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Exergy and Energy Analysis of a Tubular Solar Still with and without Fins: Comparative Theoretical and Experimental Approach

Prof. Dr. Ravishankar Sathyamurthy (✉ raviannauniv23@gmail.com)
KPR Institute of Engineering and Technology https://orcid.org/0000-0002-2881-3455
Abd Elnaby Kabeel
Tanta University
Ali Chamkha
Kuwait College of Science and Technology
Hemanth Arun Kumar
BS Abdur Rahman Crescent Engineering College: B S Abdur Rahman Crescent Institute of Science & Technology
Hariprasath Venkateswaran
BS Abdur Rahman Crescent Engineering College: B S Abdur Rahman Crescent Institute of Science & Technology
Athikesavan Muthu Manokar
BS Abdur Rahman Crescent Engineering College: B S Abdur Rahman Crescent Institute of Science & Technology
Ramani Bharathwaaj
KPR Institute of Engineering and Technology
Sathiyaseelan Vasanthaseelan
KPR Institute of Engineering and Technology

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Exergy and energy analysis of a tubular solar still with and without fins: Comparative theoretical and experimental approach

Ravishankar Sathyamurthy[a], Abd Elnaby Kabeel[b,c], Ali Chamkha[d,e]*, Hemanth Arun Kumar[f],
Hariprasath Venkateswaran[f], Athikesavan Muthu Manokar [f], Ramani Bharathwaaj[a],
Sathiyaseelan Vasanthaseelan[a]
[a] Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Arasur, Coimbatore, Tamil Nadu, India (raviannauniv23@gmail.com)
[b] Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Egypt (kabeel6@hotmail.com)
[c] Faculty of Engineering, Delta University for Science and Technology, Gamasa, Egypt
[d] Faculty of Engineering, Kuwait College of Science and Technology, Doha District, Kuwait (a.chamkha@kcst.edu.kw)
[e] Center of Excellence in Desalination Technology, King Abdulaziz University, PO Box 80200, Jeddah 21589, Saudi Arabia
[d] Department of Mechanical Engineering, B.S.Abdur Rahman Crescent Institute of Science and Technology, Chennai - 600 048, India (ahemanthkumar27@gmail.com, hariprasat16@gmail.com)
*Corresponding author
Dr. Ali J Chamkha, Institute of Research and Development, Duy Tan University, Da Nang 550000, Vietnam. achamkha@yahoo.com

Abstract

Today, availability of clean water is hard as the residents are expanding and moving fast to achieve rapid urbanization as a result need for clean water has been raised. Solar stills are the solution to desalinate to obtain pure water. This paper represents the theoretical and experimental study of tubular solar still with and without fins. The reading was recorded from 8:00 AM to 6:00 PM. Efficiency of TSS with fins and without fins are 23.39% and 13.76% respectively. The rate of irreversibility from the basin of TSS with flat is higher than TSS with finned absorber. Similarly, the rate of irreversibility from water is significantly reduced using finned absorber. Also, the exergy efficiency of TSS with finned absorber is higher compared to TSS with flat absorber.

Keywords: Tubular solar still; fins; desalination

1. Introduction

Nearly about 780 Million of people lack access to water around the world. It is predicted that 50% of the world population will suffer from water scarcity in 2050. To fulfill the necessity of desalination of water can be done .Solar stills can be used to remove salt from the sea water, solar still desalination is free from pollution and provides high quality pure form of water. The setup of this solar still desalination can be used in residential areas to overcome water scarcity in the urban areas. The drawback of solar stills is the low productivity rate and require constant sunlight for the process to be done effectively (Abdelgaied et al. (2020); Muthu Manokar et ak, (2020); Balachandran et al. (2020); Attia et al. (2020, 2021); Muthu Manokar et al. (2020); Kumar et al. (2020); Sharshir et al. (2020); Essa et al. (2020); Fath et al. (2003)). For a single slope and pyramid shaped Fath et al. (2003) carried out a thermo economic analysis. Their study revealed that, the performance of traditional solar still was significantly higher than the solar still in the shape of a pyramid. There is an increase of about 30% in the fresh water produced using conventional solar still than pyramid shaped solar still. Abu-Arabi and Zurigat (2005) performed a simulation on double glass cover cooling with regenerative effect and conventional solar still. Their results revealed that the regenerative effect from double glass cover cooling improved the cumulative yield by 70% than a single slope conventional solar still. Arunkumar et al. (2013) used a concentric tubular solar still and in addition to that a parabolic concentrator is attached to focus the incoming solar radiation. Additionally, air- and water-cooling methods were employed to reduce the cover temperature. Through improved cooling of air and water flow the productivity of water produced was increased from 2050 ml/day to 3050 ml/day. With continuous cooling water flow in the concentric tube, the fresh water produced was furthermore increased to 5000 ml/day. Arunkumar et al (2016) enhanced the productivity of compound parabolic concentrator tubular solar stills. A saline water trough of rectangular shape was designed and fabricated and this trough is attached along with the pyramid type and single slope solar still. The integrated solar still has produced an accumulated yield of 7770 ml/day whereas, the single slope solar still produced a maximum cumulative yield of 6460 ml/day. Kabeel et al (2019) improved the performance of the tubular solar still by controlling the cover cooling and water depth. It is found that lowering the water depth increases the performance, by this the productivity of fresh water rate reached a maximum value of 5.85 L/m². Elashmawy (2019) describes the performance of the high temperature stand-alone tubular solar still by changing the thickness and surface cooling. By reducing the thickness by 40% the productivity and efficiency had been enhanced by 21% and 13.35% respectively. Elashmawy (2017) conducted three experiments using tubular solar still namely rectangular trough with a black cloth, half cylindrical trough without cloth and parabolic concentrator-solar tracking system integrated half cylindrical trough without cloth. The daily yield is about 4.71,3.6 and 3.53L/m² day. Panchal (2015) have proved that the combined application of both black granite gravel and vacuum tubes increased the DBSS fresh water productivity to 65% and with the application of vacuum tubes alone in DBSS enhanced the fresh water productivity by 56%. Panchal and Thakkar (2016) had validated the thermal and experimental analysis carried out on solar still directly coupled with evacuated tubes during summer and winter climatic conditions. They concluded that the introduction of evacuated tubes and Polyurethane Foam type insulation material to the experimental model enhanced the distillate output and also helps in reducing heat loss. Rahbar et al. (2015) proposed new correlations to predict the fresh water produced and heat transfer coefficient of an TSS using CFD and theoretical approach. From the characteristic curve of their study, it can be concluded that on lower cover temperature and higher water temperature, the yield from TSS was higher. Sarhaddi et al. (2017) carried out experiments on a weir cascade solar still by incorporating PCM energy storage to estimate the energy and exergy under clear sky condition and semi-cloudy condition. From the results of exergy and energy analysis, it has been summarized that the still with PCM is preferred for semi-cloudy days and still without PCM is suitable for sunny days. Experiments conducted on a typical sunny day with clear sky revealed that the exergy efficiency of solar still without PCM was slightly lower than semi-cloudy days, whereas, the energy efficiency reduced using PCM during semi-cloudy condition as it affects the melting process of PCM beneath the basin. Shanmugam et al. (2018) conducted experiments to study the yield enhancement of solar still by incorporating nanoparticles and PCM in the basin of the still model. The distillate yield of SB-SS with wick material by nanoparticles as FWCW and PCM is 4.120 and 7.460 kg/m^2 day. Sharshir et al. (2016) studied the performance of continuous solar desalination model comprised of HDH unit and SS with an evacuated solar water heater unit. The experimental study shows that the distillate productivity of the SS with exit warm water from HDH is 242% higher than the CSS system and there is about 39% rise in the gain output ratio. The effect on forced convection on cover cooling of pyramid solar still was experimentally carried out by Taamneh & Taamneh (2012). A small DC powered fan was used to cool the entire cover surface. Experimental results revealed that an improvement in daily freshwater yield of about 2.99 litres per day (25%) is achieved using with forced convection which is higher compared to the free convection still. Bhaskar and Rai (2018) investigated the productivity and exergy analysis of tubular solar still operated in active and passive mode individually. This study showed that the daily fresh water yield of the TSS in active mode is 52% more than the passive mode and also the TSS with fan had exergy efficiency of about 133% higher than the TSS in passive mode. Xie et al. (2016) have designed and constructed a novel conceptual design of low temperature- multi effect desalination system that comprises an array of Tubular Solar Still capable of producing freshwater independently to investigate the performance affecting parameters- vacuum pressures, heating conditions and evaporation temperatures. Panchal and Mohan (2017) presented a cost effective optimized solar still model with its different approaches of augmenting the productivity of solar still by adding some modification such as fins, increasing the number of effects and adding energy absorbing materials inside the basin.

The effect of humid air present in the tubular enclosure on heat and mass transfer was experimentally studied by Ahsan and Fukuhara (2010). Other similar configuration of solar still includes improving the exposure area by attaching hollow and solid fins. In addition to the fins, additional materials such as wick material, PCM, ethanol, solar pond, etc. can further increase the fresh water. The proposed model provided new outputs for the tubular solar still. Finally, it is concluded that the daily and hourly production of the Tubular solar still can be accurately predicted.

