Case Study

Comparative exergy and exergy efficiency analyses of fabricated single and double slope solar still plants at Indore: case study

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Abstract

In this research project two solar still plants have been fabricated; single and double slope still plants. The exergy and exergy efficiency concepts have been applied for the comparative analyses of both solar stills. Experimental readings, i.e. various temperatures, amounts of distilled water and solar radiations have been taken for solar stills at different time intervals in Indore (22° 43' 4.51" N and 75° 49' 59.88" E). The percentage variations in the different parameters, i.e. increments in temperature, increments in quantity of water, thermal efficiencies, rates of exergy at inlet/outlet and exergy efficiencies have also been calculated for stills at various solar intensities and time intervals. After experimental and comparative analyses, better outputs have been shown at 14:50 PM for double slope and 14:45 PM for single slope plant due to the cumulative effects of solar radiations on the still plants. During this period thermal/exergy efficiencies, i.e. 46.630/1.949% and 47.259/3.389% were found the best. The performance of single slope solar still has been found better, and 14:30 to 14:50 PM time interval has been recorded superior for the distillation of water through still plants where percentage increments of the performance evaluating parameters were enhanced.

Keywords Single and double slope solar stills · Thermal efficiency · Rates of inlet and outlet exergy · Exergy efficiency · Solar radiation

List of symbols

C	Specific heat of water (J/kg K)
dT_w	Temperature difference which was achieved due to solar energy (K)
$I_b R_B$	Solar radiation which is available for single and double slope solar still (W/m ²)
L	Length of the solar still (m)
m	Mass flow rate of pure water (kg/s)
T_0, T_w and T_s	Ambient, water and Sun's surface temperatures (K)
W	Width of the solar still (m)

Greek symbols

η	Thermal efficiency of the solar still (%)
α_g, ρ_g and τ_g	Absorptivity, reflectivity and transmissivity of the glass
ψ_{in} and ψ_{out}	Exergy at inlet and outlet for single and double slope solar still (W)

1 Introduction

A technology has been developed by the researchers for the purification of water which is simple, economical and also eco-friendly. This technology is based on the solar energy. Solar still plant is used to purify the water by heat of the Sun [1]. In this still plant the water evaporates and this water vapour goes upside where the tilted glass is placed. At the glass surface, water condenses and

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in this process all impurities like salts, heavy metals and the microbiological element/organism are removed from water. Due to gravitational activity, the purest water collects in the container which is cleaner than the rain water [1–4]. Solar distillation plants are used for industrial processes, in hospitals for the sterilization, in automobile workshops for the radiator and battery maintenance and also in the laboratories. The benefits of these distillation plants are: pure water is produced for the drinking purpose, very less or negligible maintenance cost is required, impure water is easily purified into potable water, moving/rotating components are not used in these type of plants so no electricity is required to operate them, minimum wastage of water is recorded and no skilled operator is required. There are two types of solar stills which have been generally used for the purification of water [1–4]; (a) basin type solar still that consists shallow brackish basin of impure water with transparent rooftop (i.e. Glass) at an angle which is used to pass solar radiation for the evaporation of impure water. On the inner surface of the rooftop, evaporated water condenses and slides on the surface of the rooftop due to gravity and pure water collects in the tank, and (b) wick type solar still which consists a wick and impure water that passes through the wick where the water is absorbed by capillary action. Solar energy is absorbed by the water which is present in the wick and that water evaporates then condenses and finally pure water collects in the tank. In this research work basin type solar still has been used and important components of basin type solar still are; (1) still basin—impure water is kept in this section and the maximum amount of solar radiation is absorbed by the water here, so it is very essential that the selected material should have high absorptivity and negligible reflectivity/transmissivity. Materials which can be selected for the basin are—leather sheet, Germanium silicon, mild steel plate, reinforced plastic and galvanized iron. In this experimental work 3 mm thick blackened galvanized iron sheet (thermal conductivity 300 W/m-K) is used, (2) sidewalls—thermal resistance is provided by this wall, otherwise heat will be transferred from the basin to the surrounding. The wall must be made of that material which has low thermal conductivity or high thermal resistance. Materials which may be chosen for side walls are—wood, concrete, thermocol and reinforced plastic. In this experimental work, composite wall is manufactured where thermocol is placed at inside and wood is placed at the outside of the wall, i.e. 8 mm thick wood (thermal conductivity, 0.6 W/mK) and 15 mm thick thermocol (thermal conductivity, 0.02 W/mK) are used for the wall, (3) top cover—from the top cover, solar radiation is passed to the water so high transmissive material must be used for cover and after evaporation, water is condensed at inner surface of this top cover so it must

