Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.30123

315 (2023) 173–181
December

Performance of single slope solar still coupled to integrated collection/storage type of solar water heater for Raipur, Chhattisgarh, India

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Received 5 September 2023; Accepted 1 November 2023

ABSTRACT

Solar stills provide better and economical options for getting clean water, especially in remote locations. In present work authors proposed an active solar still coupled to an integrated collection/storage type of solar water heater. Mathematical model of the proposed system has been developed to evaluate the thermal performance of the proposed system. Numerical computations have been performed considering the climate of Raipur, Chhattisgarh, India (21.2514°N, 81.6296°E). The effect of depth of water in solar still and the mass flow rate (MFR) of water flowing from heater into the solar still has been investigated. It is seen that the lower depth of water in basin gives more output in comparison to higher depth. At higher mass flow rate of water from solar water heater into the still, the output produced is more in comparison to low MFR. When the mass flow rate of water increased from 0.0020 to 0.012 kg/s the increased in the hourly output of still is about 51.4%. However, at higher MFR the pumping power required will be more. At 0.03 m water depth in basin the annual distillate output produced for Raipur is 2,288 kg/m^2 and when the depth of water is increased to 0.12 m the annual output produced is 705 kg/m^2 (MFR of water from pond is considered as 0.011 kg/s). when the depth of water is increased from 0.3 to 0.12 m the decrease in annual output is about 69.2%. The cost/liter of water produced from the proposed design is Rs. 1.08/L (US$ 0.013/L) for Raipur, Chhattisgarh, India (at 0.03 m water depth).

Keywords: Solar distillation; Solar water heater; Annual performance; Distillate output; Mass flow rate

1. Introduction

Drinking water scarcity is a major problem people are facing all over the world. Pure drinking water is the main international health issue today. The warm, arid regions of the Middle East and some parts of India experience the worst water shortages. Increased groundwater salinity and intermittent rainfall are characteristics of these regions. Increased industrialization and agricultural production have a greater impact on the contamination of freshwater supplies. Thermal desalination by solar energy is the process of obtaining potable water. Desalination uses solar energy to remove some portion of pure water from salinized water. It is one of the most renowned applications of renewable energies.

The solar distillation system is generally divided into either passive or active distillation. Passive desalination systems include works on single double-slope basin solar stills [1]. Single slope solar still (SSSS) gives more yield than double slope stills in cold climates, whereas in hot climates, double slope stills give better performance [2]. The passive solar stills include various design changes that include wick stills [3–6], diffusion stills [7,8], and multiple effects basin stills [9–11]. The number of design changes

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includes hemispherical stills [12], spherical stills [13], and pyramid-shaped stills [14]. Active solar distillation systems include the integration of solar stills with external heating sources, including solar ponds [15–17].

The active solar distillation system also includes works on still cover cooling, cover cooling by evaporatively cooled water [18], still integrated with an external condenser [19], and solar still integrated with a greenhouse [20]. The depth of water in basin and the mass flow rate (MFR) of water flowing into solar still from external heating source are key factors that affects the performance of an active solar distillation system. The effect of MFR of water and depth of water in still have been investigated by various researchers in past [21–32]. It is seen that the variations in water depth and MFR of water flowing affects thermal performance of active solar stills.

Coupling SSSS with solar flat plate collector and solar concentrating systems [33–36] gives reasonable annual output of about 2,400 L/m² (0.03 m depth) for Delhi, India when coupled to flat plate collector [33] and when SS coupled to concentrating systems (parabolic trough concentrator) the daily output reported was 11.14 L/m² [35]. Kabeel et al. [37] proposed an active solar distillation system coupled with parabolic dish concentrator (PDC) and reported 13.63 L/m²·d distillate output for the climate of Ismailia, Egypt. This seems to be a good alternative to fulfil the demand of pure water requirements but the main issue with this design is the increase cost of solar flat plate collector which enhances the overall cost of water produced this issue has been found as a research gap after reviewing literature on active solar still. To address this issue the objective of the present work is to explore the possibility of integrating an economical integrated collection/storage type of solar water heater (ICSSWH) with single slope solar still. The cost of ICSSWH is comparatively lesser than that of flat plate collector [39]. This will reduce the overall cost of water produced. Sodha et al. [39] proposed an economical ICSSWH consists of rectangular galvanized iron open shallow tank of area 1 m² the inner and bottom surfaces were blackened and the tank was covered by a transparent glass at the top in contact with water. The sides and bottom of the tank was insulated and assembly was encased in a wooden box.

In this work, we proposed this design of an active solar distillation system integrated with ICSSWH (Fig. 1). A mathematical model of this system has been presented. Numerical computations have been performed to analyse the effect of water depth in the basin of the still and the MFR of water into the solar still from the water heater. The monthly and yearly output of water produced by the proposed system has been numerically computed for Raipur, Chhattisgarh, India. The cost per liter of water generated (Rs/L) has been determined at different water depths.

2. *Mathematical model*

Assumptions:

(i) Entire unit is leak proof,
(ii) Quasi-steady state condition has been assumed,
(iii) Water and glass cover absorptivity is negligible,
(iv) Thermal capacity of glass and insulating material is neglected,
(v) All components of system is perfectly insulated,
(vi) Water heater is disconnected during no sunshine hours.