2. Experimental setup and procedure

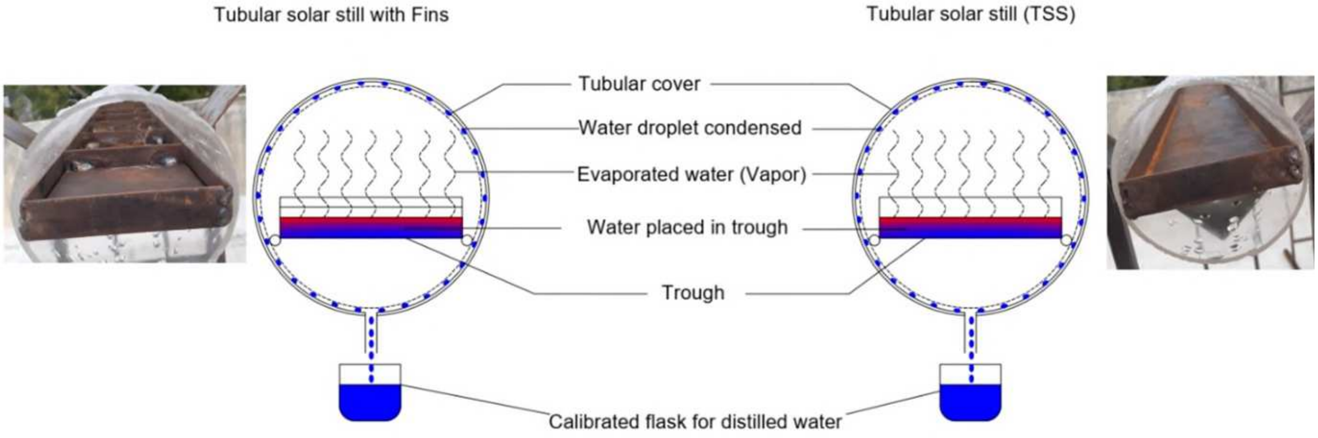

Fig. 1. Schematic diagram and experimental test rig of TSS with fins (left) and without fin (right)

The schematic diagram and experimental test rig photograph of TSS with fins (left) and the TSS without fins (right) is depicted in Fig 1. This experimental setup consists of a transparent tube made up of glass, a steel rectangular water basin called trough and a calibrated flask to collect the freshwater produced. The glass tube allows the penetration of solar irradiance from any direction which helps in augmenting the evaporation process in this desalination system. The trough containing saline water is placed in the transparent glass tube. The trough is coated in black color in order to reduce the refection of solar irradiance by absorbing all the solar irradiance transmitted through the outer transparent glass tube. Solar thermal heat produced by the solar radiation are absorbed by the saline water in the trough. As a result of heating, the saline water gets heated and evaporated. The evaporated water vapour get condensed on the inner surface of the glass tube due to the release of latent heat of evaporation. The condensed water flows down by the effect of gravity and collected at the bottom of tube as a freshwater. Two experimental models of TSS in which one of the models having fins attached with trough and another without fins in trough are used and a comparative experimental study between the two models is carried out. Fins used in the trough helps in boosting the desalination process because of the increased surface area of absorber and enhanced greenhouse effect within the still.

3. Results and discussion

The experimental data recorded such as solar radiation, ambient temperature, cover, basin, and water temperature from the modified tubular solar still using flat and finned absorber is presented in this section with a detailed discussion. Using the empirical correlations, the instantaneous thermal and exergy efficiencies are determined. In addition to the predicted yield is correlated to the experimental results obtained from the study. Furthermore, a comparison of different solar still using fins, and phase change materials were made to justify the present experimental investigation.

3.1.Thermal analysis

In this section, a comparative interpretation between the theoretical and experimental study of TSS with and without fins are carried out. The hourly variation of operating parameters for TSS with and without fins including solar intensity, glass temperature, basin temperature, water temperature and ambient temperature are plotted in graph as shown in Fig. 2 and Fig. 3. Maximum solar intensity of about 963.7 W/m^2 was attained at midday and its starts decreasing gradually. While solar intensity starts decreasing during evening, the temperature of TSS's glass, basin and water starts increasing around evening. The TSS integrated with fins reacts faster and higher to solar intensity than the TSS without fins. The distillate output rate of any solar still is determined by the temperature of water inside still and the performance of still is also depend upon many factors such as air temperature inside still(cavity between the basin and glass cover area), lower glass cover temperature, absorber plate temperature, surface area of absorber etc.,

Fig. 2 shows the solar intensity of TSS without fins are measured starting from 8:00 AM – 6:00 PM are presented in the above figure. Solar intensity ranges from 150W/m^2 - 1000W/m^2. At the beginning of the day, solar intensity of is about 270 W/m² and the temperature is about 20 °C. The ambient, basin, water, glass temperature are about 31, 31, 29, 28 °C and their solar intensity is about 400 W/m^2-450 W/m^2.Solar intensity reaches as high as 963.7W/m² at the noon time and the ambient temperature is about 37.5 °C. The ambient, water, glass temperature reaches its peak at around 3pm and then gradually decreases, also the solar intensity drops to 150 W/m^2 around 6:00 AM.

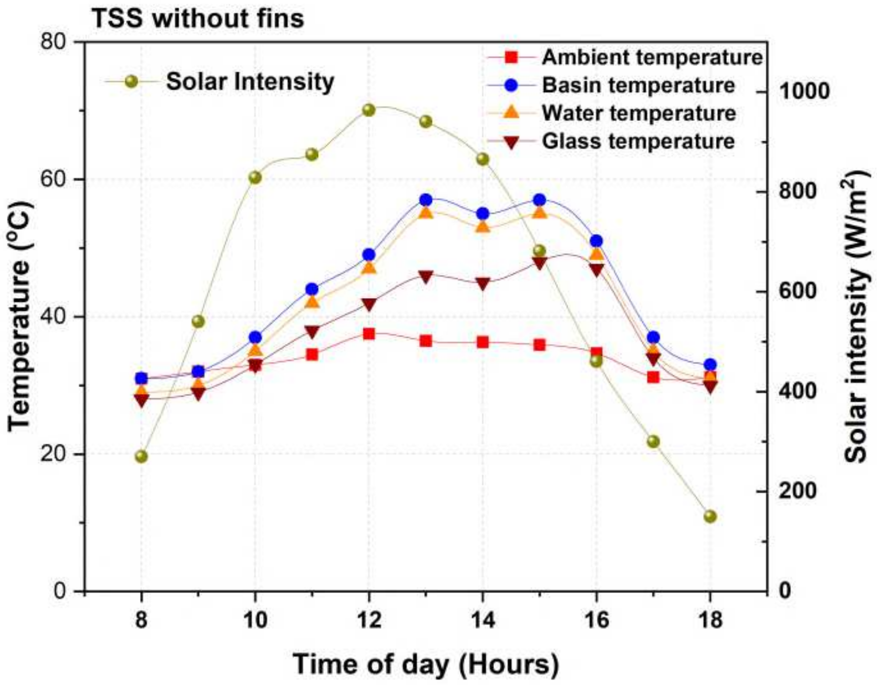

Fig. 2 Hourly variation in solar intensity, ambient, basin, water, and glass temperature recorded from TSS without fins

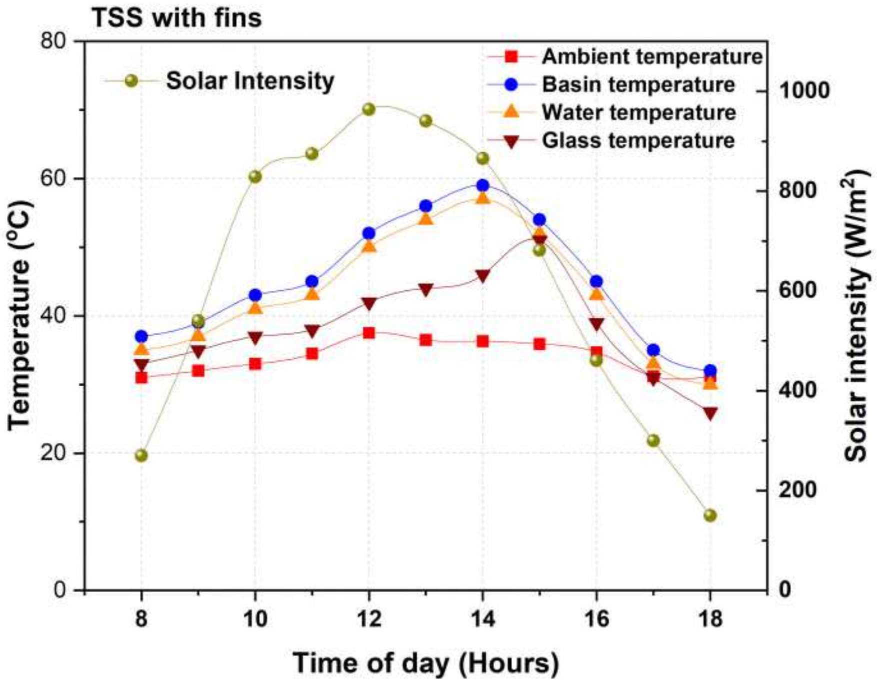

Fig. 3 Hourly variation in solar intensity, ambient, basin, water, and glass temperature recorded from TSS with fins

Fig. 3 shows the solar intensity of TSS with fins, the ambient temperature is lower due to lower solar intensity in the day time.so that the basin, water and glass temperature remains lower. The ambient temperature increases from 9:00 AM to 12.00 PM, while the ambient temperature reaches its maximum value of 37.5 around 12:00 PM. The solar intensity increases and reaches a maximum value of 963.7 W/m^2 during the noon. The basin and water temperature attains their maximum temperature around 59, and57 ^{o}C at 2:00 PM. The glass temperature reaches a maximum value of 51 ^{o}C at 3:00 PM. In noon time the ambient temperature decreases to 31.2 ^{o}C so that the solar intensity also decreases and reaches a lower value of 150 W/m^2. Thus, the basin, water and glass temperature also decrease.

