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Effects of dissimilarity of water depth on energy and exergy efficiencies and productivity of single slope solar still coupled to evacuated tubular collectors

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ABSTRACT

This research work investigates the effect of variation of water depth in the basin on energy and exergy efficiencies and productivity of solar still of single slope type coupled to a number (N) of identical evacuated tubular collectors in series arrangement. The analysis has been done for archetypal days of June and January for the complex climate of New Delhi using computer codes written in MATLAB-2015a. The relevant data have been accessed from Indian Meteorological Department located at Pune in India. The optimum values of water depth for average daily efficiencies and productivity have been estimated to be, respectively, 0.56 and 0.42 m.

Keywords: Exergy; Efficiency; Productivity; Evacuated tubular collectors; Solar still

1. Introduction

The design and performance analysis of solar still in active mode is the necessity of contemporary time because of acute scarcity of fresh drinking water in remote locations throughout the world. The active type solar still incorporated with photovoltaic thermal can be installed at remote location for supplying potable water as well as electricity because the system is self-sustainable. Unlike conventional RO system for water purification, solar still works on energy received from sun, which is a gift by nature to the world. This energy is free of cost. The working principle of solar still is greenhouse effect. The solar still imitates the natural hydrological cycle. The loop is open in natural hydrological cycle; whereas loop is closed in the case of solar still. The active type solar still came into picture in 1983 for the first time in which a flat plate collector was included with solar still of single slope (SS) type. An improvement in the yield of 24% over conventional solar still having same area of cross section of the basin was reported due to the provision of heat by collector to the basin of solar still [1]. Since then, a lot of developments throughout the world have been reported.

Suneja and Tiwari [2] did transient study for double basin solar still having inverted absorber. They concluded that the daily freshwater yielding was increased with the rise in the value of water depth due to increased sensible heat of water mass. The value of potable water yielding decreases with enhancement in depth of water in the basin for the period of daytime due to storing of sensible heat by water mass; however, the production of fresh water was found to enhance with the enhancement in solar intensity as reported by Badran and Al-Tahaineh [3]. In another investigation, Khalifa and Hamood [4] studied SS type solar still in passive mode theoretically and consequently validated results experimentally. They concluded that the freshwater yielding was diminished

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with the enhancement in water depth during daytime due to increase in sensible heat storage by water mass in the basin. Further, recommendation of higher water depth value for solar still in active mode was made by Taghvaei et al. [5] for getting higher daily yield. Feilizadeh et al. [6] investigated solar still of SS type and reported that the nocturnal yield was increased with the increase in water mass in the basin due to sensible heat storage in daytime. Singh and Tiwari [7] investigated solar still of basin type included with photovoltaic thermal (PVT) integrated concentrators and reported results similar to earlier reported results by Taghvaei et al. [5].

Kabeel et al. [8] investigated solar still of pyramid type having titanium oxide coated absorber and concluded that freshwater yielding was 6.06% higher with coated absorber over uncoated absorber due to improvement in thermophysical property. It was also concluded that daily freshwater yielding was increased with the enhancement in water depth due to sensible heat storage of water mass. Singh et al. [9] reported similar result for SS solar still included with N similar PVT integrated flat plate collectors. Kabeel et al. [10] studied solar still of tubular type for daytime and reported that the freshwater yielding was higher for lower water depth during daytime due to less solar energy absorption of water mass in the form of sensible heat. Manokar et al. [11] and Modi et al. [12] investigated solar still of pyramid type and spherical type in that order and reported that the production of potable water was higher at lower water depth during daytime due to the less absorption of solar energy by water mass. Recently, Singh [13] has performed sensitivity analysis of solar still of double slope (DS) type in active mode by incorporating exergy and reported that the number of collectors was the most significant parameter because of having highest significant figures among all input parameters. Gül and Akyüz [14] have investigated solar photovoltaic thermal system experimentally from exergy viewpoint and concluded that hourly exergy efficiencies varied between 13.8% and 14.32%. Sharma et al. [15] validated solar still of double slope type experimentally by incorporating a number (N) of alike evacuated tubular collectors (ETCs). They reported values of correlation coefficients for glass cover and water temperatures and potable water yielding as 0.9932, 0.9928 and 0.9951, respectively.

Kumar et al. [16] have reviewed solar stills by incorporating ETCs and concluded that the performance of the system depends on the heat transfer rate from absorber tube to the working fluid. Raturi et al. [17,18] have investigated solar stills for sensitivity analysis by incorporating concentrator integrated ETCs and ETCs separately. They concluded that this type of analysis provides information to the designer and installer for focusing a particular parameter as the effect of input parameters on the output is known in advance. Singh et al. [19,20] have reported a study on the effect of mass flow rate (MFR) variation on DS by incorporating PVT concentrators and concluded that the exergy-based performance parameters decrease initially with the variation in MFR and then becomes almost constant after MFR reaches a value of 0.11 kg/s. Singh et al. [21] studied the effect of variation of water mass on solar still by incorporating ETCs and concluded that the daily efficiency first increases with the increase in water mass and then becomes almost constant. Kumar et al. [22] have reviewed the solar still analysis using computational fluid dynamics approach and concluded that this technique seems to be one of the potent tools used for analysis.