Energy balance equation for glass:

$$\alpha'_g I + h_1\left(T_w - T_g\right) = h_2\left(T_g - T_a\right) \tag{1}$$

$$h_1 = h_{\mathrm{cw}} + h_{\mathrm{ew}} + h_{\mathrm{rw}} \tag{2}$$

$$h_{\mathrm{cw}} = 0.884\left[\left(T_w - T_c\right) + \frac{\left(P_w - P_c\right)\left(T_w + 273\right)}{268.9\times10^{-3} - P_w}\right]^{1/3} \tag{3}$$

$$h_{\mathrm{ew}} = 16.273\times10^{-3} h_{\mathrm{cw}} \frac{\left(P_w - P_c\right)}{\left(T_w - T_c\right)} \tag{4}$$

$$h_{\mathrm{rw}} = \varepsilon_{\mathrm{eff}}\sigma\left[\left(T_w + 273\right)^2 + \left(T_g + 273\right)^2\right] \tag{5}$$

$$P_w = \exp\left[25.317 - \frac{5144}{T_w + 273.15}\right] \tag{6}$$

$$P_c = \exp\left[25.317 - \frac{5144}{T_c + 273.15}\right] \tag{7}$$

$$h_2 = h_{\mathrm{rg}} + h_{\mathrm{cg}} \tag{8}$$

$$h_{\mathrm{rg}} = \varepsilon_c\sigma\frac{\left[\left(T_c + 273\right)^4 - \left(T_a + 273\right)^4\right]}{\left(T_c - T_a\right)} \tag{9}$$

$$h_{\mathrm{cg}} = 5.7 + 3.8v \tag{10}$$

Energy balance of water in basin:

$$M_w c_w \frac{dT_w}{dt} = \alpha'_w I + Q_u - h_1\left(T_w - T_g\right) - h_b\left(T_w - T_b\right) \tag{11}$$

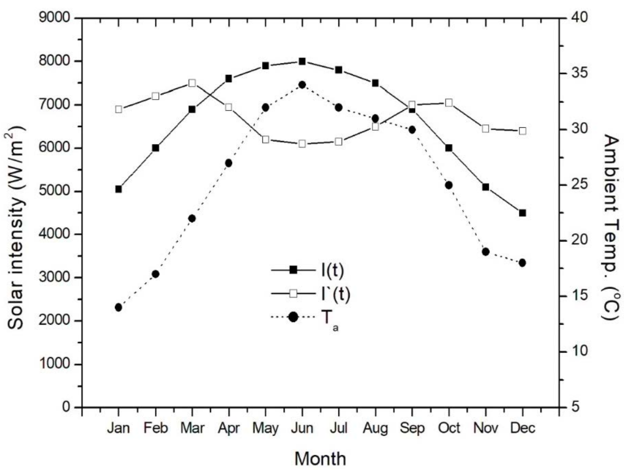

Fig. 1. Solar radiation and ambient temperature for Raipur climate.

$\dot{Q}_u$ is useful heat given by water heater, it is given by:

$$Q_u = \dot{m}_w c_w \left(T_{\mathrm{wt}} - T_w\right) \tag{12}$$

Energy balance of basin liner:

$$\alpha'_b I + h_2\left(T_w - T_b\right) = U_b\left(T_b - T_a\right) \tag{13}$$

Energy balance of solar water heater will be:

$$M_{\mathrm{wt}} c_w \frac{dT_{\mathrm{wt}}}{dt} = \left(\alpha\tau\right) I - U_l\left(T_{\mathrm{wt}} - T_a\right) \tag{14}$$

U_l is heat loss coefficient between water heater and ambient.

From Eq. (14) we have:

$$T_{\mathrm{wt}} = \frac{K_2(t)}{K_1}\left[1 - \exp\left(-K_1 t\right)\right] + T_{w0}\exp\left(-K_1 t\right) \tag{15}$$

In Eq. (15) the values of constants K_1 and $K_2(t)$ are given by:

$$K_1 = \frac{U_l}{M_{\mathrm{wt}} c_w}$$

$$K_2(t) = \frac{(\alpha\tau) I + U_l T_a}{M_{\mathrm{wt}} c_w}$$

From Eqs. (1) and (13):

$$T_g = K_3 + K_4 T_w \tag{16}$$

$$T_b = K_5 + K_6 T_w \tag{17}$$

The value of constants K_3, K_4, K_5 and K_6 will be given by:

$$K_3 = \frac{\alpha'_g I + h_2 T_a}{h_1 + h_2} \tag{18}$$

$$K_4 = \frac{h_1}{h_1 + h_2} \tag{19}$$

$$K_5 = \frac{\alpha'_b I + U_b T_a}{U_b + h_2} \tag{20}$$

$$K_6 = \frac{h_2}{U_b + h_2} \tag{21}$$

From Eq. (3) we have:

$$\frac{dT_w}{dt} + aT_w = f(t) \tag{22}$$

$$a = \frac{h_2 - h_2 K_6 - h_1 K_4 + m_w c_w + h_1}{M_w C_w} \tag{23}$$

$$f(t) = \frac{\alpha_w I + m_w C_w T'_{\mathrm{wt}} + h_1 K_3 + h_2 K_5}{M_w C_w} \tag{24}$$

From Eq. (22) the transient water temperature will be given by:

$$T_w = \frac{f(t)}{a}\left[1 - \exp(-at)\right] + T_{w0}\exp(-at) \tag{25}$$

T_{w0} is the temperature of water in basin of solar still at time $t = 0$ s.

