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Performance and exergy analysis of a double-basin solar still with different materials in basin

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ABSTRACT

Distillation efficiency and productivity of the passive single-basin solar still is very low. In this work, an additional basin is incorporated in the double-slope solar still to enhance the distillate output and to reduce the thermal energy losses. For further improvement in the productivity, different materials were used in the basin. Wick materials such as jute cloth, waste cotton pieces and black cotton cloth were used to increase the evaporation area. In addition to increase the heat storing capacity, mild steel pieces were used in the basin as energy storing materials. An exergy analysis was carried out to explain the effect of different materials on the exergy evaporation rate and exergy efficiency of the single- and double-basin solar stills. It shows that the basin with mild steel pieces has a maximum exergy efficiency of 2.072 and 1.412% for double- and single-basin stills, respectively. A payback analysis also conducted to prove the benefit of the double-basin still.

Keywords: Double-basin still; Exergy analysis; Latent heat recovery; Solar desalination; Materials in basin

1. Introduction

Fresh water is very vital for all the living beings to live in the World. It is necessary for drinking, cooking, irrigation and many other applications. Although water covers approximately 70% of the earth's surface, the supply of potable water is rapidly disappearing. This is because only 0.62% of the available water is in the form that can be traditionally treated for human consumption. Therefore, there is a need to produce pure water from the available sources. Solar desalination is one of the cheapest methods for this problem. A diversity of approaches are used for the separation of fresh water from saline water; namely multi-stage flash, multiple effect, reverse osmosis, electrodialysis, ion exchange, phase change and solvent extraction are used for the separation of fresh water from the saline water [1].

The above methods are expensive for production of small amount of pure water. Although solar still is widely used in solar desalination, its productivity is very low. Numerous research works are carried out in

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the solar still to improve the productivity. The works can be classified into passive and active methods. Murugavel et al. [2] made a detailed review on passive methods and concluded that the usage of different materials in the basin improves the productivity significantly. Active method needs external energy to improve the performance of the system [3]. A few black materials can absorb additional amount of heat energy which increase the productivity of still. Black rubber, mild steel pieces and black gravel are such materials having these properties [4,5]. The distillate of the system depends on the exposed area of the water in the basin. The performance of a solar still with different size of sponge cubes placed in the basin was experimentally studied [6]. Murugavel and Srithar [7] investigated the effect of using wick materials in the basin to improve the performance of the single-basin solar still. Velmurugan et al. [8] studied the performance of the still with black rubber, sponge and sand in the basin. Velmurugan and Srithar [9] reviewed the various parameters affecting the performance of the solar still.

The most prohibitive drawback of a solar still is its low efficiency which is primarily the result of the immediate loss of the latent heat of condensation through the glass cover of the still. The stills which recover and reuse the latent heat losses are called as multi-effect solar still [10–16]. A detailed review on the multi-effect solar still was carried out by Rajaseenivasan et al. [15].

Various researchers have proved that, in addition to the first law, the design of thermodynamically efficient heat transfer system is based on the second law of thermodynamics. The use of exergy analysis in desalination processes from a thermodynamic point of view is of increasing significance to identify the spots of maximum losses and improve the performance of the system [17]. Kumar and Tiwari [18] studied the exergy performance of a single-basin still in passive mode and an active one where the solar still is coupled with a photovoltaic/thermal (PV/T) system. They concluded that the exergy efficiency of the active solar still was around five times higher than the passive one. Shanmugan et al. [19] performed an energy and exergy analysis on single-slope single-basin solar still. Kumar and Tiwari [20] provided an analytical expression for instantaneous exergy efficiency of a shallow basin passive solar still. Kianifar et al. [21] studied the exergy and economic analysis on pyramid type solar still using active and passive cases. In active case, a small fan is used to increase the condensation rate. The results show that during summer, active unit has higher exergy efficiency than passive one while in winter there is no considerable difference between the exergy efficiency of the units.