From extant research, one can conclude that the effect of dissimilarity of water depth on the performance parameter of some solar stills has been studied. However, study of the effect of the dissimilarity of water depth on the performance of solar stills of many other types including solar still of SS type included to N identical evacuated tubular collectors (NETCs) has not been carried out till date. NETC-SS has been analysed for energy, exergy, cost, exergo-enviro-economic and energy metrics analyses; however, effect of water depth on efficiencies and productivity has not been reported in the available literature. Hence, this research article deals with the effect of dissimilarity of water depth on efficiencies and productivity for NETC-SS. The main objectives of the research work are as follows:

- To estimate hourly thermal and exergy efficiencies and productivity followed by the computation of their daily values at optimum number of ETCs (N) and fluid mass flow per unit time ($\dot{m}_f$) for various values of water depth for NETC-SS.
- To compute average daily thermal and exergy efficiencies and productivity at selected values of N and $\dot{m}_f$ for various values of water depth for NETC-SS.

2. Description of SS type solar still type coupled to N alike ETCs

Fig. 1 represents the setup of solar still of SS types integrated with NETCs. The system contains NETCs having series arrangement, pump and solar still. Geometrically, ETC contains vacuum between two concentric cylinders. The cylinders are made of glass. The vacuum does not allow convective heat loss. So, heat loss is lower in ETC as compared with other types of collectors. The inner side of inner glass cover is made black using paint so that this surface can work as an absorber plate. U-tube made of copper has been placed inside the inner glass cylinder. The tube made of copper is provided because of its good thermal conductivity property.

The basin area having rectangular shape has been considered as 2 m × 1 m and it has been oriented south for getting highest yearly energy gain. The material for solar still has been taken as glass reinforced plastic and galvanized iron for the stand material. The inclination of condensing cover made of glass having 0.004 m thickness has been considered as 15° because most of the season in New Delhi is summer. The thermal conductivity of glass is 0.816 W/m-K and that of insulation is 0.166 W/m-K. The thickness of insulation is 0.1 m. The radius of copper tube used in ETC is 0.0125 m and its thickness is 0.0005 m. The outermost radius of glass tube in ETC is 0.024 m and its thickness is 0.002 m. Values of absorptivity of absorber plate, transmissivity of glass, length of ETC and angle of ETC are 0.80, 0.95, 2 m and 30°, respectively. The collector has been oriented towards south for getting better energy gain.

The solar flux having short wavelength reaches the water surface after partly reflection and absorption by the condensing cover. Again, water surface reflects some part,

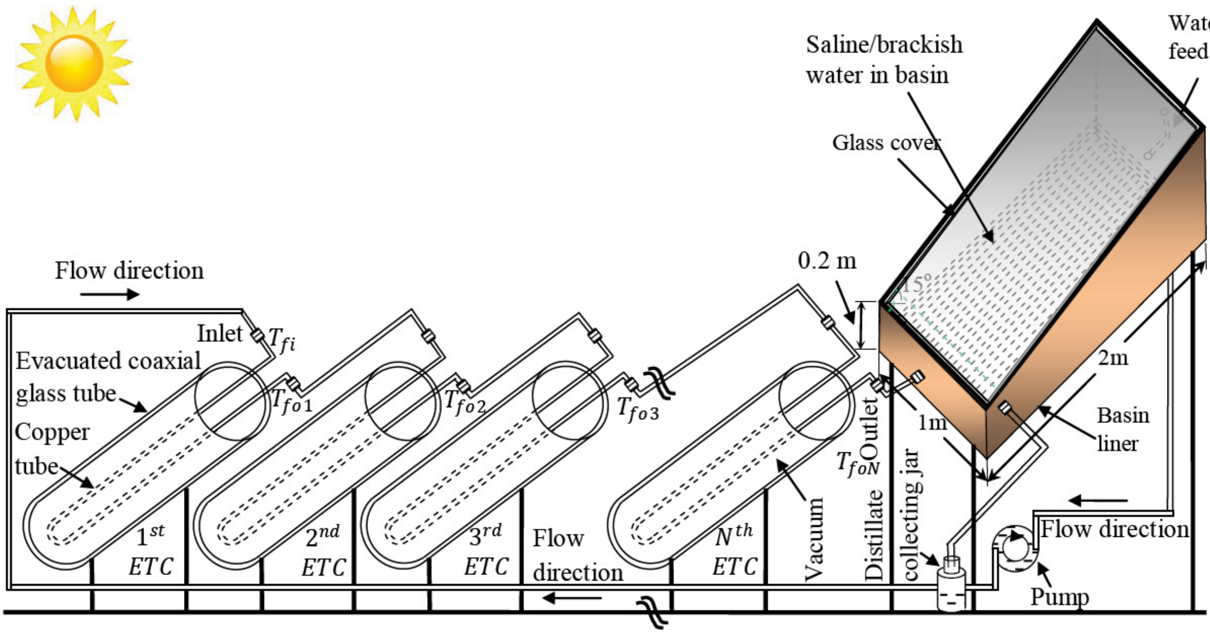

Fig. 1. Schematic diagram of NETC-SS.

a part of energy is absorbed by water and the remaining energy goes to blackened surface kept just below the water mass. The temperature of basin liner rises, and it further transmits heat to water mass. The water temperature value increases due to heat received from sunlight, basin liner and collectors. Due to difference of temperatures between inner side of glass cover and water surface, water gets evaporated, which further gets condensed at inner side of glass cover through film wise condensation. The condensed water comes down along inner side of glass cover, which is collected in a jar. An opening at the bottom of solar still is provided for flushing out sediments after a certain period of time.