be neither absorbent and nor adsorbent. Materials can be used as top cover are—glass and polythene with clean and smooth surface. In this work, 5 mm thick glass plate is installed on the basin of the solar still with rubber tube as frame border, and (4) channel—pure condensed water which appeared on the inner surface of the tilted glass is glided and collected in the passage called channel. Materials for the channel are—poly vinyl chloride (P.V.C.) and galvanized iron (G.I.) but here P.V.C. pipe is used as channel material [1–4]. Single and double slope solar stills have been shown in Fig. 1 [1–4]. Fabricated single and double solar stills have been shown in Figs. 2 and 3, respectively.

The maximum temperature difference between feed water and collected water is required to achieve high efficiency of solar still with low leakages of heat and water from the system, and high feed water temperature is also required for the same. High feed water temperature can be obtained through better solar radiation absorption and better thermal resistive surfaces of the side walls but less temperature of glass surface can be achieved by poor radiation absorbing surface. Some research manuscripts have been reviewed before doing this experimental work; performance analyses have been done on various single slope solar still plants at different climatic conditions with modified designs by numerical, modeling or experimental approaches [5–14]. Similarly, various analyses have also been performed on different double slope solar still plants separately with minimum basin depth, different energy

Fig. 1 Single and double slope solar stills distillation layout

Fig. 2 Fabricated single slope solar still

Fig. 3 Fabricated double slope solar still

storing materials and multi wicks by consideration of air velocities and forced convective heat transfer [15–21]. Then exergy concept has been applied to the solar distillation plants [22–26]. Kabeel et al. worked in the climate of the Birkat Elsab City, Monufia, Egypt on two different solar still plants considering composite material and phase changing material, and found the total cost of distilled water with composite material was about 0.0014–0.00163 US dollars per liter and it was less than the phase changing material by 27%. They also found productivity, energy efficiency and exergy efficiency with composite material about 3.27 L per square meter, 48.22% and 3.08% which were better than the phase changing material by 37.5%,

38% and 37% respectively [23]. Yousef et al. performed comparative analyses on traditional solar still plant, still plant with the phase changing material, still plant with phase changing material-pin fin arrangement, still plant with phase changing material-steel wool fibers, still plant with steel wool fibers and still plant with pin fin arrangement in the basin. They received accumulative freshwater as 3.26, 3.572, 3.81, 3.685, 4.08 and 3.78 kg/m² respectively, which were 10%, 17%, 13%, 25% and 16% more than traditional solar still plant [24]. Sharshir et al. also analyzed the performance of modified solar still plant which has brackish water with graphite and copper oxide as nano particles with classical or traditional solar still plant. They concluded that the energy efficiencies of the modified solar still with graphite and with copper oxide were 41.18% and 38.61% respectively, but for the traditional plant efficiency was only 29.17%. They compared productivity of the modified plant with traditional plant and found productivity enhanced by 41.18% and 32.35% with graphite and copper oxide. Exergy efficiency and cost of water production of the modified solar still plant were also confirmed better than traditional plant [26]. Some important outputs related to various solar still plants are also discussed as; Kabeel [27] found 4.0 L/m²/day water with concave wick basin pyramidal shaped solar still, Wassouf et al. [28] achieved 1.8 L/m²/day water with pyramidal and triangular prism shaped solar still. Rajamanickam and Ragupathy [29], Kumar et al. [30] and Ahsan et al. [31] produced 3.07, 4.2 and 1.6 L/m²/day water with double slope, hemispherical shaped and triangular shaped solar still plants respectively. Kumar et al. [32] produced 2.5 L/m²/day water with compound parabolic concentrator concentric tubular solar still with water cooling and Velmurugan et al. [33] found 2.77 L/m²/day water with fin type solar still. The most important objective of this research work is to obtain clean water from the brackish water, experimentally. In this work, single and double slope solar stills have been fabricated in the workshop for the comparative experimental analyses. Various temperatures and quantities of distilled water through both solar still plants have been found with different solar intensities. Then increments in temperature and quantity of water, thermal efficiencies, rates of exergy at inlet/outlet and exergy efficiencies have been calculated for different time intervals. These comparative outputs have been used to analyses the performance of the solar still plants and identified which plant is doing better, single slope or double slope solar still plant. Dimensions of the fabricated double slope solar still are; length of the basin is 80 cm, width of the basin is 120 cm, height of the basin is 30 cm and approximate angle of the glass surface is 30°–31° and maximum height of the solar still is 65 cm. Dimensions of the glass used in this experimental work are; 80 cm length and 70 cm width. Similarly,