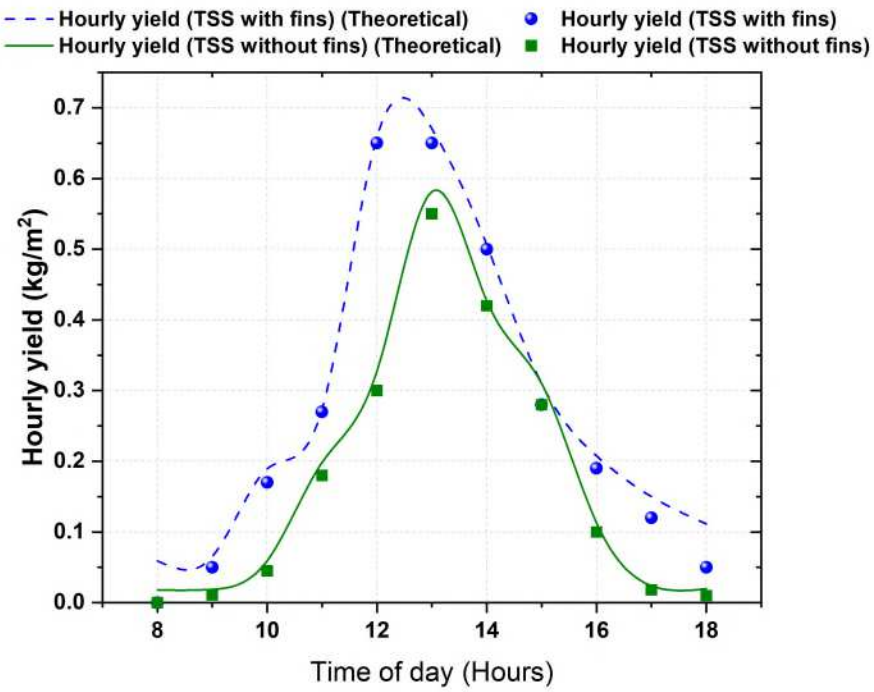

Fig. 4 Hourly variation of theoretical and experimental distillate yield for TSS with and without fins.

The experimental and theoretical results on hourly fresh water production from TSS using flat and finned absorber is plotted in Fig. 4. It is seen from Fig. 4 that using a flat absorber, the hourly fresh water produced is lower as compared to finned absorber. There is a gradual increase in the yield from the sun rise and reaches the maximum during the peak solar intensity. It is also seen that the experimental and theoretical yield are in agreement in both the cases. From the Fig. 4, it is clear that the theoretical distillate yield is always greater than the experimental distillate yield from the TSS. The maximum theoretical freshwater yield value achieved by the TSS with fins is 0.67 kg/m^2 and by the TSS without fins is 0.58 kg/m^2. The maximum experimental freshwater yield value achieved by the TSS with fins is 0.65 kg/m^2 and by the TSS without fins is 0.55 kg/m^2 which shows that the fins present in the TSS will naturally augment the freshwater yield due to the enhanced surface area of absorber. These fins increased the rate of absorption of heat in the basin due to the increased surface area in the basin by the water. The presence of fins in the basin furthermore distributes the heat throughout the water for augmenting the rate of evaporation from the surface of water. With simultaneous increase in the rate of evaporation inside the enclosure, the amount of water produced from the solar still is increased.

Fig. 5 and 6 shows the results of predicted and measured yield of TSS without and with fins on the absorber respectively. The predicted yield from solar still is measured using

Equation (1) to (3). It can be seen that the experimental yield produced from the TSS in well agreement with the predicted yield with a confidence level of 95%.

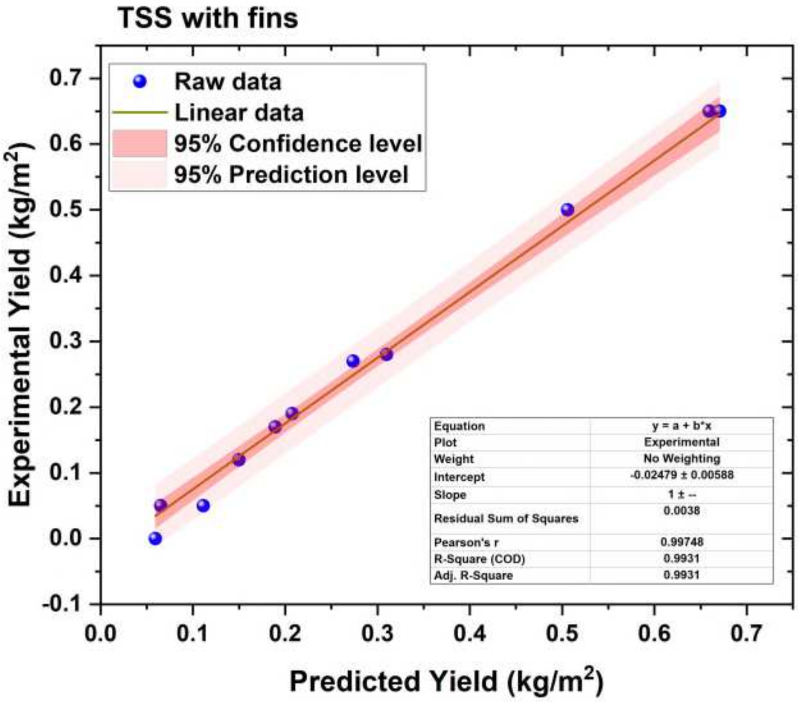

Fig. 5 Predicted and measured yield of TSS with fins

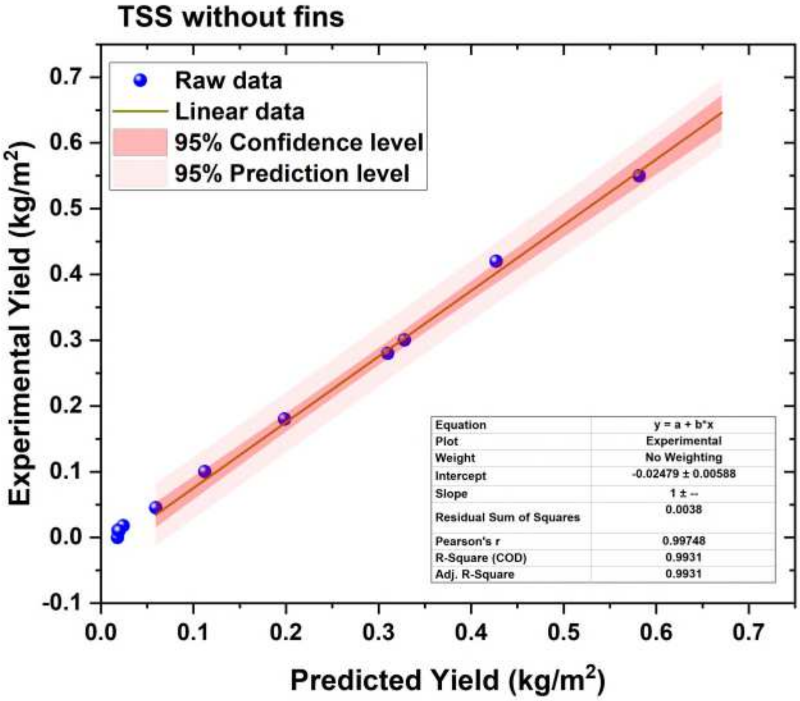

Fig. 6 Predicted and measured yield of TSS without fins

The hourly yield from the tubular solar still under both the cases can be mathematically expressed as [43],

$$m_e = \frac{h_e \times A_w \times (T_w - T_g)}{h_{fg}} \quad (1)$$

The influential parameter for determining the yield of fresh water from solar still were partial difference in pressure, evaporative heat transfer coefficient, temperature difference and convective heat transfer coefficient as mathematically expressed in Equation (2) and (3). Mathematically, the EHTC is estimated as (Shukla and Sorayan (2005)),

$$h_e = \frac{16.273 \times 10^{-3} \times h_c \times (P_w - P_g)}{(T_w - T_g)} \quad (2)$$

In the similar way, the CHTC is mathematically expressed as (Shukla and Sorayan (2005)),

$$h_c = 0.884 \left\{ (T_w - T_g) + \frac{(P_w - P_g)(T_w + 273.15)}{(268.9 \times 10^{-3} - P_w)} \right\}^{1/3} \quad (3)$$

Table. 1 Daily yield of different research work done in TSS by various researchers