3. Mathematical equations

The rate of useful heat ($\dot{Q}_{uN}$) and temperature at the exit of last collector (T_{foN}) from series connected N identical ETCs can be written as [23]:

$$\dot{Q}_{uN} = \frac{\left(1-K_k^N\right)}{\left(1-K_k\right)}\left(AF_R(\alpha\tau)\right)_1 I(t) + \frac{\left(1-K_k^N\right)}{\left(1-K_k\right)}\left(AF_R U_L\right)_1 \left(T_{fi}-T_a\right) \quad (1)$$

$$T_{foN} = \frac{\left(AF_R(\alpha\tau)\right)_1}{\dot{m}_f C_f}\frac{\left(1-K_k^N\right)}{\left(1-K_k\right)} I(t) + \frac{\left(AF_R U_L\right)_1}{\dot{m}_f C_f}\frac{\left(1-K_k^N\right)}{\left(1-K_k\right)} T_a + K_k^N T_{fi} \quad (2)$$

Now, energy balance equations for outer surface of condensing cover, inner surface of condensing cover, basin liner and water mass can be, respectively, written as:

$$\frac{K_g}{L_g}\left(T_{gi}-T_{go}\right)A_g = H_{1g}\left(T_{go}-T_a\right)A_g \quad (3)$$

$$\alpha'_g I_S(t) A_g + h_{1w}\left(T_w - T_{gi}\right)A_b = \frac{K_g}{L_g}\left(T_{gi}-T_{go}\right)A_g \quad (4)$$

$$\dot{Q}_{uN} + \alpha'_W I_S(t) A_b + h_{bw}\left(T_b - T_W\right)A_b = h_{1w}\left(T_W - T_{gi}\right)A_b + M_W C_W \frac{dT_W}{dt} \quad (5)$$

$$\alpha'_b I_S(t) A_b = h_{bw}\left(T_b - T_W\right)A_b + h_{ba}\left(T_b - T_a\right)A_b \quad (6)$$

Following Singh et al. [24], Eqs. (3)–(6) can be solved with the help of Eq. (1) to get water temperature (T_w) and glass cover temperature at the inner surface (T_{gi}) as follows:

$$T_W = \frac{\bar{f}(t)}{a}\left(1-e^{-at}\right) + T_{W0}e^{-at} \quad (7)$$

$$T_{gi} = \frac{\alpha'_g I_S(t) A_g + h_{1W} T_W A_b + U_{cga} T_a A_g}{U_{cga} A_g + h_{1W} A_b} \quad (8)$$

The various unknown terms used in all the equations. are given in the appendix of the study by Singh et al. [24]. After evaluating the values of T_w and T_{gi} from Eqs. (1) and (2), respectively, one can evaluate the value of hourly freshwater output as:

$$\dot{m}_{ew} = \frac{h_{ewg} A_b \left(T_W - T_{gi}\right)}{L'} \times 3{,}600 \quad (9)$$

All unknown terms used in Eqs. (1)–(9) can be seen in Singh et al. [24].

4. Analysis

The analysis for knowing the effect of dissimilarity of water depth on efficacies and productivity of solar still of SS type coupled to N alike ETCs by incorporating exergy can be carried out as follows:

4.1. Thermal efficiency

The thermal efficiency can be computed by considering first law of thermodynamics as the basis. The values of hourly and daily thermal efficiencies of NETC-SS can be expressed as follows [24]:

$$\eta_{\text{hourly,thermal}} = \frac{\left[h_{\text{ewg}} \times A_b \times \left(T_W - T_{\text{gi}}\right)\right]}{\left[\dot{Q}_{\text{uN}}\left(t\right) + \frac{A_b}{2}\left(I_S\left(t\right)\right) + \frac{P_u}{0.38}\right]} \times 100 \quad (10)$$

$$\eta_{\text{daily,thermal}} = \frac{\sum_{t=1}^{24}\left[h_{\text{ewg}} \times A_b \times \left(T_W - T_{\text{gi}}\right)\right]}{\sum_{t=1}^{24}\left[\dot{Q}_{\text{uN}}\left(t\right) + \frac{A_b}{2}\left(I_S\left(t\right)\right) + \frac{P_u}{0.38}\right]} \times 100 \quad (11)$$

where $\dot{Q}_{\text{uN}}\left(t\right)$ is hourly heat gain from N similar ETCs having series connection and its expression can be seen in Singh et al. [24]. P_u is the pump work. Numerators in Eqs. (10) and (11) indicate hourly and daily energy outputs from the system, respectively. h_{ewg} indicates evaporative heat coefficient from water to inner side of glass cover. A_b and $I_s(t)$ indicate, respectively, basin liner area and solar intensity impinging on glass cover. All unknown terms in Eqs. (10) and (11) can be seen in Singh et al. [24]. One can note that values of solar flux, useful heat gain and pump work used in Eqs. (10) and (11) are zero for nighttime. However, the production of fresh water and hence energy output from solar still of SS type will continue to get collected during nighttime also because of storing of sensible heat by water mass during daytime. The value of latent heat is considered as 2,400 kJ/kg.

4.2. Exergy efficiency

The value of exergy efficiency can be computed taking first and second laws of thermodynamics as the basis. The value of exergy efficiency per hour as well as per day basis for NETC-SS has been computed as follows [25]:

$$\eta_{\text{hourly,exergy}} = \frac{A_b\left[h_{\text{ewg}} \times \left\{\left(T_W - T_{\text{gi}}\right) - \left(T_a + 273\right) \times \ln\frac{\left(T_W + 273\right)}{\left(T_{\text{gi}} + 273\right)}\right\}\right]}{\dot{m}_f \times C_f \times \left[\left(T_{\text{foN}} - T_{\text{fi}}\right) - \left(T_a + 273\right) \times \ln\frac{\left(T_{\text{foN}} + 273\right)}{\left(T_{\text{fi}} + 273\right)}\right] + \left[0.933 \times A_b \times \left(I_S\left(t\right)\right)\right] + P_u} \times 100 \quad (12)$$