the dimensions of single slope still are; length, width and height of the basin are 76, 56 and 9 cm, the approximate angle of the glass surface is 13°–15°, maximum height of the solar still is 22 cm, length and width of the glass are 76 and 58 cm respectively.

2 Methodology

In this experimental research activity, the comparative thermal analyses have been done for single and double slope solar still plants at Sushila Devi Bansal College of Technology, Indore, India. Latitude and Longitude of this location are 22° 43' 4.51" N and 75° 49' 59.88" E respectively. After finding the different temperatures and quantities of distilled water, the thermal efficiencies [1–4] and exergy efficiencies [22–26] have been found in different climatic conditions by adopting the following methodology. First, the thermal efficiency can be defined as the ratio of the amount of heat that is absorbed by water which is present in the basin of the solar still to the solar energy or solar radiation which is received by the rooftop i.e. glass surface of the still [4]. Thermal efficiencies of the single and double slope solar still plants have been found at different time intervals by the following equation [34–38].

$$\eta = \left[\frac{(m C dT_w) + (m h_{fg})}{(\tau_g I_b R_B L W)} \right] \times 100 \quad (1)$$

where η is the thermal efficiency of the solar still in percentage, m is the mass flow rate of pure water which was obtained by evaporation and condensation processes in kg/s, C is the specific heat of water in J/kg K and it is assumed as 4186 J/kg K, dT_w is the temperature difference which was recorded due to the solar energy in Kelvin, $I_b R_B$ is the solar radiation that is available for single and double slope solar still as shown in Fig. 4 in W/m², L and W are the length and width of the solar still in meters. α_g , ρ_g and τ_g are absorptivity, reflectivity and transmissivity of the glass and these terms can be defined as; the absorptivity is the ratio of absorbed radiation to the total incident radiation, the reflectivity is the ratio of reflected radiation to the total incident radiation and the transmissivity of the glass is the ratio of transmitted radiation to the total incident radiation respectively. For this experimental research work, these constants have been taken as—combined absorptivity-reflectivity 0.2 and transmissivity 0.8. The maximum useful work that received from any thermodynamic system if the system approaches to thermodynamic equilibrium state with the surroundings is called available energy, i.e. exergy of the system [39–42]. In this research work exergy inputs, exergy outputs and exergy efficiencies for single and double slope solar stills have been calculated by the following equations [22–26, 34–37].

$$\Psi_{in} = I_b R_B L W \left\{ 1 - (4T_0/3T_s) + (1/3) (T_0/T_s)^4 \right\} \quad (2)$$

$$\Psi_{out} = \{ (m C dT_w) + (m h_{fg}) \} [1 - (T_0/T_w)] \quad (3)$$

$$\eta_{\Psi} = \left\{ \frac{(m C dT_w) + (m h_{fg})}{I_b R_B L W \left\{ 1 - (4T_0/3T_s) + (1/3) (T_0/T_s)^4 \right\}} \right\} [1 - (T_0/T_w)] \quad (4)$$

where Ψ_{in} and Ψ_{out} are the rates of exergy at inlet and outlet for single and double slope solar stills in Watt, T_0 , T_w and T_s are the ambient, water and Sun's surface temperatures. Surface temperature of the Sun has been taken as 5800 K [34–37, 43].