The temperature of glass will be given by Eq. (16) and the temperature of water is given by Eq. (25). The hourly distillate output will be given by:

Eq. (17) can be solved to determine the water temperature; Eq. (15) will give the temperature of condensing cover. The hourly distillate output will be given by:

$$m_{\mathrm{ew}} = \frac{h_{\mathrm{ew}}\left(T_w - T_c\right)}{L} \times 3600\ \mathrm{kg/m^2h} \tag{26}$$

The monthly and yearly distillate output will be:

$$M_m = \sum_1^{24} m_{\mathrm{ew}} n \tag{27}$$

$$M_a = \sum_1^{12} M_m \tag{28}$$

The values of solar energy absorbed by glass, water and basin will be given by:

$$\alpha'_g = \left(1 - R_g\right)\alpha_g \tag{29}$$

$$\alpha'_w = \left(1 - \alpha_g\right)\left(1 - R_g\right)\left(1 - R_w\right)\alpha_w \tag{30}$$

$$\alpha'_b = \alpha_b\left(1 - \alpha_g\right)\left(1 - R_g\right)\left(1 - R_w\right)\alpha_w \tag{31}$$

R_g is solar flux reflected by glass, R_w is the solar flux absorbed by the water.

2.1. Value of solar radiation at inclination

The extra-terrestrial solar radiation is:

$$I_{\mathrm{ON}} = I_{\mathrm{sc}}\left[1 + 0.334\cos\left(\frac{360 \times n}{365}\right)\right] \tag{32}$$

Considering all the atmospheric parameters taken into account, the direct (normal) solar radiation will be:

$$I_N = I_{\mathrm{ON}}\exp\left(\frac{-T_R}{0.9 + 9.4\,\mathrm{Sin}\,\alpha_s}\right) \tag{33}$$

The turbidity factor (T_R) is given in Appendix-I.

$$\mathrm{Sin}\,\alpha_s = \mathrm{Sin}\,\delta\,\mathrm{Sin}\,\phi + \cos\delta\cos\phi\cos\omega \tag{34}$$

The beam, the diffuse and the global on a horizontal surface, are given as:

$$I_{\mathrm{HB}} = I_N \sin\alpha_s \quad (35)$$

$$I_{\mathrm{HD}} = \frac{1}{3}\left(I_{\mathrm{ON}} - I_N\right)\sin\alpha_s \quad (36)$$

$$I_{\mathrm{HG}} = I_{\mathrm{HB}} + I_{\mathrm{HD}} \quad (37)$$

Using Liu and Jordan [40] relation for the angle of incidence, θ_i:

$$\cos\theta_i = \sin\alpha_s \cos\beta + \sin\beta\cos\alpha_s \cos\left(\gamma - A_\omega\right) \quad (38)$$

Various intensities can be estimated on an inclined surface.

3. Numerical computations

Numerical computations have been performed to determine hourly, monthly, and annual yield from still coupled with integrated with solar water heater for the climate of Raipur, Chhattisgarh, India (21.25140N, 81.62960E). The average of ambient temperature and solar radiation for various months has been considered for computations (Fig. 1). The number of clear days in various months for Raipur is given in Appendix-I. Various parameters used for computation have been given in Table 1. For computations, the initial temperature of the glass cover and basin water (still and water heater) is assumed to be equal to the atmospheric temperature. The values of coefficients depending on temperature have been computed by using the initial values. The hourly yield is computed for 24 h. The cycle is repeated continuously until the point where the daily cycle repeats itself. The schematic of the setup is shown in Fig. 2.

Table 1
Design parameters of single slope solar still and solar water heater

Solar still	Solar water heater	Site parameter
$A_g = A_b = 1$ m^2	$A_p = 1$ m^2	Latitude = 21.25140N
$d_w = 0.03$–0.12 m	$C_w = 4{,}190$ J/kg·°C	Longitude = 81.62960E
$h_w = 100$ W/m^2	$\alpha\tau = 0.8$, $U_l = 23.2$ W/m^2·°C	$\omega = 15°$/h
$h_b = 0.8$ W/m^2·°C	$m_w = 0.0020$–0.012 kg/s	$I_{sc} = 1{,}367$ W/m

