to simplify the analysis. Mass transfer coefficients are derived from established correlations, and natural convection is modeled using Rayleigh and Grashof numbers for curved surfaces. Simulations under constant solar radiation (750 W/m²) and ambient temperature (28°C) reveal that the trough exhibits the highest temperature (up to 60°C), followed by saline water, humid air, and the cover (lowest at ~40°C), with all components stabilizing after approximately 2 hours. Cumulative distillate yield reaches approximately 0.5 kg after 8 hours of operation. Parametric analyses demonstrate that a 2.5-fold increase in solar radiation intensity results in a 3.4-fold rise in productivity, while enlarging the diameter from 0.1 m to 0.4 m yields a 4.5-fold enhancement, though at increased cost. The model provides valuable insights for optimizing TSS designs in water-scarce regions, highlighting the potential for sustainable, low-cost desalination.

Keywords: Heat Transfer, Mass Transfer, Thermal Analysis, Tubular Solar Still.

1. Introduction

Access to clean and safe drinking water remains one of the most pressing global challenges of the twenty-first century. Rapid population growth, industrialization, and climate change continue to intensify pressure on freshwater resources, particularly in arid and semi-arid regions (Arunkumar et al. 2012) and Elashmawy (2017). Although large-scale desalination technologies such as reverse osmosis and multi-stage flash distillation can supply potable water, these systems are energy-intensive and often dependent on fossil fuels, resulting in high operational costs and environmental concerns (El-Dessouky and Ettouney 2002).

In contrast, solar desalination offers a sustainable and environmentally friendly alternative, especially for remote and rural communities where solar radiation is abundant (Fath et al. 2003).

Solar stills represent one of the simplest and most economical solar desalination technologies. Operating on the natural process of evaporation and condensation, they require minimal maintenance and can be constructed using locally available materials. Since the early systematic studies on solar distillation systems (Fudholi et al. 2014), extensive efforts have been devoted to improving the performance of conventional basin-type solar stills (Gleick 1998).

Despite their simplicity and reliability, basin stills generally suffer from low freshwater productivity, which limits their large-scale implementation (Kabeel and Abdelgaied 2016).

Eltawil and Omara (2014) tried to enhance the productivity of a single slope solar still. The solar still was equipped with a flat plate solar collector, a spraying unit, perforated tubes, and an external condenser. They reported that the productivity of modified still improved between 51-148% depending upon the proposed modification.

Mehta et al. (2025) reported a 17% improvement in the suggested solar still and found its productivity as 5.9 L/day. They also confirmed that applying both cooling the condensing cover and also recovery of heat offers a practical solution to potable water shortage in coastal regions.

Tareemi and Sharshir (2025) also investigated the performance improvement of a double-slope solar still via sand and condensing cover cooling. They proposed black sand as the minerals derived from it are suggested as alternatives to synthetic nanofluids. They reported remarkable improvements in efficiency and productivity.

The performance of a solar still is governed by coupled heat and mass transfer processes occurring between the saline water surface, the humid air inside the enclosure, and the condensing cover (Kalogirou 2004). Internal heat transfer includes convective, evaporative, and radiative components. The classical correlations developed by R. Dunkle (Kumar and Tiwari 1996) remain the foundation for estimating internal convective and evaporative heat transfer coefficients. These relations have been widely adopted and later refined to improve prediction accuracy under different climatic and operational conditions (Malik et al. 1982).

Early modeling approaches frequently assumed steady-state operation for simplicity. However, solar still performance is inherently transient because solar intensity, ambient temperature, and wind speed vary continuously throughout the day (Muftah et al. 2014). Steady-state assumptions may therefore oversimplify real system behavior. Unsteady (transient) models based on time-dependent energy balance equations provide more realistic predictions of temperature evolution and distillate yield (Nafey et al. 2000; Naim and El Kawi 2002).

To overcome the productivity limitations of conventional basin stills, researchers have proposed several alternative geometrical configurations. Among these, tubular solar stills have attracted attention due to their compact structure and potential for enhanced heat and mass transfer performance (Omara et al. 2013). In tubular systems, a cylindrical absorber is enclosed within a transparent tubular cover, modifying natural convection patterns and vapor distribution inside the still (Panchal and Mohan 2017).

The curvature of the tubular cover increases the effective condensation area and influences the internal thermal field (Shukla and Sorayan 2005). However, this geometry also introduces additional analytical complexity. Solar incidence angles vary over the curved surface, and vapor flow behavior differs significantly from that in planar basin stills (Tripathi and Tiwari 2004; Dunkle 1961). As a result, accurate modeling of unsteady heat and mass transfer becomes essential for predicting and optimizing tubular solar still performance.

Numerous enhancement techniques have been investigated to increase solar still productivity, including fins, wick materials, phase change materials (PCM), nanofluids, and external reflectors (UNESCO 2020). While these modifications improve thermal storage and evaporation rates, comprehensive transient analyses focused specifically on tubular configurations remain limited.