2. Objective of the work

The above literature shows that, the productivity of the solar still can be increased by varying water depth, using of wick and energy storing materials in basin, external collectors and utilizing the latent heat of condensation [4–8,15,18,22–25]. In that, recovering the latent heat of condensation is a simple technique to utilize the waste heat by adding an additional basin. The authors used a double-basin still in the earlier work [4,16] and concluded that providing a minimum mass of water in basin increases the productivity of stills. The main objective of this work is to enhance the productivity of the still by varying the lower basin condition. Different wick and energy storing materials (jute cloth, waste cotton pieces, black cotton cloth and mild steel pieces) were used to enhance the performance of the double-basin still. All the materials were selected on the basis of availability and their cost. Jute cloth and black cotton cloth are easily available at low cost. Waste cotton pieces are available from local mill at free of cost. Mild steel pieces are easily available with reasonable cost, when compared with other high heat capacity materials. Thus, mild steel pieces (black colour coated) were used in this study. Exergy analysis was carried out to study the maximum possible work done by the single- and double-basin stills at different basin conditions.

3. Experimental set-up and procedure

A single-basin single-slope (SB) solar still and a double-basin double-slope (DB) solar still were fabricated with 1.4 mm thick mild steel plate as per the schematic diagram given in Fig. 1. The photographic view of the stills was given in Fig. 2. The inner size of the double basin was $0.9 \times 0.7 \times 0.18$ m and single basin was $0.9 \times 0.7 \times 0.08$ m. Window glass of 4 mm thickness was used as a transparent cover for SB still and DB still. The upper basin of the DB still was also made of same window glass material (Fig. 3) to ensure the transparent to the lower basin. Each side of the upper basin is divided into three compartments by using glass, and each glass cover has a height of 8 cm. Silica gel was used as a bonding material to fix the glasses in upper basin. The transparent cover of SB still and DB still and upper basin of DB still were placed inclined at 30˚ to horizontal for maximum production [26]. In DB still, the upper basin (lower cover) was fixed at 8 cm above the lower basin and the transparent cover is fixed at 10 cm above the lower cover (Fig. 1). The basin of SB still and lower basin of the DB still were black coated to increase radiation absorption. The outer side walls and bottom of the

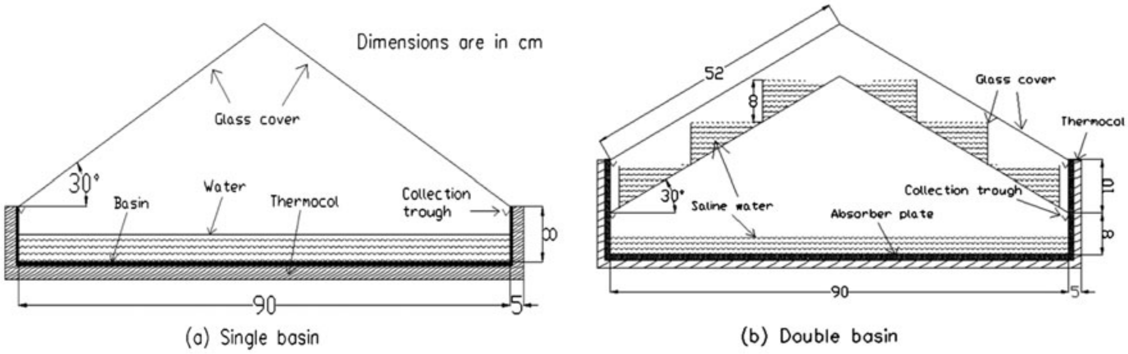

Fig. 1. Schematic view of solar stills.

Fig. 2. Photographic view of the stills.

stills were insulated by 50 mm thermocol to reduce the heat loss. V-shaped collection troughs were provided below the lower edges of the covers to collect the condensate in SB still and DB still. Distillate outlets were provided to drain the water through hoses and to store in jars. The make-up water was added from the storage tank through control valve, for every half an hour to maintain the constant mass of water in the basin. In DB still, two separate control valves were used to supply the make-up water to the upper and lower basin. Provisions were made to supply raw water, drain the basin water and insert thermocouples.

Fig. 3. Photographic view of the upper basin of the double-basin still.

The salt deposition on glass surface of the upper basin will affect the radiation transmittance into the lower basin. Also, the absorption capacity of lower basin gets affected. Hence, frequent cleaning of upper basin glass and lower basin absorber surface is necessary. Mild steel pieces are washed clearly after the each experiment is completed to avoid the corrosion and rust formation in basin.