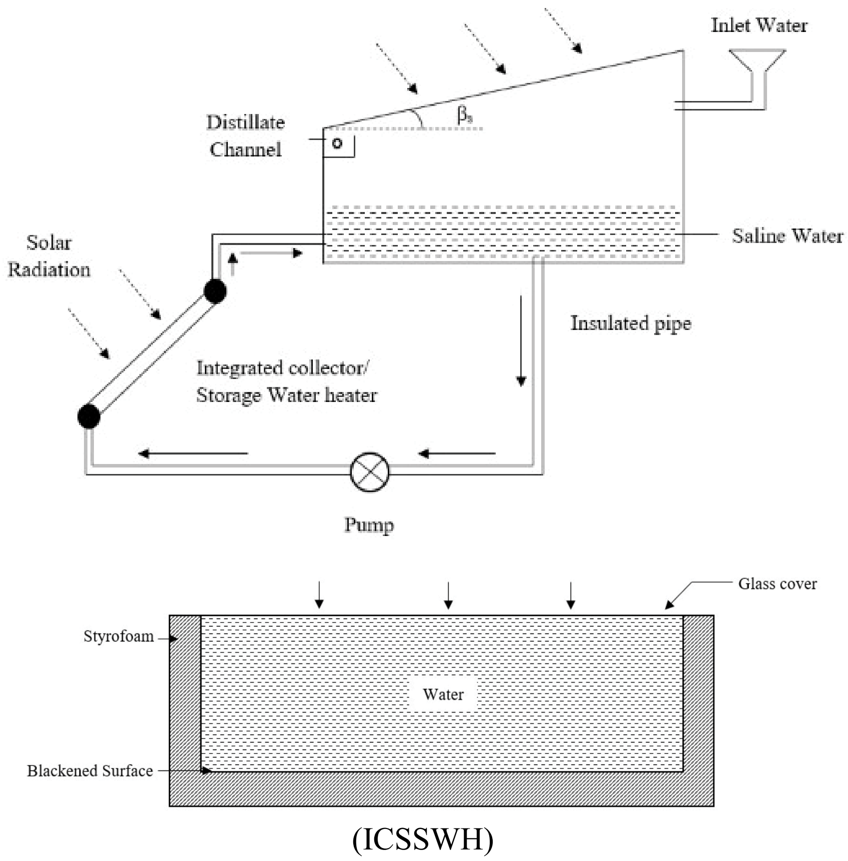

Fig. 2. Active single slope solar still coupled with ICSSWH.

3.1. Effect of MFR of water from water heater into still

The amount of water flown into the still from the solar water heater will directly affect the distillate output produced from SSSS. The effect of MFR on still performance has been computed. The depth of water in the basin of still is kept constant (3 cm). Numerical computations have been performed on a typical data set (T_a = 30°C, I = 500 W/m²) by varying the mass flow rate, *viz.*, 0.002, 0.006, 0.010 and 0.012 kg/s. The hourly distillate output increases by increasing the MFR of water. When the MFR of water increases from 0.002 to 0.012 kg/s, the increase in the distillate output is about 51.4% (Fig. 2). With an increase in the MFR of hot water flowing from the water heater into the solar still, the rate of addition of hot water to the still increases. This will increase the overall temperature of the water in the solar still and ultimately result in higher productivity. Although the output increases by increasing the flow rate of water, the required pumping power increases by increasing the MFR.

3.2. Annual performance of still and effect of water depth

Hourly, monthly and annual output has been computed by Eqs. (26)–(28). The outlet temperature of water from the water heater coming into the SS has been determined by Eq. (15). The MFR of water coming into the solar still has been considered as 0.010 kg/s. The value of solar radiation (inclined surface) is calculated by Eq. (37). Piping losses are neglected. Yield from the SS coupled with heater has been computed by varying the water depth into the basin of SS. The depth of water considered are 0.03, 0.06, 0.09 and 0.12 m. The average of solar radiation and ambient temperature for the composite climate of Raipur, Chhattisgarh, India has been considered for computing yield. Monthly average of meteorological data considered for numerical computations has been given in Fig. 2.

Water depth in basin affects the distilled produced, more depth increases the thermal capacity increase in temperature will be less that reduces the amount of water evaporated from still. At lower depth, the mass of water is less hence the increase in water temperature will be more this will enhance the rate of water evaporation indirectly the water condensate will increase. The same is reflected here in the analysis, numerical computations have been performed at various water depth to determine the output from still. The annual yield at 0.03 m water depth is 2,288 L/m² at 0.12 m water depth the total annual output produced is 705 L/m².

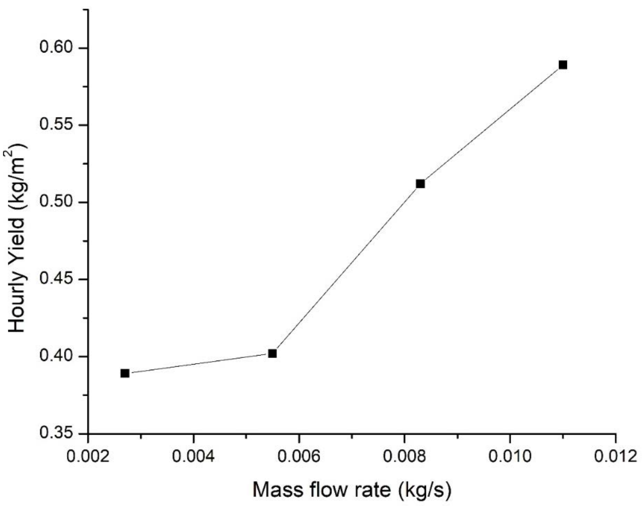

Fig. 3. Hourly distillate output at different mass flow rate.