Therefore, the present study aims to investigate the unsteady heat and mass transfer characteristics of a tubular solar still through detailed mathematical modeling and experimental validation. By developing a transient energy balance model and examining time-dependent thermal behavior, this research seeks to contribute to the improved design and optimization of efficient, low-cost solar desalination systems suitable for water-scarce regions.

Taking into account the aforementioned limitations, the Tubular Solar Still (TSS) is considered to be a good candidate since it provides a large surface of solar radiation entry and also the circular aperture leads to easier distillate collection. In the given structure, the

basin is a semicircular that holds saline water exposed to solar radiation and the curvature above works as the condensing cover.

Therefore, the main goal is the unsteady modeling of the heat and mass transfer in a TSS. To the best knowledge of the author, such a study on a TSS has not been found in literature and it can help to find more accurate temperatures of basin, saline water, humid air and the cover.

2. Materials and Methods
2.1. Heat and Mass Transfer Analysis

Inside the given still (Fig. 1), different heat and mass transfer types happen which lead to freshwater production inside the still. It is then redirected to the outside and collected in a graduated flask. To gain freshwater, the following heat transfer modes happen:

The solar energy is transferred through the top transparent cover and mainly absorbed by the blackened still trough. The absorbed heat is transferred into saline water inside the trough convectively and initiates the vaporization and it also exchanges heat with the humid air convectively. The vapor partial pressure difference between saline water surface and above, accelerates the vaporization and therefore, vapor is moved upwards until it reaches the cooler cover. As a result, vapor condensed into water drops and due to gravity force, the drops slide down and redirected into outside. Through vaporization, heat is transferred convectively and evaporatively into humid air and after condensation, the stored heat inside the humid air is transferred convectively and condensatively into cover. Moreover, the radiative heat exchange between saline water and the cover should also be taken into account. Finally, the cover experiences convective and radiative heat transfers with the atmosphere. All these modes of heat transfer are formulated in the followings:
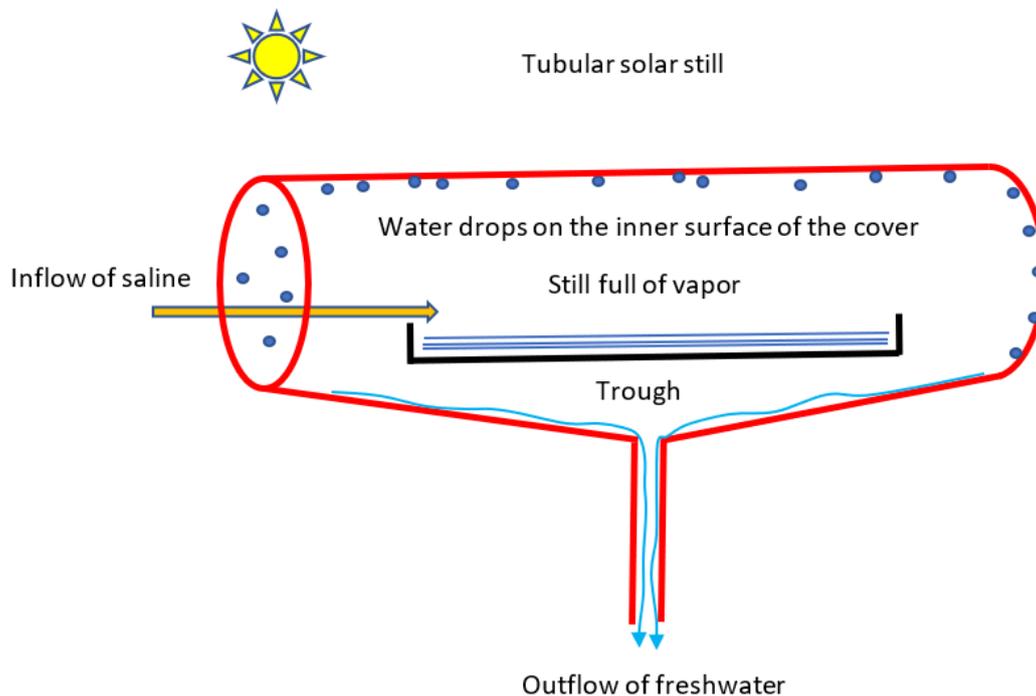

Fig. 1. The schematic of a tubular solar still

To do the mass and heat balances, the following assumptions are made:

1) The water temperature inside the still is uniform and such an assumption seems logical as the depth of water is kept as low as possible;

2) Leakage of vapor from inside to the outside of still is negligible. This assumption is also near to reality as the components can be glued/sealed as perfectly as possible;

3) Vapor close to the water surface is also considered saturated;

4) Solar energy is negligibly absorbed by the humid air (vapor inside the still).