S. No	Literature	Study	Fresh water produced	Location
1	Fath et al (2003)	Pyramid and single slope solar still	2.6 l/m^2 d	Aswan, Egypt
2	Abu-Arabi and Zurigat (2005)	Regenerative solar still	4.15kg/m^2	Marmul, Oman
3	Arunkumar et al (2013)	Cover cooling of tubular solar still with water and air medium	5000 ml/day	Coimbatore, India
4	Arunkumar et al (2016)	Parabolic concentrators on tubular solar still	7770ml/day	Coimbatore, India
5	Kabeel et al (2019)	Tubular solar still with cover cooling – effect on water depth	5.85 l/m^2	Tanta, Egypt
6	Elashmawy (2019)	Tubular solar still with cover cooling technique	2.4 l/m^2	Hail, Saudi Arabia
7	Elashmawy (2017)	Tubular solar still with parabolic concentrator	4.21 l/m^2	Hail, Saudi Arabia
8	Panchal (2015)	ETC integrated double slope solar still	-	Patan, India
9	Panchal & Thakkar (2016)	ETC integrated solar still	0.81kg	Patan, India
10	Rahbar et al. (2015)	Computational analysis on tubular solar still – CFD approach	0.99kg/m^2h	-
13	Sarhaddi et al. (2017)	Weir cascaded solar still	1.08kg/m^2.h	Zahedan,Iran
14	Shanmugan et al. (2018)	Nano coated absorber plate and PCM	7.46 kg/m^2 (summer) 4.12 kg/m^2 (Winter)	Chennai, India
15	Sharshir et al. (2016)	Continuous desalination using wick and shallow reservoir solar still	37 l/day	Kafrelshiekh, Egypt
16	Taamneh & Taamneh (2012)	Pyramid type solar still	2.99 l/per	Mashad,
17	Bhaskar & Rai (2018)	Tubular solar still	0.168 L	Allahabad, India
18	Xie et al (2016)	Multi stage tubular solar still	0.40 kg/hr	Chengdu, China
19	Panchal & Mohan (2017)	Methods adopted in finned solar still	1.05 kg/m^2 h	-
20	Ahsan & Fukuhara (2010)	Tubular solar still	NA	Fukui, Japan
21	Rabhi et al (2017)	Pin fins with external condenser	3.49 kg/m2	Gafsa-Tunisia
22	El-Sebaii & El-Naggar (2017)	Finned single slope solar still	5.4 kg/m2	Tanta, Egypt
23	El-Sebaii et al (2015)	Fin configuration on solar still	5.37 kg/m2	Tanta, Egypt
24	Velmurugan et al (2008)	Single basin solar still with fin for enhancing productivity.	2.81 kg/m2	Madurai, India
25	Velmurugan et al (2008a)	Industrial effluent desalination using fins in solar still	2.77 kg/m2	Madurai, India
26	Rajaseenivasan & Srithar (2016)	CO2 mitigation on solar still using square and circular fins	4.55 kg/m2	Madurai, India
27	Alaian et al. (2016)	Pin fins and wick inside single slope solar still	4820 ml/m2	Mansoura, Egypt
28	Manokar et al. (2017)	Acrylic solar still with pin fins	2.64 kg/m2	Chennai, India

29	Muthu Manokar & Prince Winston (2017)	Comparative analysis on galvanized iron and Acrylic solar still with pin fins	2.34 kg/m2	Chennai, India
30	Panomwan Na Ayuthaya, R.t al (2013)	The thermal performance of an ethanol solar still with fin plate to increase productivity.	3.5 kg/m2	Thailand
31	Jani & Modi (2018)	Circular and square hollow fins in single slope solar still	1.49 kg/m2 (circular fin) 0.94 kg/m2 (square fin)	Valsad, India
32	Srivastava & Agrawal (2013)	Single slope solar still with extended porous fins	7 kg/m2	Rewa, India
33	Yousef et al (2019)	Pin fin heat sink PCM based energy storage in solar still	3.9 kg/m2	Alexandria, Egypt
34	Appadurai & Velmurugan (2015)	Solar pond integrated solar still	3	NA
35	Omara et al. (2011)	Corrugated absorber single slope solar still	3.5 kg/m2	Kafrelshiekh, Egypt

3.2.Energy Efficiency

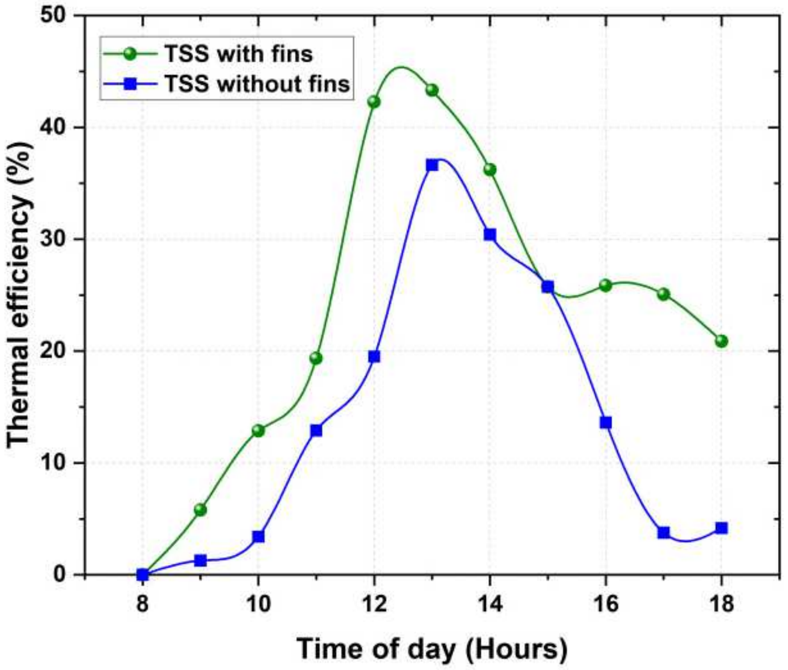

Fig. 7 Instantaneous variations in thermal efficiency of TSS with and without fins.

The instantaneous hourly changes in thermal efficiency of the TSS using flat absorber and finned absorber is plotted in Fig. 7. The instantaneous thermal efficiency of the solar still is calculated using Equation (4) and as follows,

$$\text{Instantaneous Thermal efficiency, } \eta_{thermal} = \frac{m_e \times h_{fg}}{I(t) \times A_w \times 3600} \times 100 \quad (4)$$

From the graph, it can be noted that the efficiency of the solar still without fins reaches the peak value during mid-day and gradually falls around evening. The thermal efficiency of the TSS having fins also reaches the maximum value during the mid-day same as the solar still without fans but the TSS with fins maintains the thermal efficiency for a significant time period in evening of that experiment day. The peak value of thermal efficiency for solar still without fins reached approximately 36.65 %, whereas for the solar still with fins it attains a peak value of about 43.13 %. Hence, the usage of fins in the TSS has a remarkable effect on the freshwater production and also helps in boosting the vapor to entrap inside the tubular enclosure.

3.3.Rate of irreversibility from water, glass and basin

The rate of irreversibility of water, glass and basin using finned absorber and flat absorber is mathematically expressed in Equation (5-7). The total rate of irreversibility is the summation of destruction of exergy and loss of exergy.

The rate of irreversibility from glass is mathematically given as (Sarhaddi et al. (2017)),

$$I_{r,g} = \alpha_g E_{sun} + U_b \times (T_b - T_w)\left(1 - \frac{T_a}{T_b}\right) \quad (5)$$

The rate of irreversibility from water is mathematically given as (Sarhaddi et al. (2017)),

$$I_{r,g} = \tau_g \alpha_w E_{sun} + U_b \times (T_b - T_w)\left(1 - \frac{T_a}{T_b}\right) - E_{evap} \quad (6)$$

The rate of irreversibility from basin is mathematically given as (Sarhaddi et al. (2017)),

$$I_{r,g} = \tau_g \tau_w \alpha_b E_{sun} + U_b \times (T_b - T_w)\left(1 - \frac{T_a}{T_b}\right) \quad (7)$$

Fig. 8 (a, b) shows the variations of irreversibility of water, glass, and basin of water, glass and basin of TSS using flat and finned absorber. It is clear that the irreversibility of basin is higher in both the case and the lower irreversibility occurs on water and glass. Also, on increased solar intensity falling on the solar still increased the irreversibility of each component. The average irreversibility rate of water, glass and basin using flat absorber is found as 26.45, 29.45 and 457.2 W respectively, whereas, for a finned absorber it is found as 24.6, 29.02 and 448.8 W respectively. It is observed that the irreversibility rate of finned absorber is reduced as compared to that of solar still using flat absorber. Also, from Fig. 8 (a) and (b) it is depicted that the irreversibility rate of water and glass were closer till reaching the peak solar intensity. From the previous literatures (Sarhaddi et al. (2017)) it is found that the irreversibility of solar still can be reduced by modifying the design of the absorber plate.

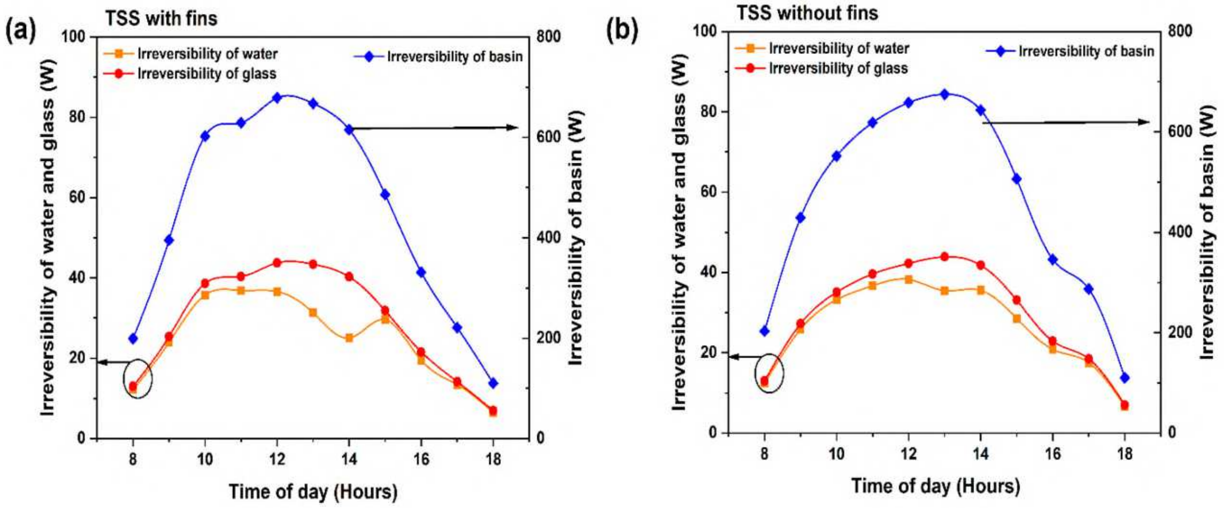

Fig. 8 Irreversibility of water, glass, and basin of TSS using (a) flat absorber and (b) finned absorber