The monthly yield of various months by varying the depth of water has been calculated and shown in Fig. 3. The monthly yield is maximum for April and May and around the month of October. The monthly distillate output is more during summer months of April and May due to higher ambient temperature and solar radiation.

4. Economic analysis

Simple technoeconomic analysis has been done and the cost of water produced by solar still. The initial cost of SS, solar water heater and other items are given:

Items	Cost
Single slope solar still	
(i) Glass 4 mm, 1 m²	Rs. 800/-
(ii) MS plate (body)	Rs. 3,500/-
(iii) Styrofoam insulation	Rs. 1,000/-
(iv) Glue, putty	Rs. 100/-
Solar water heater	
(i) MS plate rectangular section	Rs. 1,200/-
(0.5 m × 0.5 m × 0.1 m)	
(ii) Glass cover 4 mm, 0.5 m²	Rs. 500/-
(iii) Styrofoam	Rs. 600/-
(iv) Black paint	Rs. 150/-
Solar pump (20 W)	Rs. 600/-
Pipes, valve, fitting etc	Rs. 500/-
Total cost	Rs. 8,950/-

Total annual cost (TAC) is given by the study of Modi et al. [13]:

TAC = CC × CRF + AMC – SV × SFF

FAC = CC × CRF

Capital recovery factor is given by:

$$\text{CRF} = \frac{i \times (1+i)^n}{(1+i)^n - 1}$$

Sinking fund factor is given by:

$$\text{SFF} = \frac{i}{(1+i)^n - 1}$$

Cost/L = Total annual cost/annual yield

Assumptions:

1. Interest rate (i) is taken as 12%, total life of SS (n) is taken as 20 y,
2. Maintenance cost (annual) is taken as 15% of first annual cost,
3. For plant salvage value is taken as 50% of the cost of useable items.

TAC is computed and the cost/L of distilled water produced by the system is determined at different water depths in SS and shown in Fig. 5.

5. Results and discussions

An active solar distillation system in which SSSS integrated with ICSSSWH has been proposed in the present work. The cost of ICSSWH is less this will reduce the overall cost of water produced by the proposed system. In this work a mathematical model of the proposed system has been developed the model will help to determine the thermal performance of the proposed system. The annual performance of the proposed system has been computed for Raipur, Chhattisgarh, India. Daily, monthly and annual distillate output from the system has been computed. The monthly average of ambient temperature and solar radiation have been considered for computations. The inclination angle of solar still has been considered equal to latitude of Raipur. The value of solar radiation for inclined surface has been computed by the method proposed by Liu and Jordan (Section 2.1 – Value of solar radiation at inclination).

The depth of water in basin and the MFR of water coming from heater are the two important parameters which directly affects the performance of the proposed system. Authors investigated the effect of these two parameters on the distillate output produced by the proposed system at a typical set of climatic parameters. To analyse the effect of depth of water in basin the MFR of water flowing is kept constant and to analyse the effect of MFR the depth of water in basin in considered constant. It is seen that with increase in mass flow rate of water flowing from heater into the system the hourly distillate output increases as the rate of mixing of hot water (form heater) into the solar still is more. This helps to increase the temperature of water kept in basin of solar still. When MFR of water increases from 0.002 to 0.012 kg/s the hourly distillate output increases by 51.4%. With increase in the depth of water in basin the hourly distillate output decreases as the mass of water is more the temperature rise is less. When the depth of water increases from 0.03 to 0.012 m the annual distillate output of solar still decreases. The annual distillate output for Raipur is 2,288 L/m^2 at 0.03 m depth whereas the annual distillate output is 705 L/m^2 at 0.12 m water depth (MFR = 0.010 kg/s). When the depth of water increases to about 0.12 m the annual distillate output decreases by about 69.2%. The comparison of the present work with some of the works on active solar distillation system is shown in Table 2. It is seen that the output produced per day is maximum 13.63 L/m^2 when the solar still is coupled with PDC. The output annual output produced in present work is 2,288 L/m^2 the proposed design is simple and cost affective thus can be implemented easily.

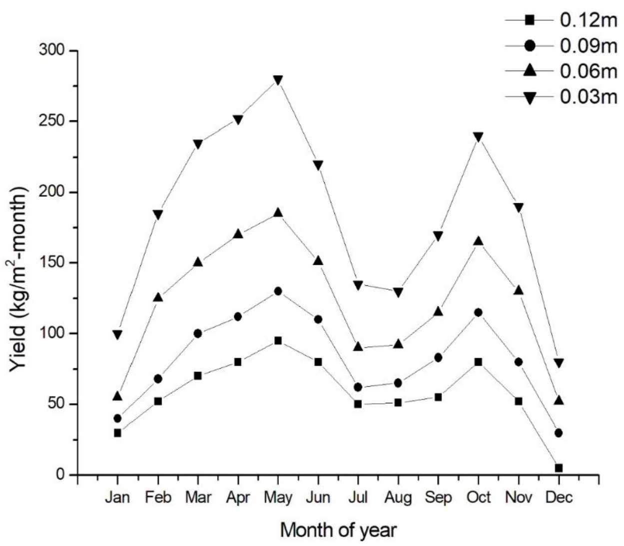

Fig. 4. Monthly yield for various months (Raipur).