3 Results and discussion

Many researchers have done work on distillation by many ways to improve the performance of the still plants, but in this experimental work single and double slope solar distillation plants have been fabricated for comparative analyses at different conditions i.e. solar intensities and time intervals. These analyses have been done to recognize which solar still plant is performing well (single slope or double slope solar still plant) and those operating conditions/time intervals have also been identified. Various experiments have been performed on single and double slope solar stills at different time intervals. Ismail [44] designed a hemispherical dome shaped transparent plastic cover still plant (size 0.5 m²) and observed when the depth of the water in the basin increases (i.e. 50%) then the efficiency of the still plant decreases (i.e. 8%). He also worked on still plant with different wind speeds and found when the speed increases distillation rate also increases. Varol and Yazar [45] fabricated conventional and novel (glass cover coated with a thin layer of SnO₂) solar still plants which covered by low Fe₂O₃ composed glasses of 4 mm thickness and tilted at an angle of 15° with the horizontal. They compared the performance of both still plants and found 3.695 L/m² distilled water between 7 AM and 9 PM and 3.050 L/m² distilled water between 9 PM and 7 AM. They concluded that the novel (or modified) still plant gives 3.26 times higher overall efficiency than conventional still plant. Minasian and Al-Karaghoul [46] worked on comparative analyses of basin and wick basin type solar distillation plants and found 85% more annual production from the wick basin type plant. Sahoo et al. [47] removed 92–96% of fluoride from the drinking water and they also investigated efficiencies of the solar still plant which were evaluated as 8.59% and 8.48% with and without insulation of the plant. Soda et al. [48] analyzed the performance of multi wick solar still plant where jute

Fig. 4 Solar radiation available for **a** double slope and **b** single slope solar stills

clothes were used as wick material. After analyses they found 2.5 L/m² distilled water daily, and overall efficiency of the plant about 34% with multi wick. Sakthivel et al. [49] used jute clothes as an energy storage medium and placed vertically in the single basin solar still plant and they analyzed this arrangement with conventional solar still and found 8% better efficiency than conventional plant. Capelletti [50] made two plastic basins with different inclination angles (45° and 35°) and recorded 16% efficiency of

the still plant with 1.7 to 1.8 L/m² distilled water in a day. Al-Karaghoul et al. [51] investigated the performance of fabricated single and double slope double decker solar still plants. They recorded 3.91 L/m² and 2.45 L/m² distilled water with 31.8% and 43.8% plant efficiencies from single and double basin with insulation respectively. Al-Hayek and Badran [52] tested solar still with reflecting mirror and conventional still plants and obtained 3 to 5.5 L/m² distilled water. Nijmeh et al. [53] fabricated single basin solar

still insulated on the bottom and sides with 10 cm thick Styrofoam and used different dissolved salts; potassium permanganate, potassium dichromate and violet dye and charcoal. After investigations, they found 5.7 L/m², 5.5 L/m² and 5.3 L/m² distilled water with 17.2%, 26% and 19% plant efficiencies for potassium permanganate, potassium dichromate and for charcoal respectively. Bassam et al. [54] investigated the effects of size/volume of sponge, water depth, use of black coal and black still cube on the performance of still plant. They found that the production rate increases from 18 to 273% with sponge. Flendrig et al. [55] fabricated solar water purifier with 3 mm thick black high density polyethylene sheet and corrugated surface at the bottom of the still basin to create better insulation. After experiments, they found 3 L/m² distilled water with 39% overall efficiency of the plant. Kumar and Bai [56] studied the performance of solar still plant with enhanced condensation method and found 30% of the plant efficiency. In this research work, experimental readings for the double slope solar still from 12:00 to 16:00 PM have been shown through Table 1 whereas the readings for single slope still from 11:35 AM to 16:00 PM have been revealed in Table 2. Changes in temperature and quantity of water have been presented in Figs. 5 and 6 with single and double slope solar stills. Better increments in the quantity of distilled water have been obtained at peak hours between 14:30 and 14:50 PM. It has also been shown in the Fig. 5 that

the increment in the quantity of distilled water is gradually increasing up to the peak hour and then gradually decreasing. Thermal efficiencies of single and double solar stills have been shown in Fig. 7 at different time intervals and this figure indicates the maximum efficiency of the fabricated solar distillation plant recorded at peak hours i.e. from 14:30 to 14:50 PM by experiments. Rates of exergy at inlet/outlet and exergy efficiencies for single and double slope solar stills have been estimated and represented in Figs. 8, 9 and 10 respectively. Better experimental outputs from both still plants have been received between 14:30 and 14:50 PM by exergy analyses.