The most important issue of solar stills is the rate of freshwater production i.e. the evaporation (m_e) and condensation (m_c) fluxes that are expressed by

$$m_e = h_{e,sw-h}(\rho_{v,sw} - \rho_{v,h}) \qquad (1)$$

$$m_c = h_{cd,h-cov}(\rho_{v,h} - \rho_{v,cov}) \qquad (2)$$

The respective mass transfer coefficients ($h_{e,sw-h}$ and $h_{cd,h-cov}$) are also given by (Ahsan and Fukuhara 2010).

$$h_{e,sw-h} = \frac{\gamma_e M_v R_v (T_{sw} + T_h)}{2 R_g T_h}.$$
$$[\frac{g\beta D_v^2 (T_{sw} - T_{cov})}{\nu}]^{\frac{1}{3}} \qquad (3)$$

$$h_{cd,h-cov} = 0.996\gamma_c^{\frac{3}{4}}.$$
$$[\frac{g\rho_{sat}(\rho_{sat} - \rho_{v,h})\lambda_{sat}^3 a^3 (T_h - T_{atm})^3}{\mu_{sat} D L^3 (\rho_{v,h} - \rho_{v,cov})^4}]^{\frac{1}{4}} \qquad (4)$$

Taking the mass balance into account, it is found that the time rate of mass loss of water from trough is equal to the time rate of evaporation from water surface inside the trough and both equal to the time rate of mass gain of water vapor in humid air. From the other hand, time variation of the mass of water vapor in the humid air can be calculated by the difference between the condensation and evaporation rates. So, one can write the followings:

$$(\rho \frac{dV}{dt})_{sw} = -m_e A_{sw} \qquad (5)$$

$$(V \frac{d\rho_v}{dt})_h = m_e A_{sw} - m_c A_{cov} \qquad (6)$$

Now, one can focus on the heat analysis of the still through writing energy balances for different components of the still.

- Saline water:

$$\frac{d(mcT)_{sw}}{dt} = \frac{d(\rho VcT)_{sw}}{dt}$$
$$= (\rho c)_{sw}\frac{d(VT)_{sw}}{dt} \qquad (7)$$
$$= Q_{sw} + Q_{c,t-sw}$$
$$- Q_{e,sw-h} - Q_{c,sw-h}$$
$$- Q_{r,sw-cov}$$

- Trough:

$$\frac{d(mcT)_t}{dt} = \frac{d(\rho VcT)_t}{dt} = (\rho cV)_t\frac{d(T)_t}{dt} \qquad (8)$$
$$= Q_t - Q_{c,t-sw} - Q_{c,t-h}$$

- Humid air:

$$\frac{d(mcT)_h}{dt} = \frac{d(\rho VcT)_h}{dt} = (\rho cV)_h\frac{d(T)_h}{dt} \qquad (9)$$
$$= Q_{e,sw-h} + Q_{c,sw-h}$$
$$+ Q_{c,t-h} - Q_{c,h-cov}$$
$$- Q_{cd,,h-cov}$$

- Cover:

$$\frac{d(mcT)_{cov}}{dt} = \frac{d(\rho VcT)_{cov}}{dt}$$
$$= (\rho cV)_{cov}\frac{d(T)_{cov}}{dt}$$
$$= Q_{cov} + Q_{c,h-cov} \qquad (10)$$
$$+ Q_{cd,,h-cov}$$
$$+ Q_{c,cov-atm}$$
$$+ Q_{r,cov-atom}$$

The heat terms (Q) are described as below based on heat/mass transfer coefficients:

$$Q_{sw} = (1 - al_{cov})(1 - \alpha_{cov})(1 - \alpha_w)\alpha_w I A_{sw} \qquad (11)$$

$$Q_{c,t-sw} = h_{c,t-sw}A_{t-sw}(T_t - T_{sw}) \qquad (12)$$

$$Q_{e,sw-h} = L h_{e,sw-h}A_{sw-h}(\rho_{v,sw} - \rho_{v,h}) \qquad (13)$$

$$Q_{c,sw-h} = h_{c,sw-h}A_{sw-h}(T_{sw} - T_h) \qquad (14)$$

$$Q_{r,sw-cov} = h_{r,sw-cov}A_{sw-h}(T_{sw} - T_{cov}) \qquad (15)$$

$$Q_t = (1 - al_{cov})(1 - \alpha_{cov})(1 - al_w)(1 - \alpha_w)(1 - al_t)\alpha_t I A_{sw} \qquad (16)$$

$$Q_{c,t-h} = h_{c,t-h}A_{t-h}(T_t - T_h) \qquad (17)$$

$$Q_{c,h-cov} = h_{c,h-cov}A_{h-cov}(T_h - T_c) \qquad (18)$$

$$Q_{cd,,h-cov} = L h_{cd,,h-cov}A_{h-cov}(\rho_{v,h} - \rho_{v,cov}) \qquad (19)$$