PV type sun meter was used to measure the global radiation. This meter has 0.36×0.17 m size PV panel to sense the sun radiation. The panel was fixed on a stand so that it can be set at any inclination horizontally. The panel stand was mounted on a base with levelling screws. A display unit was connected with PV panel. The unit was calibrated to display the radiation in W/m^2. Digital anemometer and mercury thermometer were used to measure wind velocity and ambient temperature, respectively. K-type thermocouples with multi-channel digital display unit were used to measure the basin, water, glass, vapour and condensate of the single-basin and double-basin (upper and lower basin) stills. The accuracies and error for various measuring instrument are given in Table 1.

Experiments were carried out in the still with constant mass of water in the upper basin (4 kg) and lower basin (13 kg-2 cm depth) of the DB still for all experiments. SB still was used for comparison purpose and 2 cm depth of water was used in basin. To increase the distillate, wick and energy storing materials are used in the lower basin of DB still and basin of SB still. Jute cloth (0.95 kg), waste cotton pieces (0.55 kg) and black cotton cloth (0.65 kg) were used in the lower basin. Mild steel pieces (12.25 kg) were used as the energy storing material. The wick materials are fully spread out in the lower basin to increase the evaporation area. Anti corrosive black painted mild steel pieces were with "C" section of 5 cm height. These pieces were placed in the lower basin with 5 cm spacing. Thus, it acts like a fin and increases the heat transfer rate.

The experiments were conducted in outdoor condition at the Energy Park, National Engineering College, Kovilpatti (9˚ 11´N, 77˚ 52´E) Tamil Nadu, India during the month of February 2012–May 2012. Both the stills were placed in north–south orientation. The readings were taken from morning 6 am to next the day 6 am, for every 30 min interval. Each experiment was carried out for 2 d to observe the performance of the stills with different basin conditions. The data for the days with same average radiation conditions are considered for analysis.

4. Exergy analysis

Energy conversion processes have been calculated based on the first law of thermodynamics—energy analysis, which is done in the author's previous work [16]. Based on the second law of thermodynamics, it is possible to calculate the exergy of a system. It is used to evaluate the maximum amount of work that can be extracted from the given quantity of energy input.

The general exergy balance equation for a solar still can be written as Hepbalsi [27],

$$\sum Ex_{\text{in}} - \sum Ex_{\text{out}} = \sum Ex_{\text{dest}} \tag{1}$$

For a solar still, it can be written as:

$$Ex_{\text{sun}} - (Ex_{\text{evap}} + Ex_{\text{work}}) = Ex_{\text{dest}} \tag{2}$$

In a solar still, exergy input is based on the radiation entering into the basin. This can be written as [28]:

$$Ex_{\text{sun}} = A_{\text{b}} \times I_{\text{s}} \times \left[1 - \frac{4}{3} \times \left(\frac{T_{\text{a}} + 273}{T_{\text{s}}}\right) + 1/3 \times \left(\frac{T_{\text{a}} + 273}{T_{\text{s}}}\right)^4\right] \tag{3}$$

where A_b is area of basin (m^2), I_s is the solar radiation (w/m^2), T_a is the ambient temperature (℃) and T_s is the surface temperature of the sun (℃).

The exergy of work rate of a solar still is given by

$$Ex_{\text{work}} = 0 \tag{4}$$

Exergy evaporation or output is the result of the evaporation and condensation of the saline water. The hourly exergy output can be calculated from [29].

$$Ex_{\text{evap}} = \frac{m_{\text{evap}} \times L}{3,600} \times \left[1 - \left(\frac{T_{\text{a}} + 273}{T_{\text{w}} + 273}\right)\right] \tag{5}$$

Table 1
Accuracy and error limits for various measuring instruments

S. No.	Instrument	Accuracy	Range	% Error
1	Thermometer	±1℃	0–100℃	0.25
2	Thermocouple	±0.1℃	0–100℃	0.50
3	PV type sun meter	±1 W/m^2	0–2,500 W/m^2	2.50
4	Anemometer	±0.1 m/s	0–15 m/s	10.00
5	Measuring jar	±10 ml	0–1,000 ml	10.00

where m_{evap} is hourly yield of solar still (kg/h), L is the latent heat of vaporization (J/kg), T_a is the ambient temperature (℃) and T_w is the water temperature (℃).