In this research work percentage increments/decrements in—temperature, distilled water quantity, thermal efficiency, rates of exergy at inlet/outlet and exergy efficiency have also been found for both solar stills as in Tables 3 and 4. Maximum and minimum available solar radiations for the single slope solar still are 930 and 500 W/m² at 12:30 and 16:00 PM, and for double slope solar still are 1100 and 600 W/m² at 13:20 and 16:00 PM respectively as in Fig. 4. Maximum and minimum thermal efficiencies for single slope solar still have been observed as 47.260% and 11.860%. Maximum and minimum rates of exergy at inlet have been calculated as 368.246 W and 198.079 W. Maximum and minimum rates of exergy at outlet have been determined as 9.906 W and 1.588 W. Maximum and minimum exergy efficiencies have also been

Table 1 Experimental readings taken from double slope solar still at different time intervals

Sr. no.	Time (PM)	Temperature of water (°C)	Solar radiation (W/m ²)	Atmospheric temperature (°C)	Amount of distilled water (L)
1	12:00	43	900	30	00
2	13:00	44	1000	33	0.005
3	13:10	45.3	1050	35	0.009
4	13:20	45.9	1100	34	0.015
5	13:30	46	1050	33	0.020
6	13:40	47.8	1070	35	0.030
7	13:50	47.9	1100	34	0.045
8	14:00	48.4	1050	32	0.060
9	14:10	48.9	1000	31	0.080
10	14:20	48.4	950	30	0.100
11	14:30	48	950	32	0.200
12	14:40	47.9	900	33	0.300
13	14:50	47.7	900	32	0.400
14	15:00	46.9	850	30	0.450
15	15:10	46	800	30	0.500
16	15:20	45.8	750	29	0.550
17	15:30	44.9	700	29	0.600
18	15:40	43	650	28	0.650
19	15:50	42.6	635	28	0.675
20	16:00	42	600	28	0.700

Table 2 Experimental readings taken from single slope solar still at different time intervals

Sr. no.	Time	Temperature of water (°C)	Solar radiation (W/m ²)	Atmospheric temperature (°C)	Amount of distilled water (L)
1	11:35 AM	48.9	800	28	0.010
2	11:50 AM	54.4	850	29	0.040
3	12:00 PM	56.8	880	30	0.055
4	12:15 PM	59.2	900	30	0.075
5	12:30 PM	59.9	910	30	0.085
6	12:45 PM	59	930	30	0.095
7	13:00 PM	57.9	920	28	0.115
8	13:15 PM	59.6	880	28	0.130
9	13:30 PM	60.6	900	29	0.140
10	13:45 PM	59.3	810	29	0.150
11	14:00 PM	59.8	810	30	0.165
12	14:15 PM	58.9	800	30	0.175
13	14:30 PM	57.05	780	28	0.195
14	14:45 PM	56.03	700	28	0.225
15	15:00 PM	53.4	680	28	0.240
16	15:15 PM	50.3	650	28	0.255
17	15:30 PM	47.1	580	29	0.275
18	15:45 PM	45.5	550	28	0.295
19	16:00 PM	40	500	28	0.310

estimated as 3.390% and 0.802% as shown in Figs. 7, 8, 9 and 10 respectively at different time intervals. Similarly, maximum and minimum thermal efficiencies for double slope solar still have been calculated as 46.639 and 1.603%, rates of exergy at inlet have been found as 1145.077 and 607 W, rates of exergy at outlet have been estimated as 18.471 and 0.523 W, and exergy efficiencies have been calculated as 1.95 and 0.048% at various time intervals as in Figs. 7, 8, 9 and 10 respectively. All these analyses have been used for the comparative analyses of single and double slope solar still plants.