3.4.Exergy efficiency

The exergy efficiency of the solar still is mathematically expressed as follows (Petla (2003); Hepbasli (2008)),

$$\eta_{exergy\ efficiency} = \frac{E_{out}}{E_{in}} \times 100 \quad (8)$$

The exergy output is mathematically expressed as (Petla (2003); Hepbasli (2008)),

$$E_{out} = E_{evaporation} = \frac{m_e}{3600} \times A_w \times h_{fg} \times \left(1 - \frac{T_a}{T_w}\right) \qquad (9)$$

Where,

h_{fg}- Latent heat of vaporization (kJ/kg)

T_w- Water temperature (K)

The exergy input is mathematically expressed as (Petla (2003); Hepbasli (2008)),

$$E_{in} = E_{sun} = A_w \times I(t) \times \left[1 - \frac{4}{3}\left(\frac{T_a}{T_{sun}}\right) + \frac{1}{3}\left(\frac{T_a}{T_{sun}}\right)^4\right] \qquad (10)$$

Where,

T_{sun}- Temperature of sun (T_{sun}=6000 K)

T_a- ambient temperature (K)

The exergy efficiency of the solar still increases with respect to time and the amount of solar radiation falling on the system. It is seen that the exergy efficiency of the both the solar still increases as the solar radiation increased and reaching the maximum of 11.8 and 10.6 % for finned and flat absorber respectively. During the start of experiment till reaching the maximum solar intensity the exergy efficiency of finned absorber TSS produced exergy efficiency.

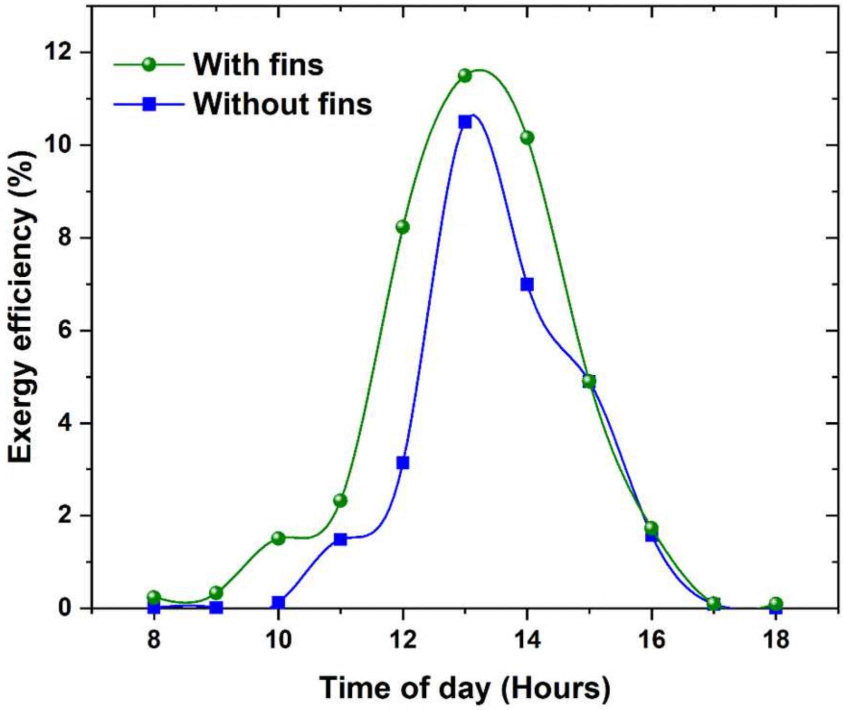

Fig. 9 Instantaneous variations on exergy efficiency from TSS using flat and finned absorber

4. Conclusions

The performance analysis of TSS with and without fins are investigated in this study. The findings of experimental and theoretical study show that the fins integrated with the basin of TSS augmented the performance and thermal efficiency higher than the TSS without fins. The distillate yield of TSS with fins is experimentally and theoretically higher than the TSS without fins. A cumulative distillate gain of 53.08 % implying an hourly thermal efficiency gain of 69.9% are recorded for the TSS with fins compared with the TSS without fins. The maximum daily distillate production has been found to be 2.93 l per day for TSS with fins. The use of fins in the basin of TSS enhanced the amount of heat absorbed by the absorber due to increase in the surface area of absorber plate which in turn results in the higher freshwater production compared to the TSS without fins. The rate of irreversibility is slightly reduced from the TSS using finned absorber while compared to the flat absorber. Similarly, by attaching fins in the absorber plate, the exergy efficiency is improved from the solar still while compared to solar still with flat absorber.

Ethical Approval

Not Applicable

Consent to Participate

Not Applicable

Consent to Publish

Not Applicable

Authors Contributions

Conceptualization, Methodology, Resources, Formal analysis, Writing - original draft preparation, review and editing, Supervision and investigation were carried out by Ravishankar Sathyamurthy, Abd Elnaby Kabeel, Ali Chamkha

Writing - original draft preparation, review and editing were carried out by Hemanth Arun Kumar, Hariprasath Venkateswaran, Athikesavan Muthu Manokar, Ramani Bharathwaaj, Sathiyaseelan Vasanthaseelan

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Competing Interests

The authors declare that there is no competing interest

Availability of data and materials

Not Applicable

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Figures

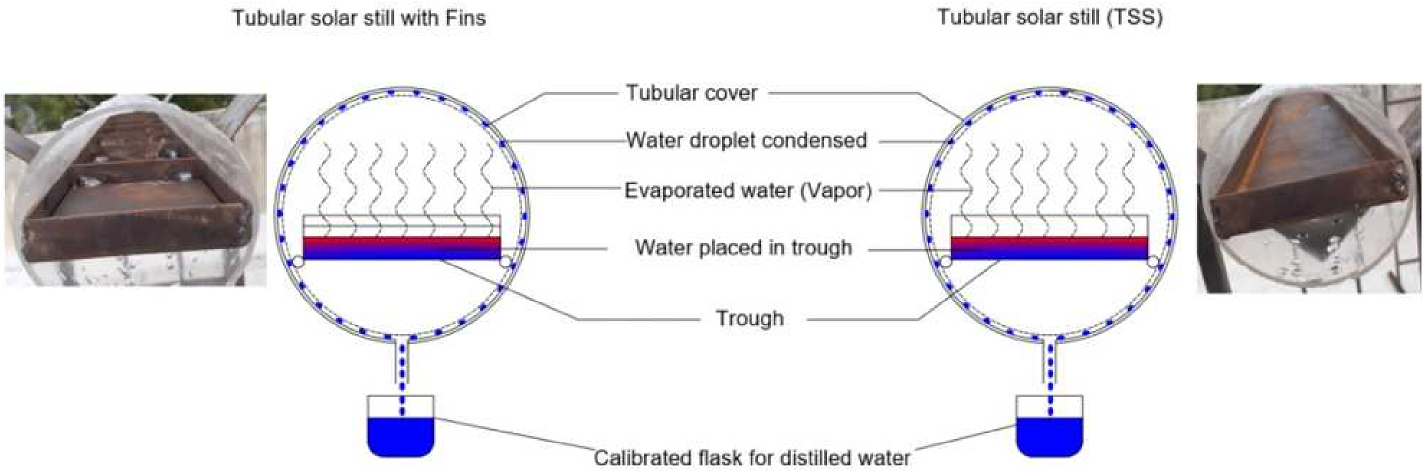


Figure 1

Schematic diagram and experimental test rig of TSS with fins (left) and without fin (right)