$$Q_{cov} = (1 - al_{cov})\alpha_{cov}I A_{cov} \qquad (20)$$

$$Q_{c,cov-atm} = h_{c,cov-atm}A_{cov-atm}(T_c - T_{atm}) \qquad (21)$$

$$Q_{r,cov-atm} = h_{r,cov-atm}A_{cov}(T_c - T_{sky}) \qquad (22)$$

The heat transfer coefficient between container and saline water ($h_{c,t-sw}$) is obtained from natural convection correlations. So, choosing the width of water (W) as the characteristic length and also computing the saline water ones (β, ν, λ) at the film temperature ($T_{f,sw}$), one can write the followings:

$$Ra = \frac{g\beta(T_t - T_{sw(bulk)})R^3}{\nu\alpha} \qquad (23)$$

For a horizontal curved surface in natural convection

$$Nu_{c,t-sw} = \begin{cases} 0.54\,Ra^{\frac{1}{4}} & 10^5 < Ra < 10^{10} \\ 0.15\,Ra^{\frac{1}{3}} & Ra > 10^{10} \end{cases} \qquad (24)$$

$$h_{c,t-sw} = \frac{Nu_{c,t-sw}\lambda_{sw}}{W} \qquad (25)$$

$$h_{c,sw-h} = \frac{h_{e,sw-h}(\rho_{v,sw} - \rho_{v,h})}{\rho_{v,sw}} \qquad (26)$$

$$h_{r,sw-cov} = \frac{\sigma(T_{sw}^2 + T_{cov}^2)(T_{sw} + T_{cov})}{\frac{1}{\varepsilon_{sw}} + (\frac{1}{\varepsilon_{sw}} - 1)\frac{A_{sw}}{A_{cov}}} \qquad (27)$$

$$h_{c,t-h} \approx \frac{\lambda_{t-h}}{H_h} \qquad (28)$$

while for humid air $\lambda_{t-h} = 0.025\ W/m\,K$.

For a long isothermal horizontal circular cylinder in an isothermal environment, the

convective heat transfer coefficient is obtained as below:

$$Nu^T = 0.772 \bar{C}_l Ra^{\frac{1}{4}} \quad (29)$$

where $\bar{C}_l$ is an approximately universal function of Prandtl number as the followings:

$$\bar{C}_l = \frac{0.671}{[1 + (\frac{0.492}{Pr})^{\frac{9}{16}}]^{\frac{4}{9}}} \quad (30)$$

$$f = 1 - \frac{0.13}{(Nu^T)^{0.16}} \quad (31)$$

$$Nu_l = \frac{2f}{\ln(1 + 2\frac{f}{Nu^T})} \quad (32)$$

$$Nu_t = \bar{C}_t Ra^{\frac{1}{3}} \quad (33)$$

where $\bar{C}_t$ is a function of Pr and tabulated in Ref. (Rohsenow et al. 1998).

$$Nu_{c,cov-atm} = [(Nu_l)^{3.3} + (Nu_t)^{3.3}]^{\frac{1}{3.3}} \quad (34)$$

$$h_{c,cov-atm} = \frac{\lambda_{atm}}{D_{still}}(Nu_{c,cov-atm}) \quad (35)$$

$$h_{r,cov-atm} = \frac{\sigma(\varepsilon_{cov}T_{cov}^4 - \varepsilon_{sky}T_{sky}^4)}{(T_{cov} - T_{sky})} \quad (36)$$

3. Results and Discussion

3.1. Validation

To validate the theoretical results, some data including saline water, humid air and condensing glass cover temperatures are extracted from Ref. (ISLAM and Fukuhara 2005) and compared with those of theoretical outcomes. Referring to Fig. 2 in the given Ref. (ISLAM and Fukuhara 2005), the trends of variation of three temperatures are plotted. As seen, the saline water has the highest temperature followed by humid air and cover, respectively. Considering Fig. 2, the same orders of temperatures are also observed. Moreover, the root mean square error (RMSE) and R-squared were also calculated and reported for each comparison to quantitatively assess the model accuracy. The maximum RMSE was found below 12℃ and the observed $R^2 = 97.8$. The reason is mostly related to the fact that the aforementioned Ref. is for the steady state conditions and the present study is for the unsteady state case. Therefore, the theoretical predictions from the present simulation showed good agreement with the corresponding experimental data.

3.2. Temperatures

The temperatures of the tubular solar still components are significant to the heat and consequently the mass transfer phenomena inside every still. In fact, through a solar still, the driving force is the temperature difference. So, the higher temperature differences between trough and saline water, saline water and humid air, humid air and cover and finally the transparent cover and the ambient air are highly significant. Therefore, the temperatures of the aforementioned components are always investigated in study of each solar still. The temperatures of trough, saline water, humid air and cover are shown in Fig. 2. As observed, the temperature of trough is highest in comparison to others and the lowest temperature is attributed to cover. Humid air and saline water temperatures are also within the two given temperatures while the temperature of saline water is higher than that of humid air. Such an observation is also observed in (ISLAM and Fukuhara 2005) and is logical. In fact, the black trough absorbs the major fraction of solar radiation and acts as the source of heat inside the trough. Through heat transfer inside the still, little by little, saline water gets heat and starts evaporation and finally the water vapor is generated inside the still. The lower temperature of transparent cover in comparison to the humid air is highly favored as it helps condensation of vapor more effectively. Based on Fig. 2, all four temperatures follow the same trend as they are affected by the variation of temperatures of the heat source i.e., the trough. The temperature of saline water is close to that of trough due to effective heat transfer mainly convection. Fortunately, the temperature difference between water vapor and cover is observed high enough to initiate and keep the condensation. Through the present study, the solar radiation intensity and the ambient temperatures are kept constant at 750 W/m^2 and 28 ℃, respectively to only observe the temperature differences. The fluctuations of solar radiation and ambient temperature undoubtedly change the trend of temperatures and the accumulated freshwater, but it is important to see the temperatures in comparison to each other.