Maximum percentage increments in the quantity of distilled water were recorded for single and double slope solar still plants so maximum increments in the thermal and exergy efficiencies have been obtained at peak hours between 14:15 and 14:30 PM. Maximum thermal efficiencies for single and double slope still plants have been achieved after 14:40 PM. Maximum rates of inlet and outlet exergy have been found between 13:00 and 14:30 PM respectively for both solar stills and between this duration solar intensities were found better. Best exergy efficiencies for single and double slope still plants have also been examined between 14:30 and 14:50 PM experimentally because the still plants were preheated and found better intensity.

Important results of this experimental work are discussed as; Maximum thermal i.e. 46.64% and exergy i.e. 1.95% efficiencies for double slope solar still have

been obtained at 14:50 PM. The maximum increments in thermal i.e. 400.09% and exergy i.e. 336.12% efficiencies have been found at 14:30 PM but minimum thermal i.e. 1.603% and exergy i.e. 0.047% efficiencies have been obtained at 13:10 PM. Maximum increment in the temperature of water i.e. 1.8 °C has been achieved at 13:40 PM but maximum increment in the quantity of water i.e. 0.1 L has been observed between 14:30 and 14:50 PM. Maximum i.e. 1145.076 W and minimum i.e. 625.513 W rates of inlet exergy have been found at 13:20 PM and 16:00 PM respectively. Maximum i.e. 18.47 W and minimum i.e. 0.523 W rates of outlet exergy have been found at 14:30 and 13:10 PM respectively. Maximum and minimum percentage changes in temperature, quantity of water, thermal efficiency, rates of inlet/outlet exergy and exergy efficiency have been obtained as 1700–0%, 400–0%, 400.092–0.018%, 7.119–0.024%, 335.906–0.375% and 336.121–0.336% respectively at 13:40–14:10 PM, 14:30–15:10 PM, 14:30–14:50 PM, 15:40–14:50 PM, 14:30–14:20 PM and 14:30–15:10 PM. After comparative analyses of these experimental outputs, 14:50 PM time interval has been recorded better for double slope solar still where solar intensity was 900 W/m² and thermal/exergy efficiencies were the best with the highest increment in the quantity of distilled water. For double slope solar still, 14:30 PM time interval can also be considered where the percentage increments in quantity of water, thermal efficiency, outlet exergy and

Fig. 5 **a** Change in temperature and **b** increment in quantity of water with double slope solar still

exergy efficiency were found highest which are good conditions for the best performance of a solar still. It has also been examined that 13:10 PM time interval is not good for still because it was showing poor performance of solar still in terms of thermal and exergy efficiencies. Experimental work with single slope solar still can also be concluded as; Maximum thermal i.e. 47.259% and exergy i.e. 3.389% efficiencies have been achieved at 14:45 PM. Maximum increments in the quantity of distilled water, outlet exergy and exergy efficiency i.e. 100, 106.161 and 108.299% have been found at

13:00 PM respectively. But minimum inlet exergy, outlet exergy and exergy efficiency i.e. 198.079 W, 1.587 W and 0.801% have been obtained at 16:00 PM. Maximum increment in the quantity of distilled water i.e. 0.03 L has been recorded at 14:45 PM. Maximum i.e. 368.245 W and minimum i.e. 198.079 W rates of inlet exergy have been received at 12:45 and 16:00 PM respectively. Maximum i.e. 9.906 W and minimum i.e. 1.587 W rates of outlet exergy have been found at 11:50 and 16:00 PM respectively. Maximum and minimum percentage changes in the temperature of water, thermal efficiency, rates of

Fig. 6 **a** Change in temperature and **b** increment quantity of water with single slope solar still

inlet/outlet exergy and exergy efficiency for single slope have been obtained as 280–3.225%, 104.766–2.44%, 10.791–0.024%, 106.161–2.702% and 108.299–2.129% respectively at 14:15–15:30 PM, 14:30–12:45 PM, 15:30–14:00 PM, 13:00–15:45 PM and 13:00–13:45 PM.