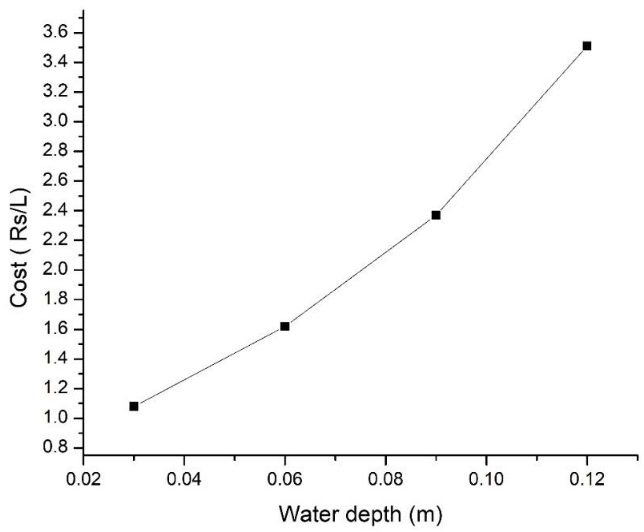

Fig. 5. Cost/L of water produced at different depths.

Table 2
Comparison of the present work with some other active distillation system

Authors	Type of active distillation system	Climate (latitude)	Result
Kumar et al. [33]	Solar still coupled with FPC	Delhi (28.6139° N, 77.2090° E)	2,400 L/m^2 (annual yield) 0.03 m depth
Kabeel and Abdelgaied [36]	Solar still + PTC + PCM	Tanta (30.7865° N, 31.0004° E)	10.77 L/m^2 (per day)
Kabeel et al. [37]	Solar still + PDC (2)	Ismailia (30.5965° N, 32.2715° E)	13.63 L/m^2 (per day)
Kumar et al. [38]	Solar still + ETC	Delhi (28.6139° N, 77.2090° E)	3.47 L/m^2 (per day)
Present work	Solar still + ICSSWH	Raipur (21.2514° N, 81.6296° E)	2,288 L/m^2 (annual yield 0.03 m depth)

The techno comic analysis has been performed to determine the overall cost of the water produced by the proposed system. It is seen that the overall cost of distilled produced for Raipur, Chhattisgarh, India is Rs. 1.08/L (US$ 0.013/L).

6. Conclusions

The following conclusions have been drawn from the proposed work:

(i) Mathematical model of the proposed active solar still has been developed. The model will help to determine the thermal performance of the proposed system.
(ii) With increase in MFR of water flowing into solar still from heater the hourly distillate output produced decreases. With increase in MFR from 0.002 to 0.012 kg/s the hourly distillate output increases by 51.4% (3 cm water depth in basin)
(iii) The depth of water in basin of solar still effects the amount of distillate output produced by the proposed system. For the climate of Raipur, the annual distillate output for Raipur is 2,288 L/m^2 at 0.03 m depth whereas the annual distillate output is 705 L/m^2 at 0.12 m water depth (MFR = 0.010 kg/s).
(iv) The monthly distillate output produced by the proposed system for Raipur is more for summer months April and May.
(v) The cost of the water produced by the proposed system for Raipur, Chhattisgarh, India is Rs. 1.08/L (US$ 0.013/L).
(vi) The technology can be commercialized to facilitate the production of pure water in remote regions as it is discovered that the proposed active solar distillation produces a respectable volume of pure water annually. A pilot solar distillation plant with a solar water heater can also be designed and developed using the suggested approach. Distilled water can be delivered using the suggested design for a fair price.

7. Future scope of work

It has been determined that the recommended active solar distillation system is an affordable and straightforward design to address the demand for pure water in remote places. Despite the suggested system being deemed appropriate, the following suggestions are made for further work:

(i) The idea can be used to wick-style solar stills. Due to the basin water's low heat capacity, the wick kind of solar still produces more during the day than a standard single slope solar still. The production will undoubtedly increase once the wick solar still is combined with a water heater.
(ii) Use of internal or external reflectors increases the amount of solar radiation received by solar still. The design may include the use of reflector to increase the overall production from the proposed active solar still.

Symbols

α'_g — Solar radiation absorbed by glass cover
I — Intensity of solar radiation, W/m^2
h_1 — Internal heat transfer coefficient, W/m^2·°C
h_2 — External heat transfer coefficient, W/m^2·°C
T_w — Water temperature, °C
T_g — Glass temperature, °C
$\dot{m}_w$ — Mass flow rate of water, kg/s
T_a — Ambient air temperature, °C
h_{cw} — Heat transfer coefficient due to convection between basin water and glass cover, W/m^2·°C
h_{ew} — Evaporative heat transfer coefficient between basin water and glass cover, W/m^2·°C
h_{rw} — Radiative heat transfer coefficient between basin water and glass cover, W/m^2·°C
M_w — Water mass in SS, kg
M_{wt} — Water mass in solar water heater, kg
P_w — Saturated vapour pressure of air at water temperature, N/m^2
P_g — Saturated vapour pressure of air at glass temperature, N/m^2
ε_{eff} — Effective emissivity
σ — Stefan's Boltzmann constant, W/m^2·K^4
C_w — Specific heat of water, J/kg·°C
T_{wt} — Water temperature in shallow pond, °C
h_b — Heat transfer coefficient between water and basin, W/m^2·°C
Q_u — Useful heat supplied to still from solar pond, W/m^2
U_t — Heat transfer coefficient from solar water heater, W/m^2·°C
α'_w — Solar flux absorbed by water
α'_b — Solar radiation absorbed by basin liner