Moreover, based on Fig. 2, the cover temperature falls within 30 ℃ to 38 ℃ while the humid air temperature is calculated between 50 ℃ and 55 ℃. The temperatures of saline water and the trough are also between

60 °C and 65 °C. Furthermore, the temperature of trough follows an ascending one from 30 °C to 62 °C within the first 2 hours of the operation and then it follows a constant trend. For the other three temperatures, the same trends are also observed. This observation is also seen in Ref. (ISLAM and Fukuhara 2005) and the constant trend is due to keeping the ambient and the solar radiation intensity constant.
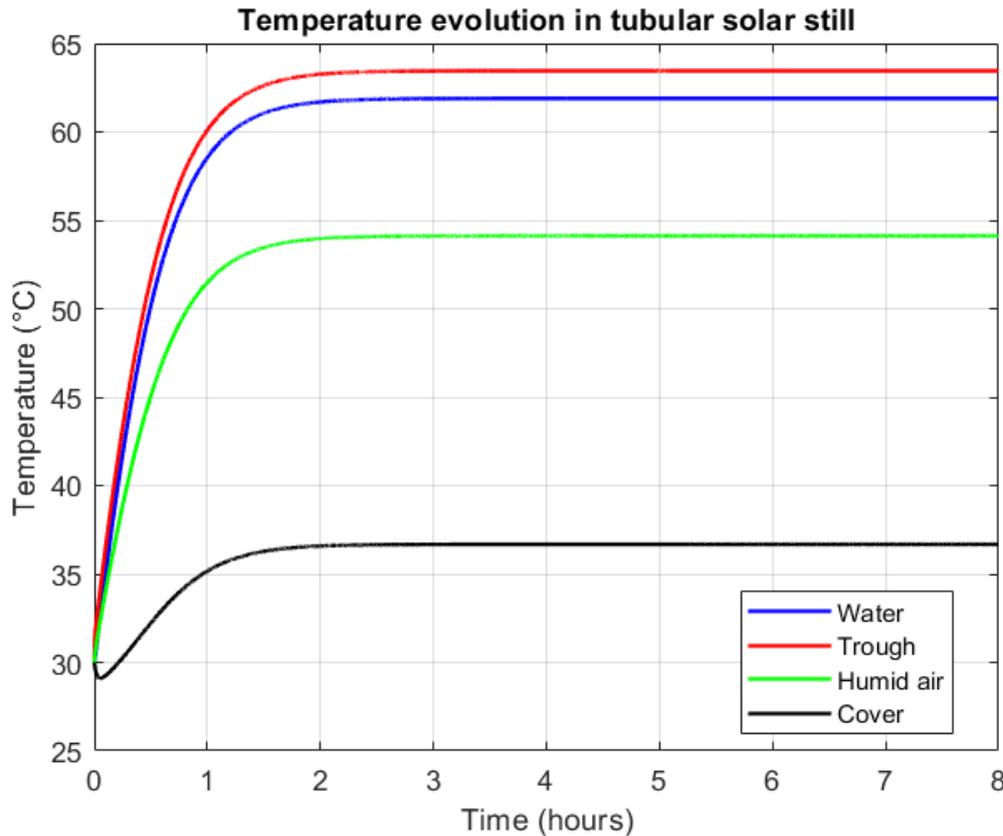

Fig. 2. Trends of temperature variations of different components of the still

3.3. Cumulative Distillate

Distillate yield is the most important factor which is considered as the decisive factor upon which, one can compare the different designs of the solar still. In fact, the main reason behind exploiting a solar still is the production of freshwater from non-potable water and meeting the primary needs of people living in remote areas. Through the present study, the accumulated freshwater, after 8 hours of operation, under the constant weather conditions was calculated $0.55\ kg$. As observed in Fig. 3, the distillate accumulation follows an increasing trend to reach the highest value at the end of the operation course.

3.4. Effect of Solar Radiation on Freshwater Production

Solar still freshwater production is strongly affected by solar radiation. But to consider its effect on the amount of freshwater production by a tubular solar still, here a parametric study is carried out. As seen in Fig. 4, the final production of the still shows an increasing trend by an increase in solar radiation i.e. a 2.5-fold increase in solar radiation intensity resulted in a 3.4-fold increase in freshwater production.