To evaluate the exergy evaporation rate of the upper and lower basin, water temperature and distillate yield of the respective basins were used.

The exergy efficiency of the solar still can be expressed as Hepbalsi [27].

$$\eta_{ex} = \frac{\text{Exergy output of solar still}\,(Ex_{evap})}{\text{Exergy input of solar still}\,(Ex_{in})} \tag{6}$$

5. Result and discussion

Fig. 4 shows the atmospheric condition (solar radiation and wind velocity) during the experimental day. It shows that the maximum solar radiation is recorded in the time of 12–1 pm and the velocity of wind is low in day time and increases in night hours.

The variation of basin, water, glass cover temperature and production rate of upper basin of the double basin still is shown in Fig. 5. The different temperatures and production rate reaches maximum at 1 pm These parameters vary with radiation due to higher convection loss through top cover and lower volumetric heat capacity of the upper basin.

Fig. 6 compares the variation of water temperature in the lower basin. The temperature of water reached maximum in the period of 1–2.00 pm for all the basin conditions. Temperature of water in the basin with black cotton cloth attained the maximum temperature of 66℃ and lowest by mild steel pieces. Since, the black cotton cloth has less heat capacity, absorbs more radiation than other materials and transfers more heat energy to water.

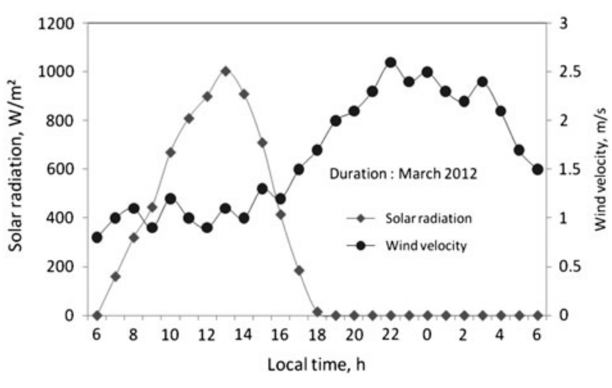

Fig. 4. Variation of solar radiation and wind velocity.

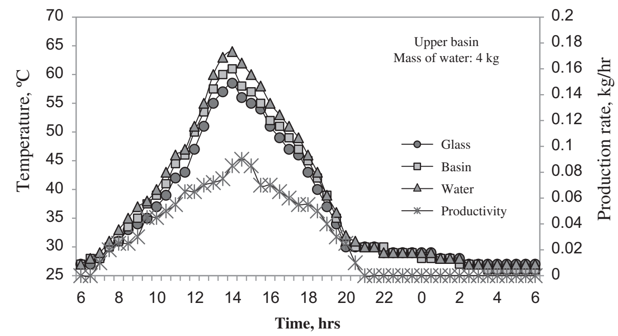

Fig. 5. Variation of different parameters in upper basin of double-basin solar still.

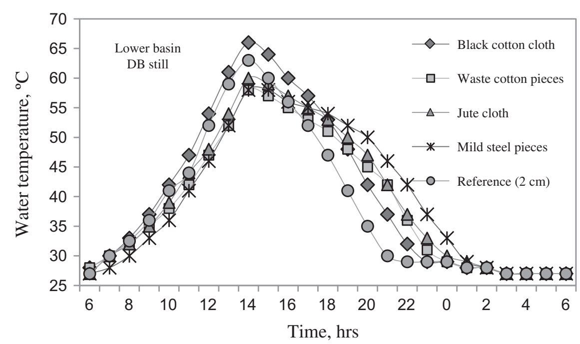

Fig. 6. Variation of lower basin water temperature with different materials in basin.