$$\eta_{\text{daily,exergy}} = \frac{\sum_{t=1}^{24}\left[A_b\left[h_{\text{ewg}} \times \left\{\left(T_W - T_{\text{gi}}\right) - \left(T_a + 273\right) \times \ln\frac{\left(T_W + 273\right)}{\left(T_{\text{gi}} + 273\right)}\right\}\right]\right]}{\sum_{t=1}^{24}\left[\dot{m}_f \times C_f \times \left[\left(T_{\text{foN}} - T_{\text{fi}}\right) - \left(T_a + 273\right) \times \ln\frac{\left(T_{\text{foN}} + 273\right)}{\left(T_{\text{fi}} + 273\right)}\right] + \left[0.933 \times A_b \times \left(I_S\left(t\right)\right)\right] + P_u\right]} \times 100 \quad (13)$$

Values of all unknown terms in Eqs. (12) and (13) can be seen in Singh et al. [24]. Numerators in Eqs. (12) and (13) indicate hourly and daily exergy outputs from the system. T_a, C_f, T_{foN} and T_{fi} indicate ambient temperature, specific heat capacity of fluid (water), temperature at the end of Nth collector and temperature at the inlet of first collector in that order. The value of solar flux has been multiplied by 0.933 to get the value of corresponding exergy and the factor 0.933 used in Eqs. (12) and (13) can be computed using the expression reported by Petela [26].

4.3. Hourly and daily productivity

The value of productivity per hour as well as per day basis for solar still of SS type coupled to N alike ETCs can be computed as [27]:

$$\text{Hourly productivity} = \frac{\left[\text{Hourly yield} \times \left(\text{SP}\right)_W\right]}{\text{Hourly cost} + \left(\text{Hourly pump work} \times \left(\text{SP}\right)_e\right)} \times 100 \quad (14)$$

$$\text{Daily productivity} = \frac{\left[\text{Daily yield} \times \left(\text{SP}\right)_W\right]}{\text{Daily cost} + \left(\text{Daily pump work} \times \left(\text{SP}\right)_e\right)} \times 100 \quad (15)$$

The value of production of fresh water on per hour basis from solar still of SS slope type coupled to N identical ETCs can be estimated using Eq. (9). The value of production of fresh water on per day basis from NETC-SS has been found by summing the value of production of fresh water on per hour basis for 24 h and pump work on per day basis can be computed by summing pump work on per hour basis for 10 h. The value of cost on per day basis has been computed by dividing uniform end-of-year annual cost (UNEAC) with 365 d. Further, the cost on per hour basis has been computed by dividing cost on per day basis with 24 h.

The value of UNEAC for the system named NETC-SS can be estimated as [28]:

$$\text{UNEAC} = \left(\text{PRC} \times \text{CARF}\right) + \left(\text{MTC} \times \text{CARF}\right) - \left(\text{SLV} \times \text{SIFF}\right) \quad (16)$$

where PRC is present cost of NETC-SS, SLV reveals salvage value of NETC-SS and MTC reveals cost of maintaining NETC-SS. The expression for MTC of NETC-SS can be estimated as multiplication of PRC with 0.1. The factor 0.1 is maintenance cost factor. It has been taken as 10%. Expressions of all unknown terms used in Eq. (10) can be seen in Singh and Tiwari [29]. CARF and SIFF reveal capital recovery factor and sinking fund factor, respectively. The cost of different components of NETC-SS has been revealed as Table 1. The life span of the system has been considered as 50 y and that of pump as 10 y. Values of UNEAC have been revealed as Table 2. The selling price of water has been considered as ₹5 and that for electricity as ₹5.

5. Methodology

The methodology followed for the computation of parameters for NETC-SS can be stated as follows:

Step I

The value of solar flux on the flat (horizontal) surface as well as surrounding temperature is taken from Indian Metrological Department situated at Pune in India. The expression presented by Liu and Jordan [29] is used to estimate the value of solar flux for the surface at an angle with horizontal surface at 30° north latitude with the help of MATLAB (R2015a) provided by Math Works.

Step II

The parameters namely T_w and T_{gi} of NETC-SS have been computed using Eqs. (7) and (8) in that order followed by the estimation of hourly and daily thermal efficiencies at different water depths using Eqs. (10) and (11) in that order.

Step III

The hourly exergy efficiency and daily exergy efficiency at different water depths for NETC-SS have been estimated using Eqs. (12) and (13) in that order. They have been evaluated for different water depth and compared.

Step IV

The average daily thermal and exergy efficiencies have been estimated considering two months namely June (summer) and January (winter) at different water depths to assess the effect of water depth on the performance of NETC-SS.

Step V

The hourly and daily productivity at different water depth for NETC-SS have been obtained using Eqs. (14) and (15), respectively. The average daily productivity has been computed considering two months namely June and January at different water depths to assess the effect of water depth on the performance of NETC-SS. The flow chart of methodology has been depicted as Fig. 2.

6. Results and discussion

The code for computation of various required parameter is written in MATLAB (R2015a). All required input data such as solar flux, surrounding temperature and velocity of air blow are provided to MATLAB. All required equations are also fed to MATLAB (R2015a). The value of solar flux on flat (horizontal) surface and surrounding temperature is depicted in Fig. 3a. Values of output received from MATLAB after running the code is depicted in Figs. 3b–6. Optimum values of $\dot{m}_f$ and N are 0.016 kg/s and 12 in that order as reported in Singh and Tiwari [30]. Selecting these values of $\dot{m}_f$ and N, further calculations have been presented in the paragraphs that follow.