3.5. Effect of Solar Still Diameter on Still Productivity

As a decisive factor, the diameter is also a matter of concern to see its effects on solar still productivity. Having a larger diameter is observed to be in favor of freshwater production. In fact, a larger diameter is along with having a bigger space for vapor and it helps evaporation to be more easily occurred. The given parametric study shows that increasing the diameter from $0.05\ m$ to $0.2\ m$ resulted in a 4.5-fold increase in the production of the still (Fig. 5). However, having a larger diameter mean more cost to the user and a compromise is needed to be considered.
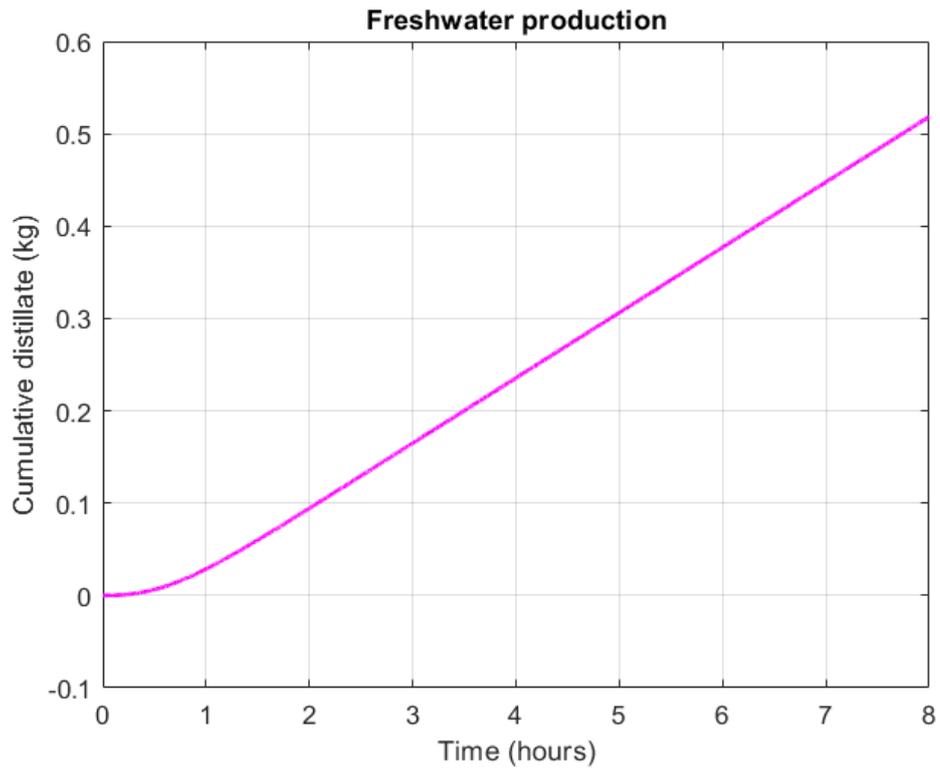
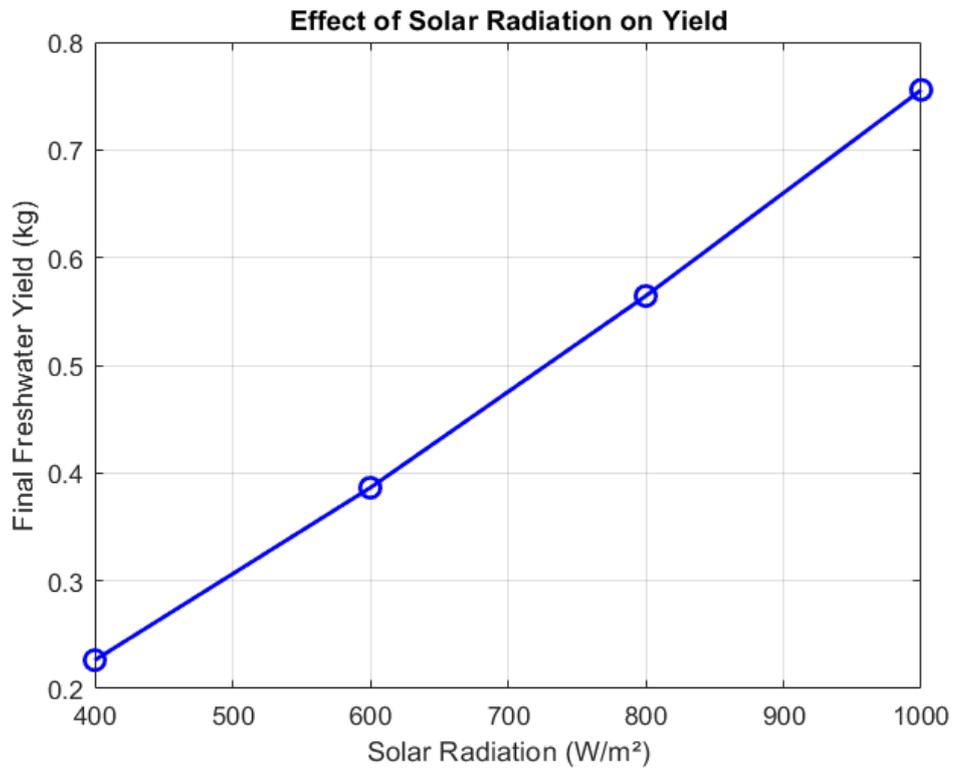**Fig. 3.** Freshwater production by the given tubular solar still