Abbreviations

SSSS — Single slope solar still
SWH — Solar water heater
MFR — Mass flow rate
TAC — Total annual cost
CC — Capital cost
CRF — Capital recovery factor
AMC — Annual maintenance cost
SV — Salvage value
SFF — Sinking fund factor
FAC — First annual cost
FPC — Flat plate collector
ETC — Evacuated tube collector
PDC — Parabolic dish concentrator

References

[1] G.N. Tiwari, Solar Energy Fundamentals, Design Modelling and Applications, Narosa Publishing House, New Delhi, 2002.
[2] G.N. Tiwari, A.K. Tiwari, Solar Distillation Practice for Water Desalination Systems, Anamaya Publications, New Delhi, 2007.
[3] G. Frick, J. von Sommerfeld, Solar stills of inclined evaporating cloth, Sol. Energy, 14 (1973) 427–431.
[4] M.S. Sodha, A. Kumar, G.N. Tiwari, R.S. Tyagi, Simple multiple wick solar still: analysis and performance, Sol. Energy, 26 (1981) 127–131.
[5] G.N. Tiwari, S.B. Sharma, M.S. Sodha, Performance of a double condensing multiple wick solar still, Energy Convers. Manage., 24 (1984) 155–159.
[6] A.E. Kabeel, Performance of solar still with a concave wick evaporation surface, Energy, 34 (2009) 1504–1509.

[7] M.Z. Khan, Diffusion of single-effect vertical solar still fixed with inclined wick still: an experimental study, Fuel, 329 (2022) 125502, doi: 10.1016/j.fuel.2022.125502.

[8] H. Tanaka, T. Nosoko, T. Nagata, Experimental study of basin-type, multiple-effect, diffusion-coupled solar still, Desalination, 150 (2002) 131–144.

[9] B.-J. Lim, S.-M. Choi, S.-H. Cho, G.-R. Lee, C.-D. Park, Designs and performance analysis of vertical multi-effect diffusion solar distiller: a review, Desalination, 527 (2022) 115572, doi: 10.1016/j.desal.2022.115572.

[10] M. Kudret Selçuk, Design and performance evaluation of a multiple-effect, tilted solar distillation unit, Sol. Energy, 8 (1964) 23–30.

[11] H. Tanaka, Theoretical analysis of a vertical multiple-effect diffusion solar still coupled with a tilted wick still, Desalination, 377 (2016) 65–72.

[12] T. Arunkumar, R. Jayaprakash, D. Denkenberger, A. Ahsan, M.S. Okundamiya, S. Kumar, H. Tanaka, H.S. Aybar, An experimental study on a hemispherical solar still, Desalination, 286 (2012) 342–348.

[13] K.V. Modi, K.H. Nayi, S.S. Sharma, Influence of water mass on the performance of spherical basin solar still integrated with parabolic reflector, Groundwater Sustainable Dev., 10 (2020) 100299, doi: 10.1016/j.gsd.2019.100299.

[14] R. Sathyamurthy, H.J. Kennady, P.K. Nagarajan, A. Ahsan, Factors affecting the performance of triangular pyramid solar still, Desalination, 344 (2014) 383–390.

[15] G.S. Dhindsa, M.K. Mittal, Experimental study of basin type vertical multiple effect diffusion solar still integrated with mini solar pond to generate nocturnal distillate, Energy Convers. Manage., 165 (2018) 669–680.

[16] A.A. El-Sebaii, M.R.I. Ramadan, S. Aboul-Enein, N. Salem, Thermal performance of a single-basin solar still integrated with a shallow solar pond, Energy Convers. Manage., 49 (2018) 2839–2848.

[17] M. Appadurai, V. Velmurugan, Performance analysis of fin type solar still integrated with fin type mini solar pond, Sustainable Energy Technol. Assess., 9 (2015) 30–36.

[18] A. Somwanshi, A.K. Tiwari, Performance enhancement of a single basin solar still with flow of water from an air cooler on the cover, Desalination, 352 (2014) 92–102.

[19] A. Rahmani, A. Boutriaa, Numerical and experimental study of a passive solar still integrated with an external condenser, Int. J. Hydrogen Energy, 42 (2017) 29047–29055.

[20] F. Mahmood, T. Al-Ansari, Design and analysis of a renewable energy driven greenhouse integrated with a solar still for arid climates, Energy Convers. Manage., 258 (2022) 115512, doi: 10.1016/j.enconman.2022.115512.

[21] G.K. Sharma, A. Mallick, R.K. Sharma, N. Kumar, D.B. Singh, A comprehensive study on the effect of variation of flow rate of fluid and N on energy metrics of N similar photovoltaic thermal flat plate collectors integrated single slope solar still, Desal. Water Treat., 283 (2023) 97–108.