The dissimilarity of thermal efficiency on per hour basis of NETC-SS at optimum values of $\dot{m}_f$ and N for a normal day of June has been revealed as Fig. 3b. Further, Fig. 4a depicts the dissimilarity of thermal efficiency on per hour basis of NETC-SS at optimum values of $\dot{m}_f$ and N for a normal day of January. One can observe from Figs. 3b and 4a

Table 1
Capital investments for solar energy operated water purifier of single slope type coupled to *N* alike ETCs

S. No.	Parameter	Cost (₹) of *N*-ETC-SS
1	Cost of solar still	23,143
2	Cost of ETC @ ₹10,500 each	22,590
3	Cost of motor and pump	1,000
4	Fabrication cost	6,000
5	Salvage value of the system after 50 y, if inflation remains @ 4% in India, [using present value of scrap material sold in Indian market]	32,501

Table 2
Value of UNEAC solar energy operated water purifier of single slope type coupled to *N* alike ETCs (*N* = 12)

n	i	P_s	M	S_s	$F_{CR,i,n}$	$F_{SR,i,n}$	UEAC
y	%	₹	@10%	₹	Fraction	Fraction	₹
50	2	55,231.28	5,523.128	32,501	0.031823	0.01182	1,549.226
50	5	54,381.56	5,438.156	32,501	0.054777	0.00478	3,121.39
50	10	53,346.59	5,334.659	32,501	0.100859	0.00086	5,890.581

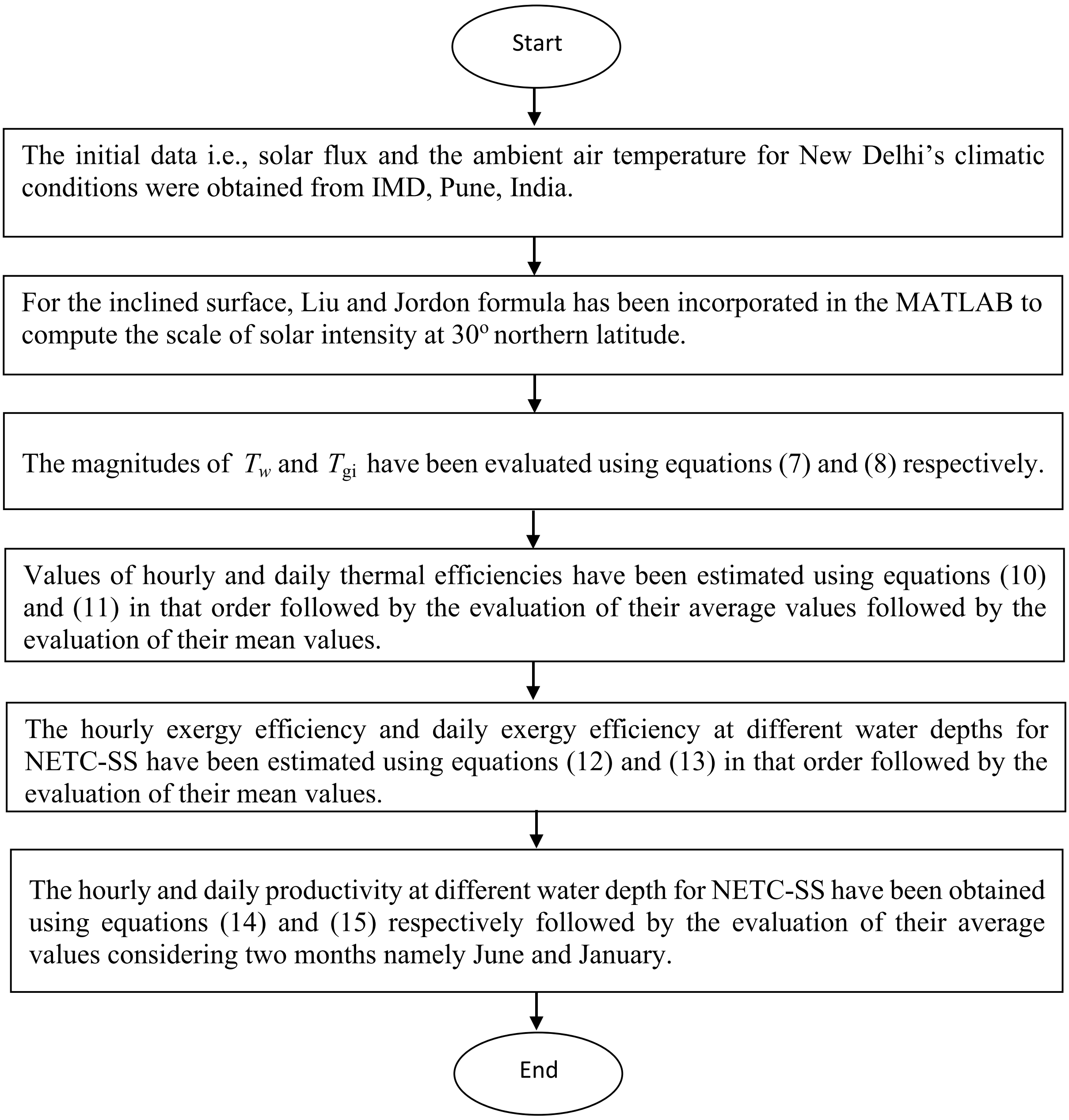

Fig. 2. Flow chart representing the estimation of effect of variation of water depth on the performance of NETC-SS.

that the value of thermal efficiency on per hour basis for NETC-SS diminishes with the enhancement in the value of water depth as per the expectation. It has been found to occur due to diminished values of water mass temperature in the basin at enhanced values of water depth. Also, difference in temperatures of water in basin and inside surface of glass becomes lower at increased depth of water. These two factors are responsible for lower production of fresh water at higher water depth in the basin during daytime.