4 Conclusion

The main aim of this experimental attempt is to get pure water from the available brackish/impure water. At the end of the experiment, 0.7 L pure water has been

collected. Single and double slope solar stills have been fabricated in the workshop, and increments in the temperature/quantity of water, thermal efficiencies, rates of exergy at inlet/outlet and exergy efficiencies have been investigated at different solar intensities. Percentage increments and decrements have also been found for various performance analysing parameters. Comparative studies have been done for both solar stills with various operating conditions to find which solar still plant is performing better/well. For single slope solar still, 14:45 PM time interval has been found better where solar intensity was 700 W/m^2 and thermal/exergy efficiencies were the

Fig. 7 Thermal efficiencies for **a** double and **b** single slope solar stills

most excellent with maximum growth in the quantity of distilled water. After comparative analyses it has been observed that 14:30 to 14:50 PM time duration gives better performance for the distillation of water through solar still plants as the distillation is the cumulative effect of solar intensity which incidents on the solar distillation plants. It has also been observed in this experimental

work that the single slope solar distillation plant gives better thermal and exergy efficiencies. Because the maximum increment in the quantity of distilled water has been recorded at comparatively poor solar intensity. Furthermore, maximum increment also depends on the position of the glass and incident solar radiation for single slope solar still. In future, different wick materials,

Fig. 8 Rates of exergy at inlet for **a** double and **b** single slope solar stills

Fig. 9 Rates of exergy at outlet for **a** double and **b** single slope solar stills

Fig. 10 Exergy efficiencies for **a** double and **b** single slope solar stills

Table 3 Percentage changes in various parameters at various time durations for double slope solar still

Sr. no.	Time durations	Percentage change in increment in temperature of water (%)	Percentage change in increment in quantity of water (%)	Percentage change in thermal efficiency (%)	Percentage change in inlet exergy (%)	Percentage change in outlet exergy (%)	Percentage change in exergy efficiency (%)
1	13:00 PM–13:10 PM	30 Increment	20 Decrement	23.7672 Decrement	4.948093 Increment	23.9054 Decrement	27.4931 Decrement
2	13:10 PM–13:20 PM	53.8462 Decrement	50 Increment	42.99638 Increment	4.787812 Increment	65.78102 Increment	58.20639 Increment
3	13:20 PM–13:30 PM	83.3333 Decrement	16.6667 Decrement	12.7793 Decrement	4.52185 Decrement	11.2253 Decrement	7.02094 Decrement
4	13:30 PM–13:40 PM	1700 Increment	100 Increment	96.88037 Increment	1.854385 Increment	111.2407 Increment	107.3948 Increment
5	13:40 PM–13:50 PM	94.4444 Decrement	50 Increment	45.45058 Increment	2.829161 Increment	50.91057 Increment	46.75853 Increment
6	13:50 PM–14:00 PM	400 Increment	No change	4.83961 Increment	4.49825 Decrement	19.43157 Increment	25.05695 Increment
7	14:00 PM–14:10 PM	No change	33.33333 Increment	40 Increment	4.73837 Decrement	45.08877 Increment	52.30557 Increment
8	14:10 PM–14:20 PM	200 Decrement	No change	5.06811 Increment	4.97653 Decrement	0.37583 Decrement	4.841649 Increment
9	14:20 PM–14:30 PM	20 Increment	400 Increment	400.0928 Increment	0.0494 Decrement	335.906 Increment	336.1214 Increment
10	14:30 PM–14:40 PM	75 Increment	No change	5.614331 Increment	5.28657 Decrement	5.81627 Decrement	0.55926 Decrement
11	14:40 PM–14:50 PM	100 Decrement	No change	0.01855 Decrement	0.024718 Increment	5.055594 Increment	5.029633 Increment
12	14:50 PM–15:00 PM	300 Decrement	50 Decrement	47.1178 Decrement	5.50888 Decrement	47.1588 Decrement	44.0781 Decrement
13	15:00 PM–15:10 PM	12.5 Decrement	No change	6.230265 Increment	5.88235 Decrement	5.56573 Decrement	0.336417 Increment
14	15:10 PM–15:20 PM	77.7778 Increment	No change	6.805381 Increment	6.22684 Decrement	7.917805 Increment	15.0839 Increment
15	15:20 PM–15:30 PM	350 Decrement	No change	7.003705 Increment	6.66667 Decrement	7.60637 Decrement	1.00682 Decrement
16	15:30 PM–15:40 PM	111.1111 Decrement	No change	7.49224 Increment	7.11993 Decrement	9.1052 Decrement	2.13746 Decrement
17	15:40 PM–15:50 PM	78.9474 Increment	50 Decrement	48.676 Decrement	2.30769 Decrement	48.2083 Decrement	46.9848 Decrement
18	15:50 PM–16:00 PM	50 Decrement	No change	5.794047 Increment	5.51181 Decrement	4.80584 Decrement	0.747154 Increment