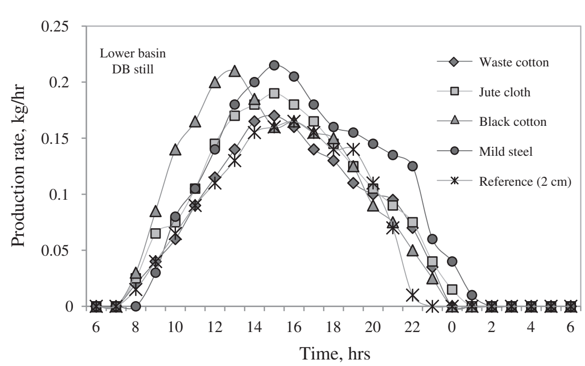

Fig. 7. Variation of lower basin productivity with different materials in basin.

Fig. 7 compares the variation of hourly productivity in lower basin for different basin conditions. It shows that the still with wick materials in the basin starts the production earlier and black cotton cloth had a considerable effect than the other materials in the morning productivity. The still with mild steel pieces increases the basin volumetric heat capacity. It absorbs and stores the heat in sunshine hours and releases it in afternoon hours.

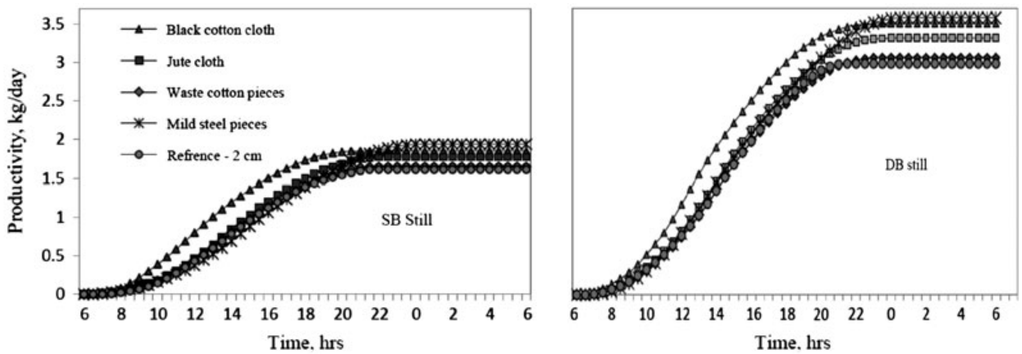

Fig. 8. Variation of cumulative productivity of the single- and double-basin stills.

Fig. 8 shows the actual cumulative production rate for the single- and double-basin stills with different materials in the basin. The production rate of the upper basin is almost same for all the lower basin conditions. Thus, it shows the black cotton cloth has a significant impact on the total production rate of the system at morning hours and the mild steel pieces for evening hours. Production rate with the jute cloth had more impact than that with the waste cotton pieces.

Figs. 9 and 10 compare the variation of exergy evaporation rate with different materials in single- and double-basin stills. It shows how the wick materials start the evaporation rate earlier and the time the energy storing materials take to start the evaporation rate due to heat storing capacity. Maximum exergy evaporation rate of 13.27 and 18.49 W were obtained with black cotton cloth in the basins at 2 pm for single- and double-basin stills, respectively.

Hourly variation of exergy efficiency for the double-basin still is presented in Fig. 11. It compares the variation of exergy efficiency for lower and higher depth and mild steel pieces in the basin. It shows higher hourly exergy efficiency rate for still with materials in the basin. The exergy efficiency is very lower during morning hours (6 am–2 pm) for all the cases

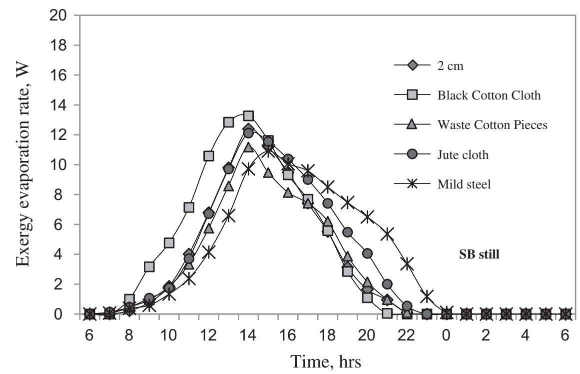

Fig. 10. Variation of exergy evaporation rate for different materials in single-basin still.