The dissimilarity of exergy efficiency on per hour basis for NETC-SS at optimum values of $\dot{m}_f$ and N for a normal day of June is depicted in Fig. 4b. Further, Fig. 5a depicts the dissimilarity of exergy efficiency on per hour basis for NETC-SS at optimum values of $\dot{m}_f$ and N for a normal day of January. One can observe from Figs. 4b and 5a that the hourly exergy efficiency of NETC-SS diminishes with the enhancement in water depth for the daytime as expected. The reason being that water mass temperature in basin diminishes as the value of water depth enhances. Further, the difference in temperatures of water in basin and inside surface of glass becomes lower at increased depth of water. These two factors are responsible for lower exergy gain by NETC-SS during sunshine hours (daytime). Also, exergy output is the function of temperature, and it is a high-grade energy, which basically reveals the quality of energy. So, lower exergy

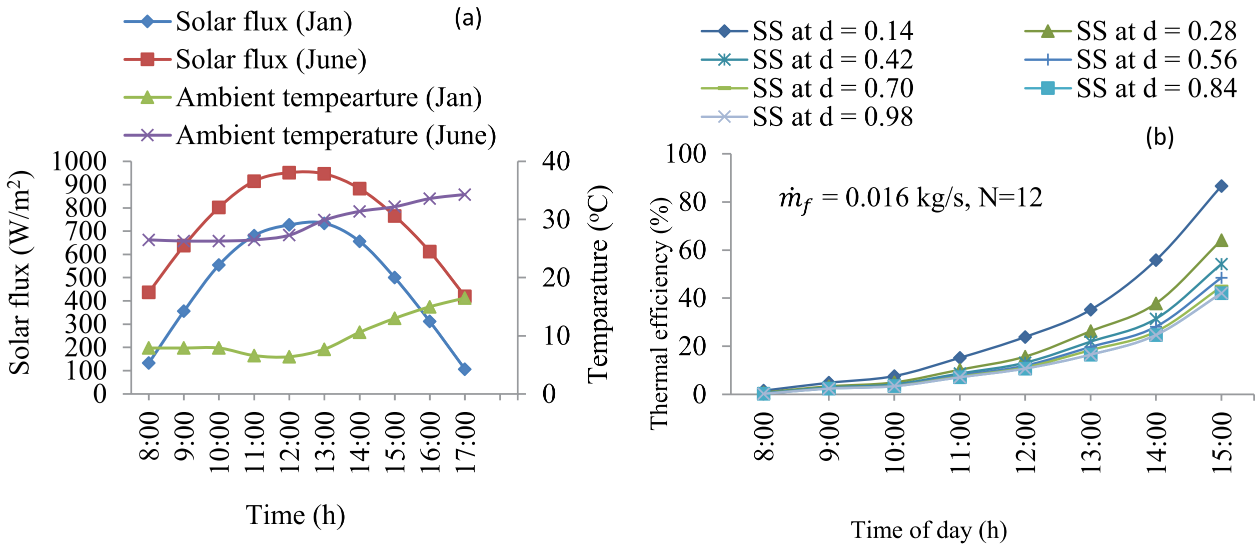

Fig. 3. (a) Hourly dissimilarity of solar intensity on the horizontal surface and surrounding temperature and (b) hourly dissimilarity of thermal efficiency of solar still of single slope type coupled to *N* alike ETCs for a typical day of June.

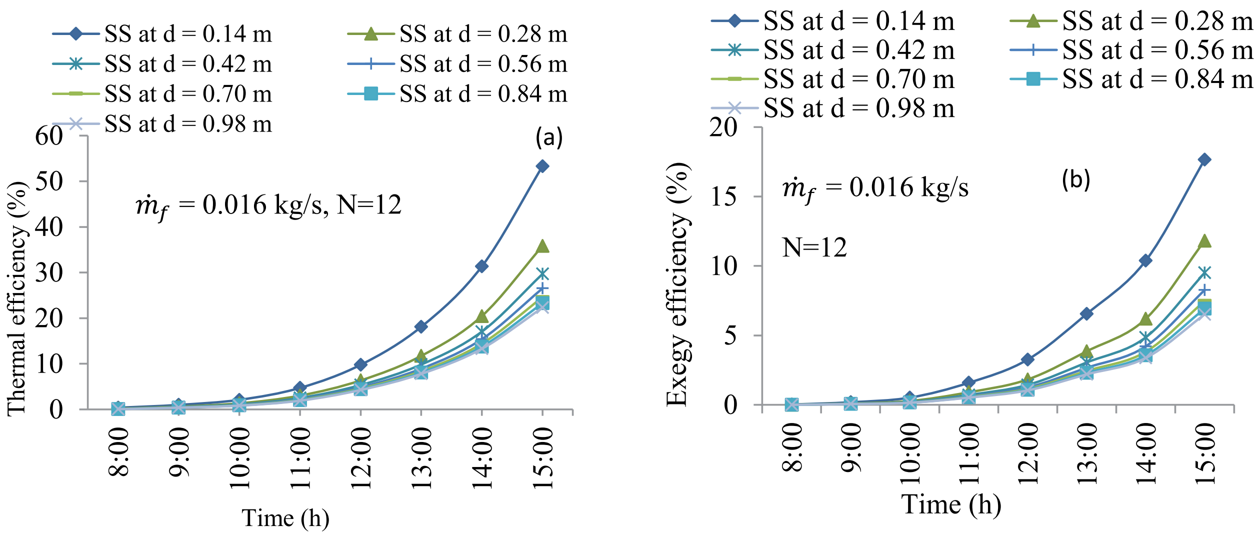

Fig. 4. (a) Hourly dissimilarity of thermal efficiency of NETC-SS for an archetypal day of January and (b) hourly dissimilarity of exergy efficiency of NETC-SS for an archetypal day of June.

is gained by NETC-SS at lower temperature because of higher loss.