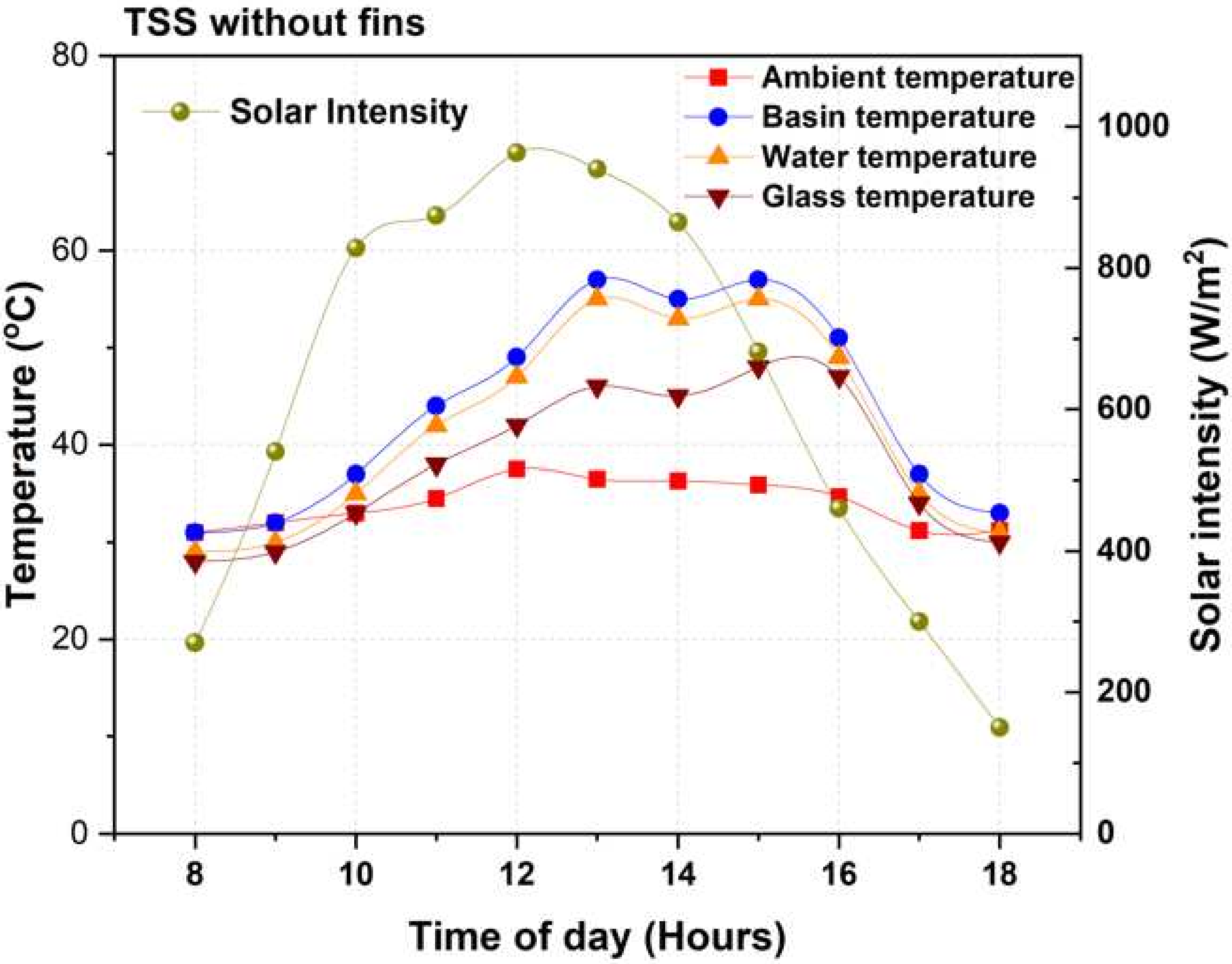

TSS without fins

Figure 2

Hourly variation in solar intensity, ambient, basin, water, and glass temperature recorded from TSS without fins

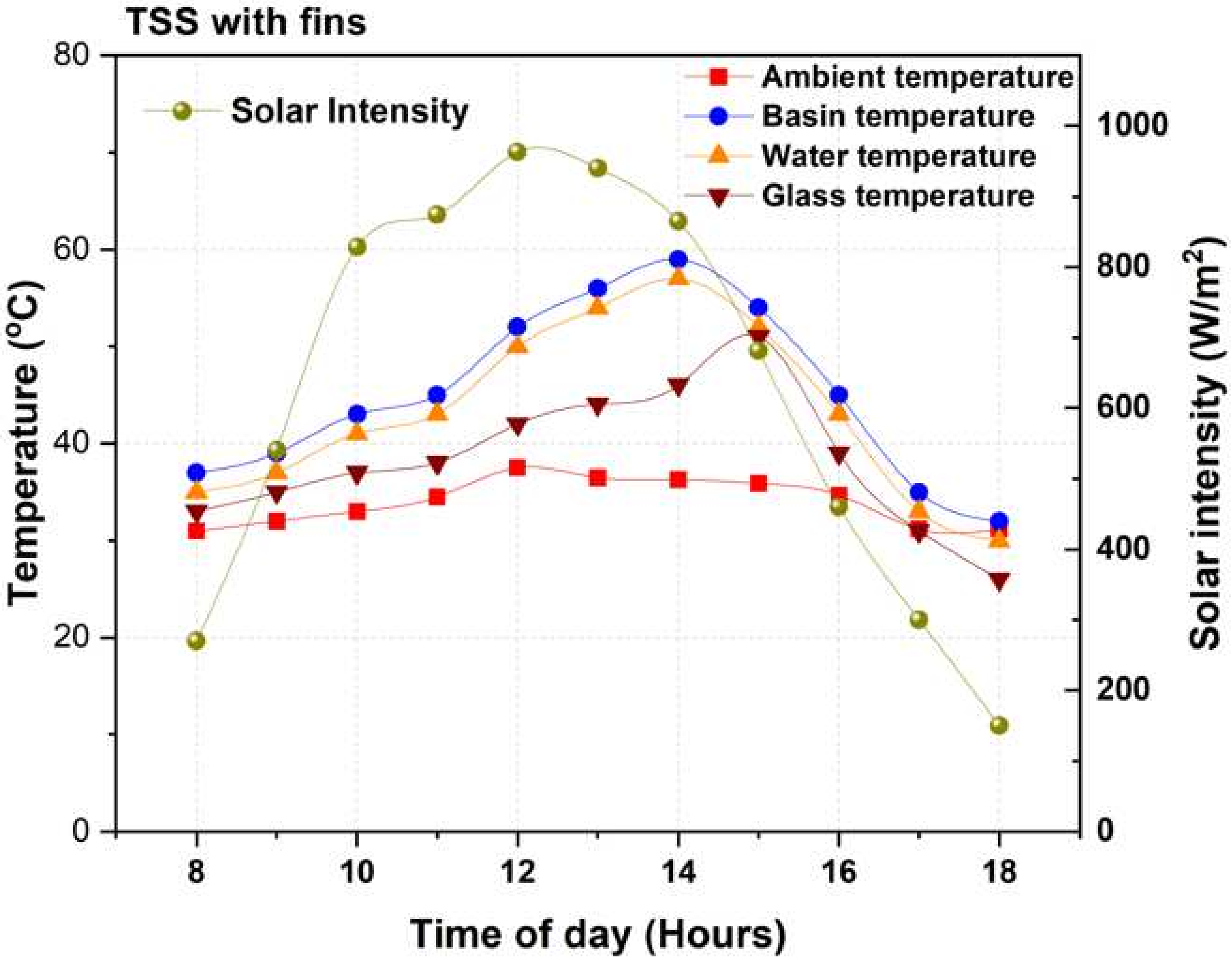


Figure 3

Hourly variation in solar intensity, ambient, basin, water, and glass temperature recorded from TSS with fins