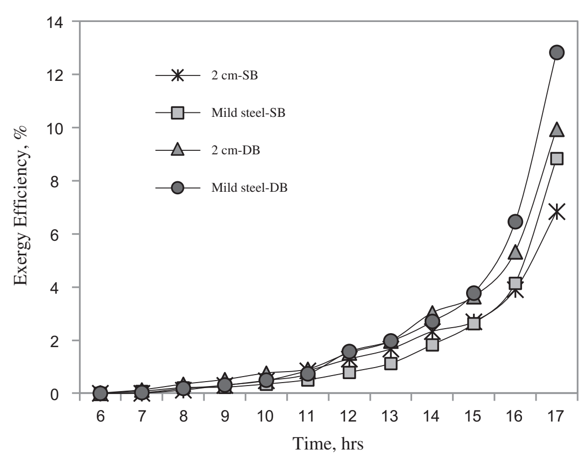

Fig. 11. Variation of exergy efficiency on different basin condition.

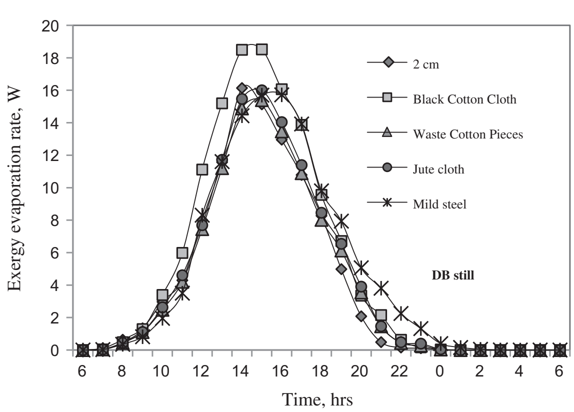

Fig. 9. Variation of exergy evaporation rate for different materials in double-basin still.

Table 2
Exergy analysis of solar still with different basin conditions

		SB still			DB still					
					Upper basin		Lower basin		Overall	
S. No.	Basin condition	Ex_{sun} (w)	Ex_{evap} (w)	η_{ex} (%)	Ex_{evap} (w)	η_{ex} (%)	Ex_{evap} (w)	η_{ex} (%)	Ex_{evap} (w)	η_{ex} (%)
1	2 cm	3,845.26	39.91	1.031	26.46	0.688	30.51	0.793	56.97	1.481
2	4 cm	3,950.26	35.74	0.924	23.38	0.592	29.66	0.751	53.05	1.343
3	6 cm	3,736.44	32.61	0.864	24.68	0.660	27.85	0.745	52.54	1.406
4	8 cm	3,783.81	29.45	0.786	24.94	0.659	22.21	0.586	47.15	1.246
5	Waste cotton	3,913.78	38.74	1.013	27.10	0.692	33.10	0.845	60.20	1.538
6	Jute cloth	4,015.35	49.24	1.282	25.91	0.645	40.73	1.014	66.65	1.659
7	Black cotton	3,764.19	50.33	1.314	27.47	0.729	46.08	1.224	73.56	1.954
8	Mild steel	3,818.32	54.13	1.412	30.22	0.791	48.90	1.280	79.12	2.072

Table 3
Comparison of productivity and efficiency in single-basin and double-basin stills at different basin conditions

		Single basin			Double basin			
S. No.	Basin condition	Productivity (ml/d)	% Increase	Efficiency (%)	Productivity (ml/d)	% Increase	% Increase (with single basin still)	Efficiency (%)
1	2 cm	1,610	Ref	31.63	2,990	Ref	85.71	57.53
2	Waste cotton pieces	1,650	2.48	32.15	3,065	2.50	85.75	57.81
3	Jute cloth	1,775	9.29	34.43	3,320	11.03	87.04	59.32
4	Black cotton cloth	1,850	14.91	35.89	3,510	17.39	89.73	60.54
5	Mild steel pieces	1,940	20.49	37.28	3,580	19.73	84.53	62.89

and it starts to increase considerably in the afternoon hours. It is due to the usage of maximum radiation received by the still to warm up the still and the energy loss to the surroundings.