The dissimilarity of hourly productivity of NETC-SS at optimum values of $\dot{m}_f$ and N for a normal day of June has been revealed as Fig. 5b. Further, Fig. 6a depicts the dissimilarity of hourly productivity of NETC-SS at optimum values of $\dot{m}_f$ and N for a normal day of January. Values of interest rate, life span of NETC-SS and the price of fresh water on per kg basis produced from NETC-SS are considered as 5%, 50 y [30] and ₹5, respectively, for the computation of values of UNEAC for NETC-SS. Considering the cost of different components of NETC-SS, the value UNEAC has been estimated using Eq. (16). The value of productivity has been estimated using Eqs. (14) and (15). One can observe that the value of productivity on per hour basis for NETC-SS diminishes as water depth gets enhanced during daytime. Further, during night time, value of productivity on per hour basis for NETC-SS increases with enhancement in water depth. It has been found to occur because fresh water yielding from NETC-SS diminishes as depth of water enhances during daytime because of diminished enhancement in temperature, which is responsible for diminished difference of temperatures between surface of water in basin and inner plane of condensing surface. During night time, an opposite phenomenon is observed because the production of fresh water from NETC-SS enhances because the enhanced sensible heat gets stored by water mass in the basin during daytime at increased water depth and this increased stored sensible heat is utilized at nighttime.

Fig. 6b depicts the dissimilarity of mean thermal efficiency, exergy efficiency and productivity on per day basis with depth of water at optimum values of $\dot{m}_f$ and N for NETC-SS. The mean value of daily thermal and exergy efficiencies of NETC-SS first increases till 0.56 m water depth and then diminishes. It has been found to occur because energy as well as exergy output initially increases till 0.56 m of water depth due to the utilization of sensible heat of water mass. After, 0.56 m of water depth, efficiencies have been found to diminish because energy output during daytime overcomes the energy output during nighttime due to increased water mass. A similar behavior has been obtained in mean average productivity. Also, average daily productivity depends on average daily yield and daily cost. The optimum values of thermal and exergy efficiencies have been obtained corresponding to 0.56 m water depth; however, the mean daily productivity has been obtained to 0.42 m water depth.

7. Conclusions

The theoretical analysis has been carried out for NETC-SS to assess the effect of water depth on thermal efficiency, exergy efficiency and productivity. Conclusions of the current research work are as follows:

- Hourly thermal and exergy efficiencies and productivity of NETC-SS have been found decreasing with increase in water depth during daytime. However, productivity has been found increasing with the increase in depth of water during nighttime.
- The average daily thermal and exergy efficiencies first rise and then decrease. The optimum value of water depth for mean daily thermal and exergy efficiencies viewpoints is 0.56 m.
- The average daily productivity first rises and then decreases. The optimum value of water depth for average daily productivity viewpoints is 0.42 m.

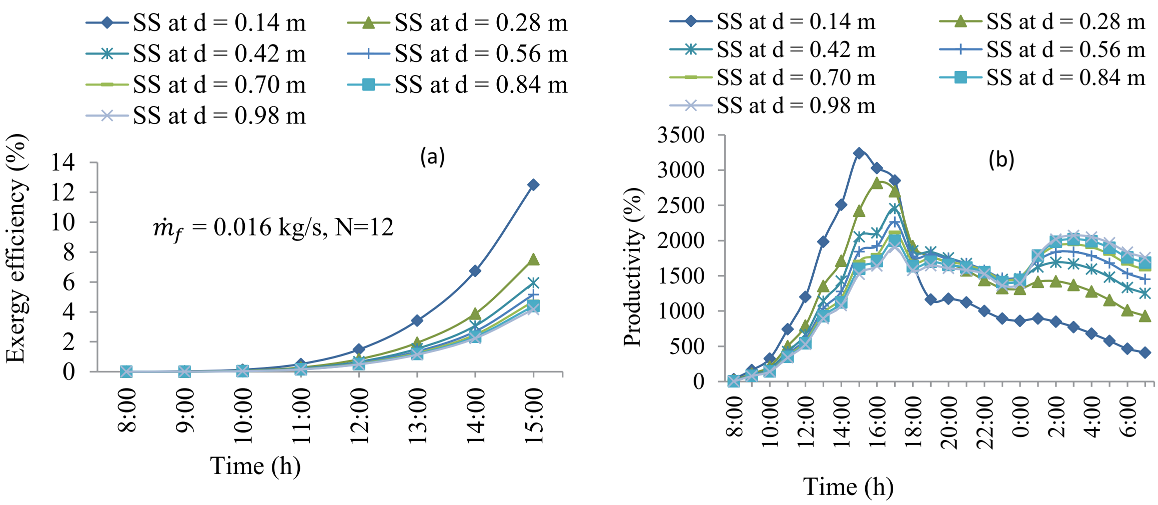

Fig. 5. (a) Hourly dissimilarity of exergy efficiency of NETC-SS for an archetypal day of January and (b) hourly dissimilarity of productivity of NETC-SS for an archetypal day of June.