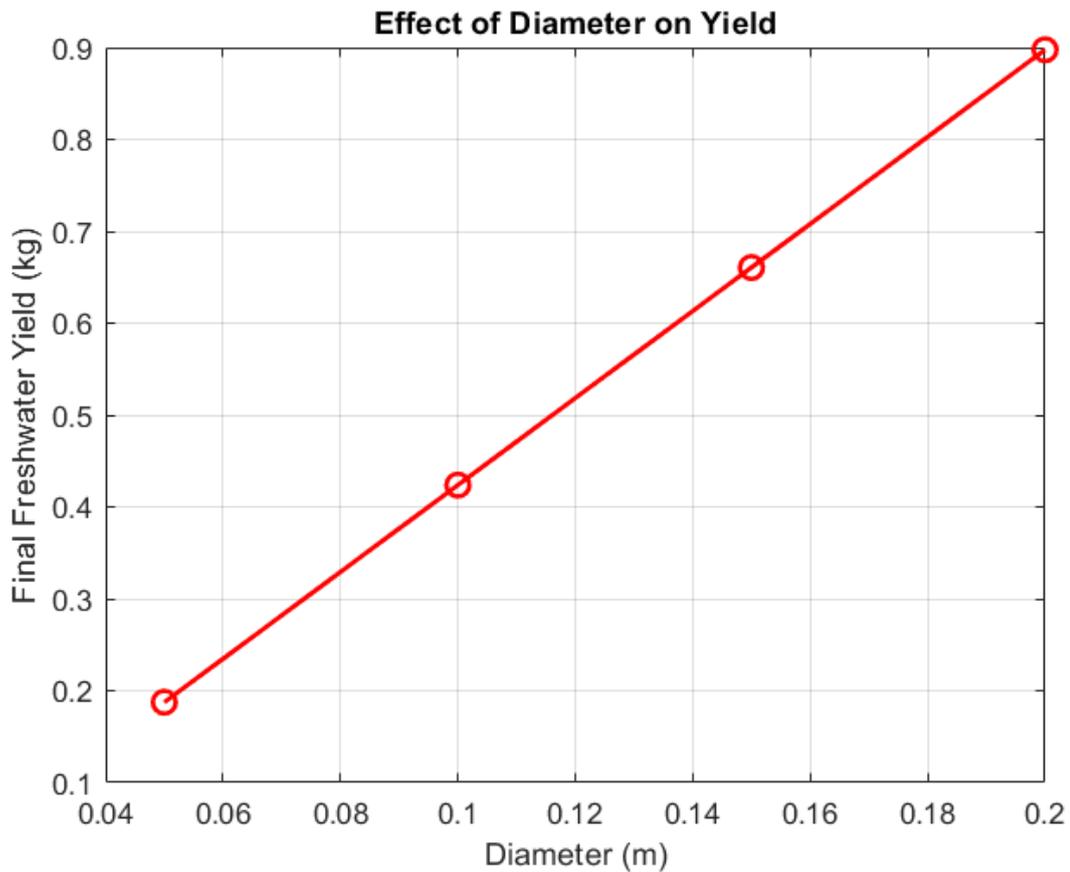**Fig. 4.** Effect of solar radiation intensity on fresh water production

Fig. 5. Effect of diameter on tubular solar still

4. Conclusion

This investigation successfully develops an unsteady heat and mass transfer model for a tubular solar still, addressing a gap in the literature by providing detailed transient predictions of component temperatures and distillate yield. The results confirm that the trough serves as the primary heat source, driving evaporation through effective convection to the saline water, while the temperature gradient between humid air and the cooler cover facilitates efficient condensation. Under baseline conditions, the system achieves stable operation within 2 hours, with a cumulative freshwater output of about 0.5 kg over 8 hours, underscoring the TSS's viability for small-scale desalination in arid areas. Parametric studies reveal strong sensitivities to solar radiation and diameter, with productivity scaling non-linearly—increasing solar intensity by 2.5 times boosts yield by 3.4 times, and quadrupling diameter enhances output 4.5-fold—emphasizing the need for balanced design considerations to optimize performance against cost and material constraints. Future work could incorporate variable environmental factors, such as fluctuating solar irradiance and wind effects, or integrate enhancements like nanofluids or phase change materials to further improve efficiency. Overall, this model contributes to advancing sustainable solar desalination technologies, offering a robust framework for researchers and engineers to refine TSS configurations for real-world applications in addressing global water scarcity. So, the main implication of the present research falls within the unsteady modeling of a tubular solar still with the aim of gaining more exact results which can help us with a better design of it.