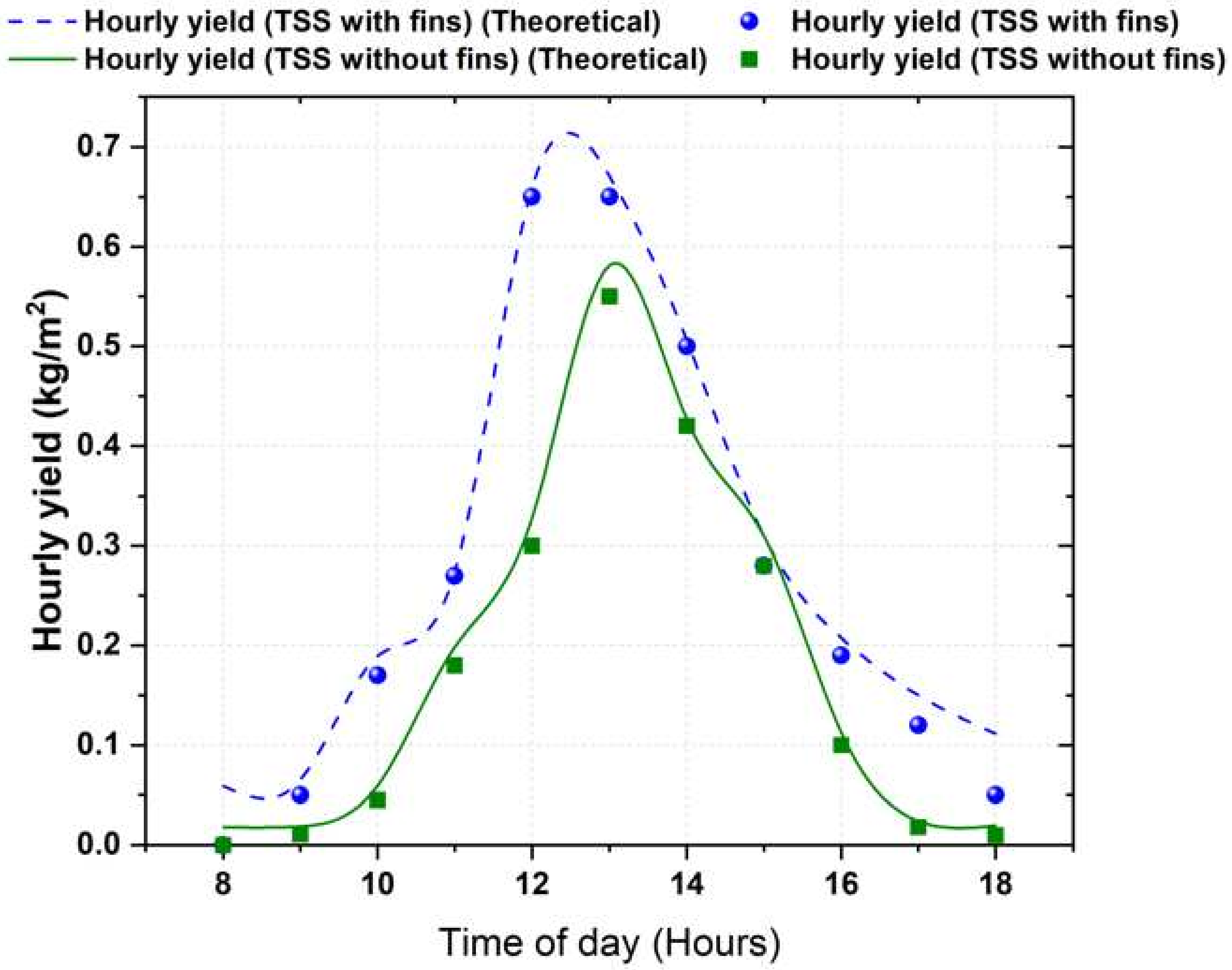
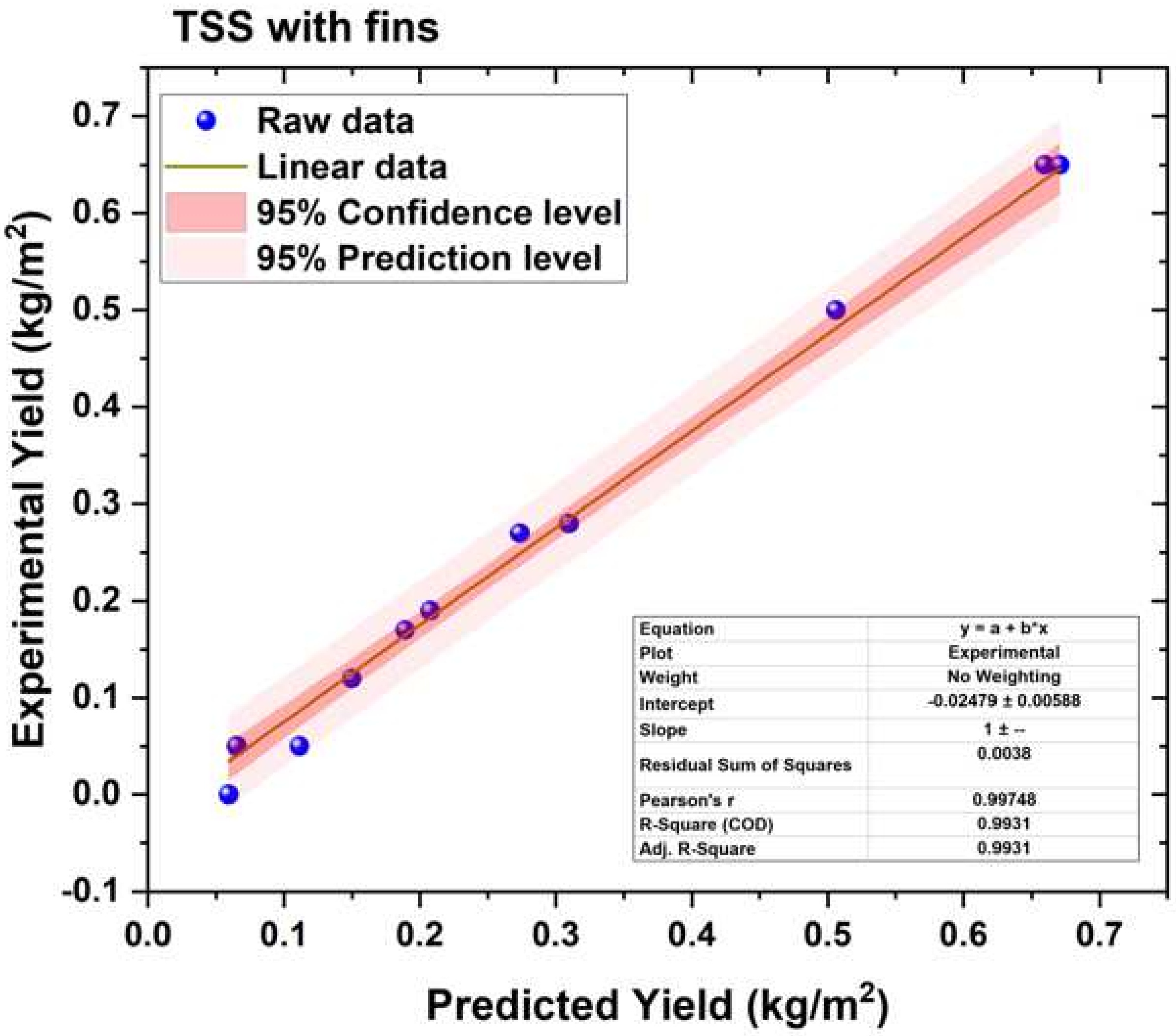


Figure 4

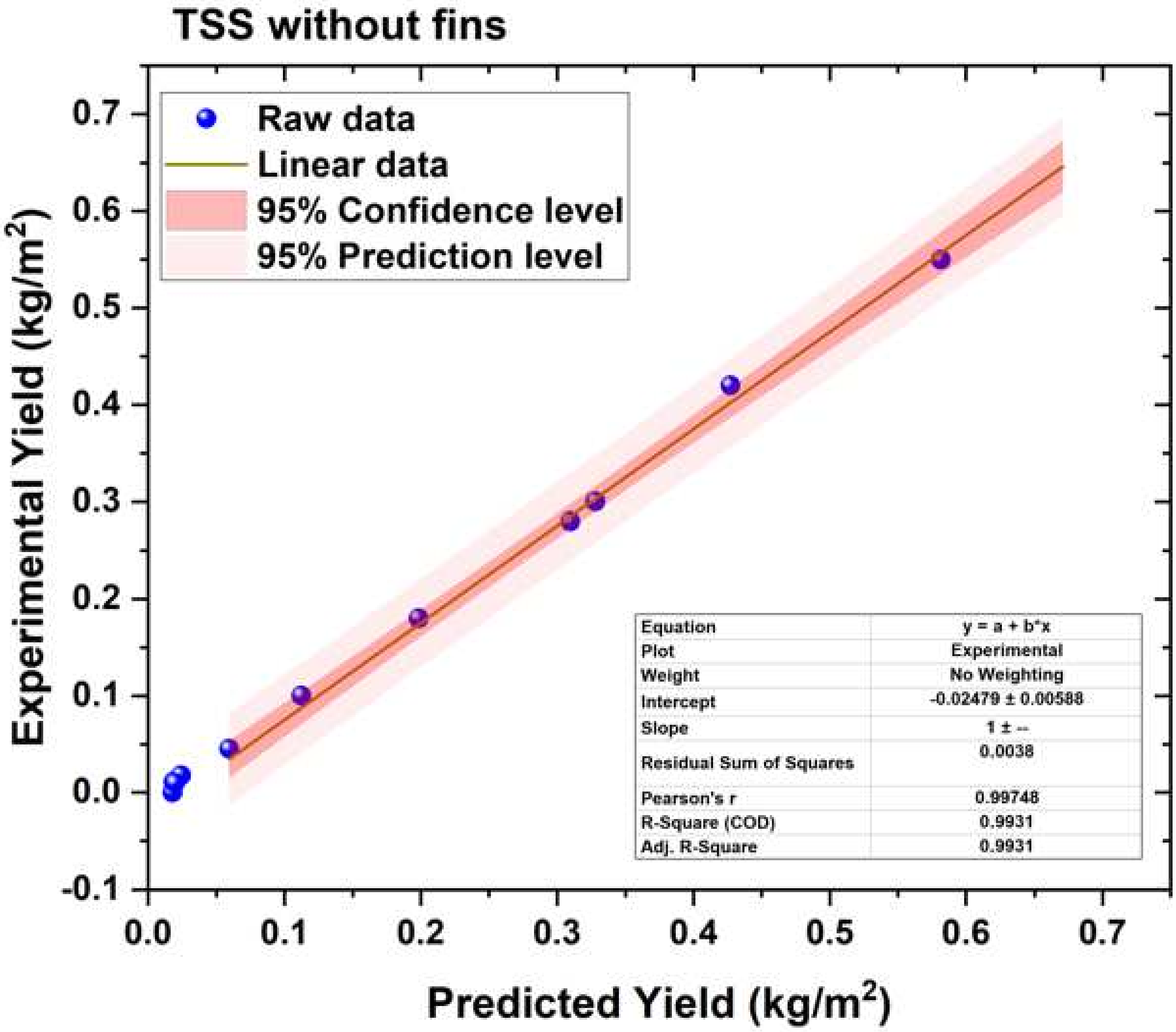
Hourly variation of theoretical and experimental distillate yield for TSS with and without fins.



Equation	y = a + b*x
Plot	Experimental
Weight	No Weighting
Intercept	-0.02479 ± 0.00588
Slope	1 ± --
Residual Sum of Squares	0.0038
Pearson's r	0.99748
R-Square (COD)	0.9931
Adj. R-Square	0.9931

Figure 5

Predicted and measured yield of TSS with fins



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Pearson's r	0.99748
R-Square (COD)	0.9931
Adj. R-Square	0.9931