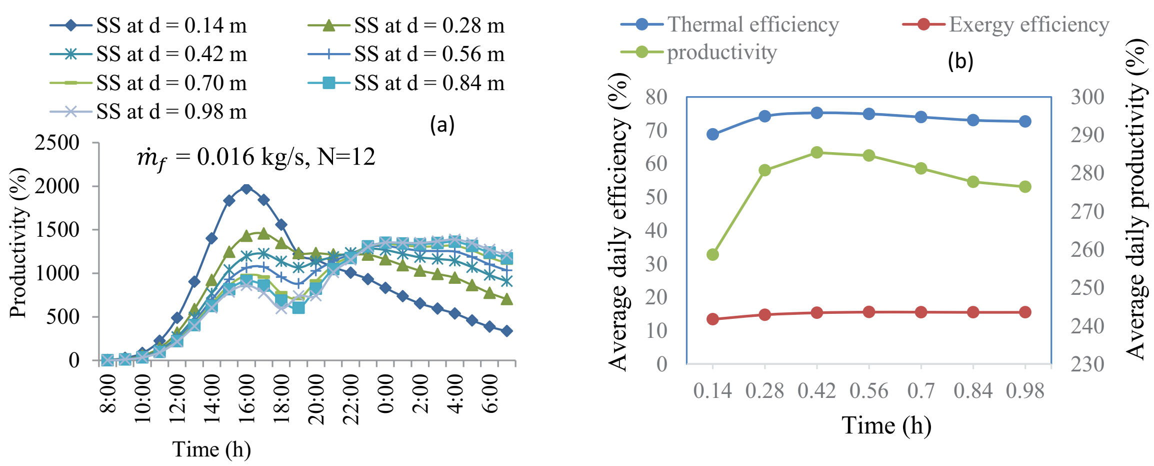

Fig. 6. (a) Hourly dissimilarity of productivity of NETC-SS for an archetypal day of January and (b) dissimilarity of average daily thermal and exergy efficiencies and productivity of NETC-SS.

8. Recommendations

The outcome of this research will help the designer and installer of solar still working in active mode for selecting the water depth from thermal efficiency, exergy efficiency and productivity viewpoints under selected values of $\dot{m}_f$ and N. The solar still of SS type working in active mode has not been tested experimentally. So, authors recommend its experimental validation before the actual installation as solar energy operated water purifier plant. The optimal values identified with this analysis are for the location of New Delhi, a similar analysis can be used to provide new values that will be optimal for different location and weather conditions. Authors plan to extend this research to include geographic and weather variations in future research.

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Symbols

A_g	–	Area of condensing surface
A_b	–	Area of basin liner
C	—	Specific heat capacity, J/kg-K
C_{man}	—	Cost of manufacturing the system including cost of piping and labor, ₹
F'	—	Collector efficiency factor, dimensionless
h_{cw}	—	Convective heat transfer coefficient from water to inner surface of glass cover, W/m²-K
h_{ewg}	—	Evaporative heat transfer coefficient from water surface to inner surface of glass cover, W/m²-K
h_c	—	Convective heat transfer coefficient, W/m²-K
h_{ba}	—	Heat transfer coefficient from blackened surface to ambient, W/m²-K
h_{bw}	—	Heat transfer coefficient from blackened surface to water mass, W/m²-K
h	—	Heat transfer coefficient, W/m²-K
h_{rwg}	—	Radiative heat transfer coefficient from water surface to inner surface of glass cover, W/m²-K
h_r	—	Radiative heat transfer coefficient, W/m²-K
h_{1w}	—	Total heat transfer coefficient from water surface to inner surface of glass cover, W/m²-K
h_{1g}	—	Total heat transfer coefficient from water surface to inner glass cover, W/m²-K
$I(t)$	—	Solar intensity on collector, W/m²
$I_s(t)$	—	Solar intensity on NETC-SEOWPSS
i	—	Rate of interest, %
K	—	Thermal conductivity, W/m-K
L_g	—	Thickness of glass, m
L	—	Latent heat, J/kg
L'	—	Length, m
$\dot{m}_f$	—	Mass flow rate of fuid/water, kg/s
N	—	Number of collectors
n	—	Life of NETC-SS, y
PF_c	—	Penalty factor due to the glass covers for the glazed portion
PF_1	—	Penalty factor first, dimensionless
PF_2	—	Penalty factor second, dimensionless
R_{01}	—	Inner radius of outer glass tube of evacuated coaxial glass tube, m
R_{02}/R	—	Outer radius of outer glass tube of evacuated coaxial glass tube, m
R_{i1}	—	Inner radius of inner glass tube of evacuated coaxial glass tube, m
R_{i2}	—	Outer radius of inner glass tube of evacuated coaxial glass tube, m
r	—	Radius of copper tube, m
T_{foN}	—	Outlet water temperature at the end of Nth water collector, °C
T_a	—	Ambient air temperature, °C
T_{gi}	—	Temperature at the inner surface of condensing cover
T_{go}	—	Temperature at the outer surface of condensing cover
T_b	—	Temperature of basin liner
t	—	Time, h
U_L	—	Overall heat transfer coefficient, W/m²-K
V	—	Velocity of air, m/s

Abbreviations

UEAC	—	Uniform end-of-year annual cost, ₹
ETC	—	Evacuated tubular collector
PVT	—	Photovoltaic thermal
SS	—	Single slope

Subscripts

eff	—	Effective
ex	—	Exergy
f	—	Fluid
in	—	Incoming
out	—	Outgoing
w	—	Water

Greek letters

α	—	Absorptivity (fraction)
η	—	Efficiency, %
$(\alpha\tau)_{eff}$	—	Product of effective absorptivity and transmittivity
σ	—	Stefan-Boltzmann constant, W/m²-K⁴
τ	—	Transmittivity

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