Table 4 Percentage changes in various parameters at various time durations for single slope solar still

Sr. no.	Time durations	Percentage change in increment in temperature of water (%)	Percentage change in increment in quantity of water (%)	Percentage change in thermal efficiency (%)	Percentage change in inlet exergy (%)	Percentage change in outlet exergy (%)	Percentage change in exergy efficiency (%)
1	11:50 AM–12:00 PM	56.363636 Decrement	50.0 Decrement	51.979416 Decrement	3.5038469 Increment	51.178527 Decrement	52.831248 Decrement
2	12:00 PM–12:15 PM	No change	33.333333 Increment	30.37037 Increment	2.2727273 Increment	43.658515 Increment	40.466104 Increment
3	12:15 PM–12:30 PM	70.833333 Decrement	50.0 Decrement	50.704675 Decrement	1.1111111 Increment	50.668673 Decrement	51.210776 Decrement
4	12:30 PM–12:45 PM	228.57143 Decrement	No change	2.4405274 Decrement	2.1978022 Increment	5.9648149 Decrement	7.987077 Decrement
5	12:45 PM–13:00 PM	22.222222 Decrement	100 Increment	102.09879 Increment	1.026401 Decrement	106.1608 Increment	108.29878 Increment
6	13:00 PM–13:15 PM	254.54545 Increment	25.0 Decrement	21.182891 Decrement	4.3478261 Decrement	16.641865 Decrement	12.852858 Decrement
7	13:15 PM–13:30 PM	41.176471 Decrement	33.333333 Decrement	34.899177 Decrement	2.2474789 Increment	34.408476 Decrement	35.850228 Decrement
8	13:30 PM–13:45 PM	230.0 Decrement	No change	10.638016 Increment	10 Decrement	8.0838628 Decrement	2.1290413 Increment
9	13:45 PM–14:00 PM	138.46154 Increment	50.0 Increment	50.501972 Increment	0.0246934 Decrement	52.870879 Increment	52.908638 Increment
10	14:00 PM–14:15 PM	280.0 Decrement	33.333333 Decrement	32.675104 Decrement	1.2345679 Decrement	37.065959 Decrement	36.279283 Decrement
11	14:15 PM–14:30 PM	105.55556 Decrement	100 Increment	104.76618 Increment	2.451836 Decrement	98.081163 Increment	103.05986 Increment
12	14:30 PM–14:45 PM	44.864865 Increment	50 Increment	67.401039 Increment	10.25641 Decrement	47.716307 Increment	64.59817 Increment
13	14:45 PM–15:00 PM	157.84314 Decrement	50.0 Decrement	48.683396 Decrement	2.8571429 Decrement	56.216953 Decrement	54.929216 Decrement
14	15:00 PM–15:15 PM	17.870722 Decrement	No change	4.5237447 Increment	4.4117647 Decrement	13.317837 Decrement	9.3171217 Decrement
15	15:15 PM–15:30 PM	3.2258065 Decrement	33.333333 Increment	49.397414 Increment	10.791259 Decrement	6.7268052 Increment	19.637162 Increment
16	15:30 PM–15:45 PM	50.0 Increment	No change	5.7693479 Increment	5.1489976 Decrement	2.7024454 Increment	8.2776596 Increment
17	15:45 PM–16:00 PM	243.75 Decrement	25.0 Decrement	18.098518 Decrement	9.0909091 Decrement	59.398911 Decrement	55.338802 Decrement

different phase changing materials and/or effect of pre-heating of water on the performance of still plants are proposed for comparatively analyses.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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