Figure 6

Predicted and measured yield of TSS without fins

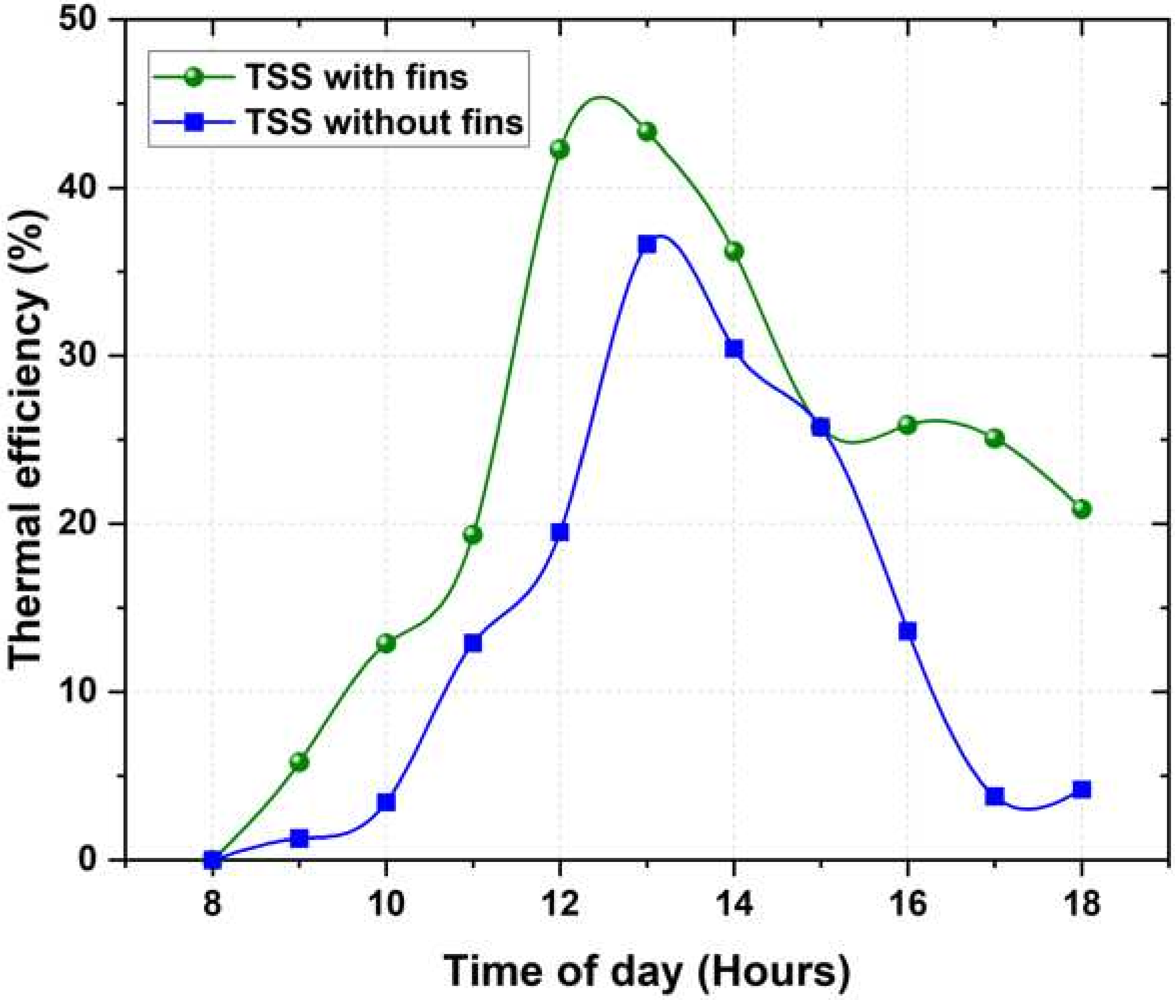

Figure 7

Instantaneous variations in thermal efficiency of TSS with and without fins.

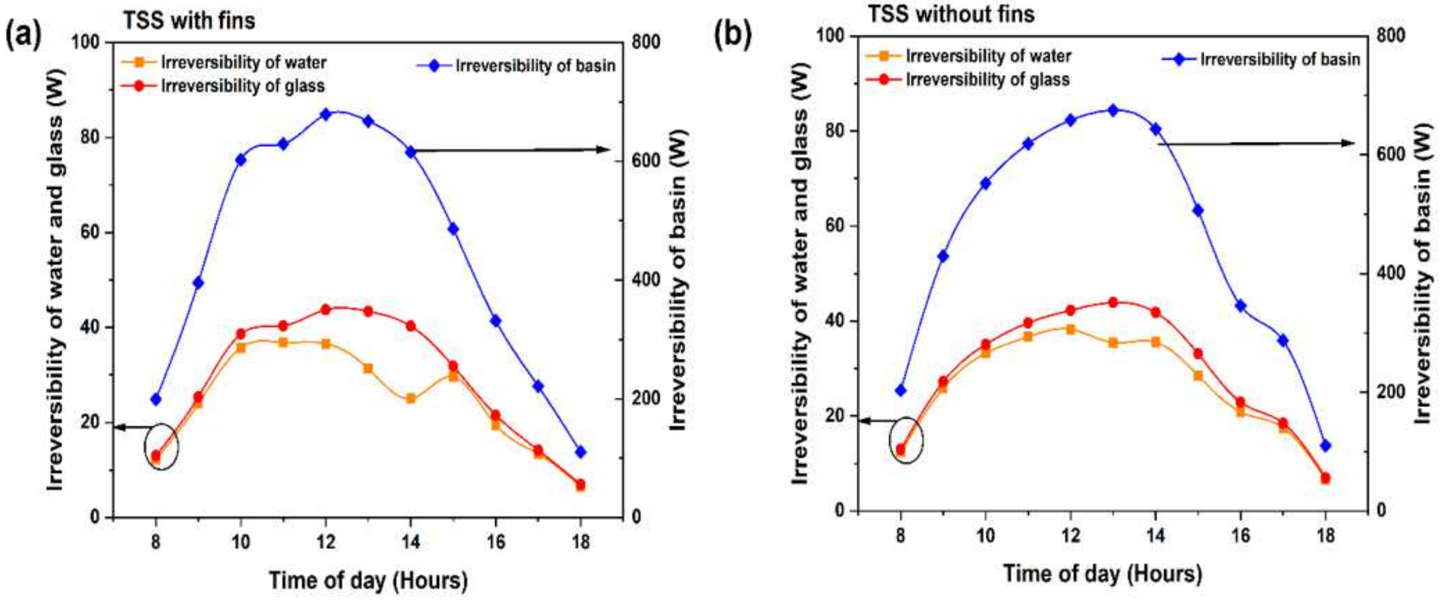

Figure 8

Irreversibility of water, glass, and basin of TSS using (a) flat absorber and (b) finned absorber

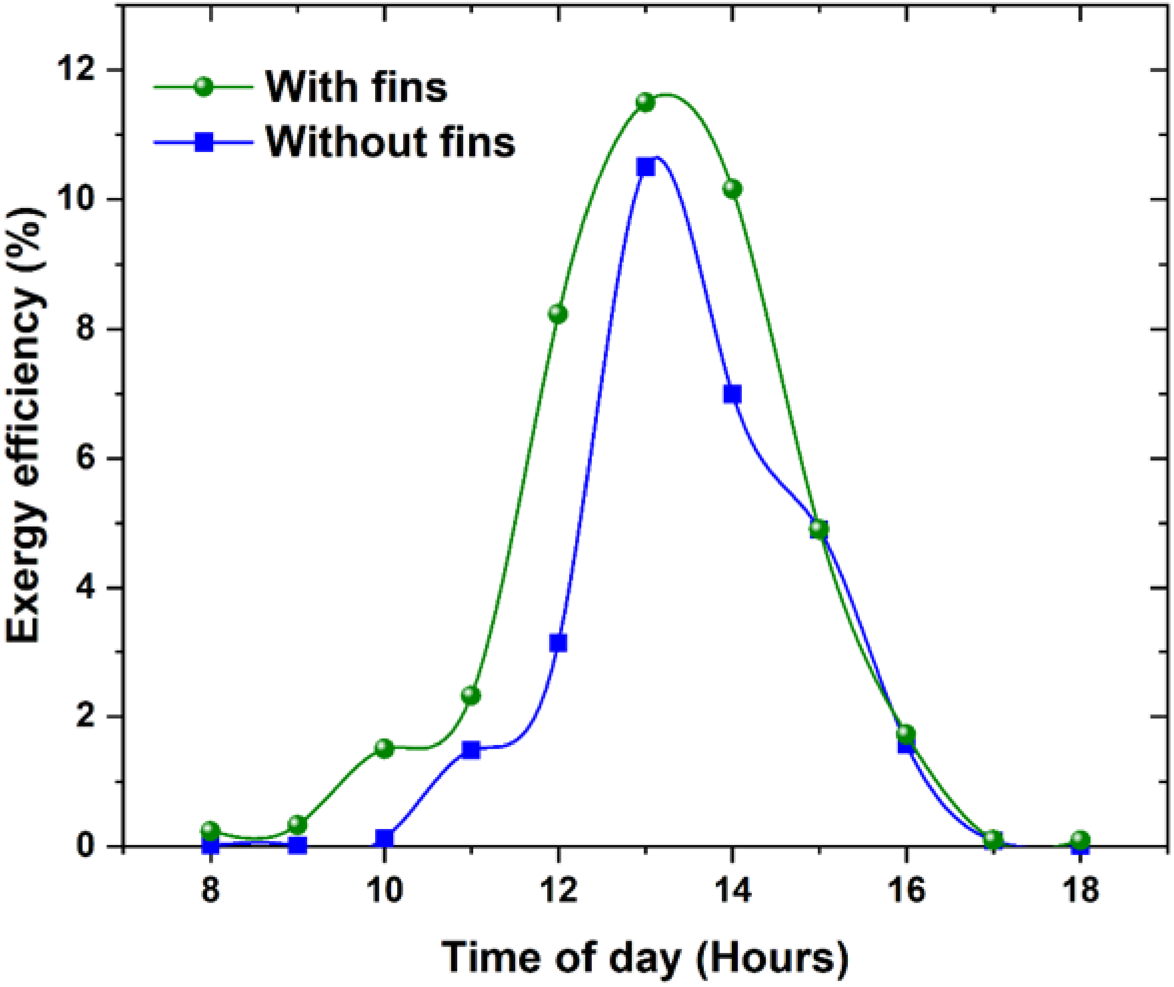

Figure 9

Instantaneous variations on exergy efficiency from TSS using flat and finned absorber