Table 2 compares the exergy evaporation rate and exergy efficiency of the upper and lower basin of the double-basin solar still. It shows that the efficiency of the upper basin is almost same for all the lower basin conditions. In the lower basin, the efficiency varied from 0.587 to 1.28% depending upon the basin condition with a maximum efficiency of 2%.

Table 3 shows the percentage of increase in productivity for the single- and double-basin stills with different basin conditions. It shows, for single- and double-basin stills, with mild steel pieces in the basin, the distillate output is 20% higher. Wick, energy storing and absorbing material were only used in the lower basin. Hence, the upper basin production rate was almost same for all conditions.

6. Payback analysis

The payback period of the system depends on the overall cost of fabrication, maintenance cost, operating cost and the cost of feed water. The cost of feed water and operation were negligible. During the experimental period, a regular maintenance was needed to maintain the transparency of the lower basin. However, this maintenance did not require any special materials or methods. Thus, the maintenance cost also was taken as a negligible one.

Overall fabrication cost of the double-basin still = 125.833$.

Overall fabrication cost of the single-basin still = 85.833$.

The cost of the distilled water per litre is taken as 0.167$ (Rs. 10), which is available local market price for one litre of water.

Productivity of the double-basin still = 3.58 l/d.

Productivity of the single-basin still = 1.94 l/d.

Here, the average year around productivity of the solar still was taken as 60% of its daily original productivity to account the year around variation in climatic condition.

Cost of water produced per day (double basin) = 0.358$.

Cost of water produced per day (single basin) = 0.194$.

Payback period (double-basin still) = Investment/Net earning = 125.833/0.358 = 352 d.

Payback period (single-basin still) = Investment/Net earning = 85.833/0.194 = 443 d.

7. Conclusion

Following are the main conclusions made from the present studies.

- Experimental result shows that the lower basin gives higher production than the upper basin in the presence of different materials with lower depth.
- Mild steel pieces stores thermal energy in the morning hours and released it during evening hours, which increases the night production.
- Exergy performance of a double-basin solar still consuming direct solar energy was presented. It was observed that the overall exergy efficiency was very low.

The payback period of the double-basin still was 352 d, whereas 443 d were required for single-basin still.

Nomenclature

A_b	—	area of basin in solar still (m^2)
Ex_{in}	—	exergy input in solar still (W)
Ex_{evap}	—	exergy output of solar still (W)
Ex_{dest}	—	exergy destructed in solar still water (W)
Ex_{sun}	—	exergy input from the sun on solar still (W)
Ex_{work}	—	exergy of work rate for solar still (W)
I_s	—	incident solar radiation on solar still (W/m^2)
L	—	latent heat of vaporization (J/kg)
m_{evap}	—	hourly yield of solar still (kg/h)
T_a	—	ambient temperature (℃)
T_w	—	temperature of water (℃)
T_S	—	temperature of the sun (6,000 K)
η_{ex}	—	exergy efficiency (%)

References

[1] S.A. Kalogirou, Seawater desalination using renewable energy sources, Prog. Energy Combust. Sci. 31 (2005) 242–281.

[2] K.K. Murugavel, K.K.S.K. Chockalingam, K. Srithar, Progresses in improving the effectiveness of the single basin passive solar still, Desalination 220 (2008) 677–686.

[3] K. Sampathkumar, T.V. Arjunan, P. Pitchandi, P. Senthilkumar, Active solar distillation—A detailed review, Renewable Sustainable Energy Rev. 14 (2010) 1503–1526.

[4] T. Rajaseenivasan, T. Elango, K.K. Murugavel, Comparative study of double basin and single basin solar stills, Desalination 309 (2013) 27–31.

[5] A.S. Nafey, M. Abdelkader, A. Abdelmotalip, A.A. Mabrouk, Solar still productivity enhancement, Energy Convers. Manage. 42 (2001) 1401–1408.

[6] B.A/K. Abu-Hijleh, H.M. Rababa'h, Experimental study of a solar still with sponge cubes in basin, Energy Convers. Manage. 44 (2003) 1411–1418.