[22] D. Kumar, R.K. Sharma, D.B. Singh, Effects of dissimilarity of water depth on energy and exergy efficiencies and productivity of single slope solar still coupled to evacuated tubular collectors, Desal. Water Treat., 278 (2022) 301–310.

[23] D. Kumar, R.K. Sharma, S.K. Sharma, V.K. Dwivedi, S. Tiwari, D.B. Singh, Influence of dissimilarity of water depth on performance of N alike photovoltaic thermal flat plate collectors included with double slope solar still: a comparative study, Desal. Water Treat., 273 (2022) 13–33.

[24] G.K. Sharma, A. Mallick, R.K. Sharma, R. Dobriyal, N. Kumar, D.B. Singh, An investigation on dissimilarity of mass flow rate and N on exergo-enviro-economic parameters for solar still of single slope type integrated with N similar PVT flat plate collectors having series connection, Environ. Sci. Pollut. Res., 29 (2022) 65842–65859.

[25] V. Singh, R. Kumar, R.K. Sharma, S.P. Singh, H. Sinhmar, D.B Singh, An investigation on effect of variation of mass flow rate and number of collectors on yearly efficiency of single slope solar still by incorporating N similar photovoltaic thermal flat plate collectors, Water Supply, 22 (2022) 5126–5148.

[26] D. Kumar, R.K. Sharma, D.B. Singh, Effect of the variation of a mass-flow-rate and a number of collectors on the performance of an active solar still, Desal. Water Treat., 248 (2022) 1–17.

[27] R.K. Yadav, M. Kumar, J. Singh, D.B. Singh, N. Kumar, Effects of the dissimilarity of water depth on energy and exergy efficiencies and productivity of solar energy, Int. J. Exergy, 38 (2022) 333–345.

[28] V. Singh, R. Kumar, D.B Singh, An investigation on effect of dissimilarity of mass flow rate on hourly, daily and annual efficiencies of double slope type solar still included with N similar PVT compound parabolic concentrators, Desal. Water Treat., 246 (2022) 36–53.

[29] D.B. Singh, D. Kumar, R.K. Yadav, S.K. Sharma, Y. Chaturbedi, N. Kumar, V.K. Dwivedi, An investigation of effect of mass flow rate variation on productivity, exergoeconomic and enviroeconomic parameters of N similar PVTCPCs included with double slope solar still, Desal. Water Treat., 243 (2021) 1–17.

[30] D.B. Singh, R.K. Yadav, Y. Chaturbedi, M. Kumar, G.K. Sharma, N. Kumar, Study on effect of dissimilarity of mass flow rate on energy metrics of solar energy-based double slope water purifier by incorporating N alike PVT compound parabolic concentrator collectors, Desal. Water Treat., 231 (2021) 27–43.

[31] D.B. Singh, A. Raturi, N. Kumar, A. Nirala, A.K. Singh, S. Tiwari, Effect of flow of fluid mass per unit time on life cycle conversion efficiency of single slope solar desalination unit coupled with N identical evacuated tubular collectors, Mater. Today Proc., 28 (2020) 2096–2100.

[32] D.B. Singh, K. Navneet, Harender, K. Satish, S.K. Sharma, M. Ashis, Effect of depth of water on various efficiencies and productivity of N identical partially covered PVT collectors incorporated single slope solar distiller unit, Desal. Water Treat., 138 (2019) 99–112.

[33] S. Kumar, G.N. Tiwari, H.N. Singh, Annual performance of an active solar distillation system, Desalination, 127 (2000) 79–88.

[34] T. Rajaseenivasan, P. Nelson Raja, K. Srithar, An experimental investigation on a solar still with an integrated flat plate collector, Desalination, 347 (2014) 131–137.

[35] A.H. Mohammed, A.N. Shmroukh, N.M. Ghazaly, A.E. Kabeel, Active solar still with solar concentrating systems, review, J. Therm. Anal. Calorim., 148 (2023) 8777–8792.

[36] A.E. Kabeel, M. Abdelgaied, Observational study of modified solar still coupled with oil serpentine loop from cylindrical parabolic concentrator and phase changing material under basin, Sol. Energy, 144 (2017) 71–78.

[37] A.E. Kabeel, M.M. Khairat Dawood, K. Ramzy, T. Nabil, B. Elnaghi, A. Elkassar, Enhancement of single solar still integrated with solar dishes: an experimental approach, Energy Convers. Manage., 196 (2019) 165–174.

[38] S. Kumar, A. Dubey, G.N. Tiwari, A solar still augmented with an evacuated tube collector in forced mode, Desalination, 347 (2014) 15–24.

[39] M.S. Sodha, S.S. Mathur, M.A.S. Malik, Review of Renewable Energy Resources Vol-1, Wiley Eastern Limited, New Delhi, 1983.

[40] B.Y.H. Liu, R.C. Jordan, Daily insolation on surfaces tilted towards equator, ASHRAE Trans., 3 (1961) 526–541.

Appendix-I

Number of clear days in various months for Raipur, Chhattisgarh, India

Month	Number of clear days	Turbidity factor
January	19	3
February	25	3.2
March	27	3.5
April	29	3.9
May	30	4.1
June	25	4.2
July	15	4.3
August	14	4.2
September	17	3.9
October	28	3.6
November	29	3.3
December	18	3.1

Appendix II