5. Conflict of interest

No potential conflict of interest was reported by the author.

6. Nomenclature

A_{h-cov}	Contact surface area between humid air and cover (m^2)
A_{cov}	Surface area of cover in contact with humid air (m^2)
$A_{cov-atm}$	Contact surface area between cover and ambient air (m^2)
A_{sw}	Surface area of saline water in the trough (m^2)

Symbol	Definition
A_{sw-h}	Contact surface area between saline water and humid air (m^2)
A_{t-h}	Contact surface area between trough and humid air (m^2)
A_{t-sw}	Contact surface area between trough and saline water (m^2)
D_{still}	Diameter of solar still (m)
D_v	Molecular diffusion coefficient of water vapor (m^2/s)
$h_{c,h-cov}$	Convective heat transfer coefficient between humid air and cover $(W/m^2\,K)$
$h_{c,cov-atm}$	Convective heat transfer coefficient between cover and ambient air $(W/m^2\,K)$
$h_{c,sw-h}$	Convective heat transfer coefficient between saline water and humid air $(W/m^2\,K)$
$h_{c,t-h}$	Convective heat transfer coefficient between trough and humid air $(W/m^2\,K)$
$h_{c,t-sw}$	Convective heat transfer coefficient between trough and saline water $(W/m^2\,K)$
$h_{cd,h-cov}$	Condensative mass transfer coefficient from humid air to cover (m/s)
$h_{e,sw-h}$	Evaporative mass transfer coefficient from saline water surface to humid air (m/s)
$h_{r,sw-cov}$	Radiative heat transfer coefficient between saline water and cover $(W/m^2\,K)$
H_h	Humid air thickness below the trough surface (m)
M_v	Molecular weight of water vapor (=18.016 $kg/kmol$)
$Q_{c,h-cov}$	Convective heat transferred from humid air to the cover (W)
$Q_{c,cov-atm}$	Convective heat transferred from cover to the atmosphere (W)
$Q_{c,sw-h}$	Convective heat transferred from saline water to humid air (W)
$Q_{c,t-h}$	Convective heat transferred between trough and humid air (W)
$Q_{c,t-sw}$	Convective heat transferred from trough to saline water (W)
$Q_{cd,h-cov}$	Condensative heat transferred from humid air to the cover (W)
Q_{cov}	Solar energy absorbed by cover (W)
$Q_{e,sw-h}$	Evaporative heat transferred from saline water to humid air (W)
$Q_{r,cov,atom}$	Radiative heat transferred from cover to the atmosphere (W)
$Q_{r,sw-c}$	Radiative heat transferred between saline water and the cover (W)
Q_{sw}	Solar energy absorbed by saline water (W)
Q_t	Solar energy absorbed by trough (W)
R_g	Universal gas constant (= 8315 $J/kmol\,K$)
R_v	Specific gas constant of water vapor (= 461.5 $J/kg\,K$)
$T_{f,sw}$	Saline water film temperature (K) $(= (T_{sw} + T_t)/2)$
T_{t0}	Temperature of saline water at the initial condition ($t = 0$)
m_c	Condensation flux $(kg/m^2\,s)$
m_e	Evaporation flux $(kg/m^2\,s)$
$\rho_{v,h}$	Density of water vapor in humid air (kg/m^3)
$\rho_{v,cov}$	Density of water vapor at cover (kg/m^3)
$\rho_{v,sw}$	Density of water vapor at saline water surface (kg/m^3)
D	Diameter of tubular solar still (m)
Gr	Grashof number (-)
I	Solar radiation (W/m^2)
L	Latent heat of vaporization (J/kg)
Pr	Prandtl number (-)
Pr	Prandtl number (-)
Ra	Rayleigh number (-)
T	Temperature (℃)
T	Temperature (K)
V	Volume (m^3)
W	Width of water (m)
a	Temperature difference fraction (-)
al	Albedo (-)
c	Specific heat capacity $(J/kg\,K)$
g	Gravitational acceleration (= 9.807 m/s^2)
m	Mass (kg)
t	Time (s)
ρ	Density (kg/m^3)

Greek Letters

Symbol	Definition
γ_c	Condensation coefficient (-)
γ_e	Evaporation coefficient (-)
β	Volumetric thermal expansion coefficient $(1/K)$
ε	Emissivity (-)
λ	Thermal conductivity $(W/m\,K)$
μ	Dynamic viscosity $(kg/m\,s)$
ν	Kinematic viscosity (m^2/s)
σ	Stefan-Boltzmann constant (= $5.67 \times 10^{-8}\ W/m^2\,K^4$)

Subscripts

Symbol	Definition
h	Humid air
atm	Atmosphere
c	Convective
cd	Condensative
cov	Cover
e	Evaporative
sat	Saturated liquid
sw	Saline water
t	Trough

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