[7] K.K. Murugavel, K. Srithar, Performance study on basin type double slope solar still with different wick materials and minimum mass of water, Renewable Energy 36 (2011) 612–620.

[8] V. Velmurugan, J. Mandlin, B. Stalin, K. Srithar, Augmentation of saline streams in solar stills integrating with a mini solar pond, Desalination 249 (2009) 143–149.

[9] V. Velmurugan, K. Srithar, Performance analysis of solar stills based on various factors affecting the productivity—A review, Renewable Sustainable Energy Rev. 15 (2011) 1294–1304.

[10] N. Al Mahdi, Performance prediction of a multi-basin solar still, Energy 17(1) (1992) 87–93.

[11] M.S. Sodha, J.K. Nayak, G.N. Tiwari, Double basin solar still, Energy Convers. Manage. 20(1) (1980) 23–32.

[12] V.S.V. Bapeshwararao, U. Singh, G.N. Tiwari, Transient analysis of double basin solar still, Energy Convers. Manage. 23(2) (1983) 83–90.

[13] A.A. Al-Karaghouli, W.E. Alnaser, Experimental comparative study of the performances of single and double basin solar-stills, Appl. Energy 77 (2004) 317–325.

[14] A.A. Al-Karaghouli, W.E. Alnaser, Performances of single and double basin solar-stills, Appl. Energy 78 (2004) 347–354.

[15] T. Rajaseenivasan, K.K. Murugavel, T. Elango, R. Hansen, A review of different methods to enhance the productivity of the multi-effect solar still, Renewable Sustainable Energy Rev. 17 (2013) 248–259.

[16] T. Rajaseenivasan, K.K. Murugavel, Theoretical and experimental investigation on double basin double slope solar still, Desalination 319 (2013) 25–32.

[17] S.A. Kalogirou, Solar Energy Engineering: Processes and Systems, Elsevier, New York, NY, 2009.

[18] S. Kumar, A. Tiwari, An experimental study of hybrid photovoltaic thermal (PV/T)-active solar still, Int. J. Energy Res. 32 (2008) 847–858.

[19] S. Shanmugan, V. Manikandan, K. Shanmugasundaram, B. Janarathanan, J. Chandrasekaran, Energy and exergy analysis of single slope single basin solar still, Int. J. Ambient Energy 33(3) (2012) 142–151.

[20] S. Kumar, G.N. Tiwari, Analytical expression for instantaneous exergy efficiency of a shallow basin passive solar still, Int. J. Therm. Sci. 50 (2011) 2543–2549.

[21] A. Kianifar, S.Z. Heris, O. Mahian, Exergy and economic analysis of a pyramid-shaped solar water purification system: Active and passive cases, Energy 38 (2012) 31–36.

[22] M.K. Phadatare, S.K. Verma, Effect of cover materials on heat and mass transfer coefficients in a plastic solar still, Desalin. Water Treat. 2 (2009) 254–259.

[23] Ş.H. Aybar, H. Assefi, Simulation of a solar still to investigate water depth and glass angle, Desalin. Water Treat. 7 (2009) 35–40.

[24] T.V. Arjunan, H.Ş. Aybar, N. Nedunchezhian, Effect of sponge liner on the internal heat transfer coefficients in a simple solar still, Desalin. Water Treat. 29 (2011) 271–284.

[25] S. Shanmugan, B. Janarthanan, J. Chandrasekaran, Performance of single-slope single-basin solar still with sensible heat storage materials, Desalin. Water Treat. 41 (2012) 195–203.

[26] A.K. Tiwari, G.N. Tiwari, Effect of the condensing cover's slope on internal heat and mass transfer in distillation: An indoor simulation, Desalination 180 (2005) 73–88.

[27] A. Hepbalsi, A key review on exegetic analysis and assessment of renewable energy sources for a sustainable future, Renewable Sustainable Energy Rev. 12(3) (2008) 593–661.

[28] R. Petela, Exergy of undiluted thermal radiation, Sol. Energy 74(6) (2003) 469–488.

[29] G.N. Tiwari, V. Dimri, A. Chel, Parametric study of an active and passive solar distillation system: Energy and exergy analysis, Desalination 242 (2009) 1–18.