ENERGY AND EXERGY EFFICIENCY ANALYSIS OF A SOLAR STILL WITH PHOTOVOLTAIC MODULES – AC HEATER

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ABSTRACT

In this paper, performance analysis of a Proposed Solar Still (PSS) (Conventional solar still with the photovoltaic modules-AC heater) was carried out on three different water depth (W_d) condition (1, 2 and 3 cm). The daily freshwater production from the PSS at the W_d of 1, 2 and 3 cm were 6.9, 5 and 3.3 kg, respectively. The energy and exergy efficiency of the PSS at the W_d of 1, 2 and 3 cm were 40.5, 26.5 and 18%, and 4.5, 2.4 and 0.9%, respectively. At 1 cm W_d, PSS produced the maximum freshwater yield as compared to the other two water depths. When the W_d is increased from 1 to 2 cm and from 1 to 3 cm, the yield is decreased up to 27.3 and 52.7%, respectively. Similarly, the energy and exergy efficiency is decreased up to 36.8 and 53.2% and 50.4 and 80.6%, respectively.

Keywords: solar still, freshwater, A.C heater, energy, exergy, water depth

1 INTRODUCTION

Electricity and consumable water is the basic requirements for the life of the human in the current world situation. The traditional energy assets are lowering step by step which prompts the turning in the utilization of sustainable power source assets. Industrialization in the present world pollutes the earth surface and also the consumable water accessible in the ground level. More than one billion individuals in the globe need access to drinking water. About 80% of all sickness in the undeveloped countries happens because of perilous water and without sufficient sanitation. Al-Nimr et al. [11] mathematically developed the Conventional Solar Still (CSS) with PV/T cells submerged in the basin water. It was submitted that this system produced a maximum yield of 7.9 kg/m2 d. Yari et al. [12] introduced a CSS integrated with Evacuated Tube Collector (ETC) and semitransparent PV cells. It was reported that this system produced a maximum yield of 4.77 kg/m2. day at minimum W_d and 30 numbers of the ETC. Kabeel et al [13] extracted the heat from the PV panel by flowing air from a DC blower. The hot air was injected to the still basin to increase the water temperature. This modified system produced 40.98% higher yield as compared to the CSS. The performance of a CSS with PCM heat energy storage and PV panel integration was studied by Elbar et al. [14]. It was published that this system produced 19.4% higher yield as compared to the CSS. Al-Nimr et al. [15] introduced a hybrid solar-wind desalination system. This system produced a maximum distilled water of 6 kg/day which was 3 to 4 times higher as compared to the CSS. Al-Nimr et al. [16] also introduced a CSS integrated with PV cells and thermoelectric generators to produce energy and distilled water. This hybrid system produced a maximum distilled water output of 8.3 $kg/m^2/h$

2 EXPERIMENTAL SETUP AND PROCEDURE

Fig. 1 demonstrates the schematic diagram of the PSS. This framework comprises of a heating element that contacts the basin water inside the PSS. The NiCr wire is put and fixed inside the PSS and the input to the heating component is given by the solar PV battery controller. This system is made with an area of 1 m^2 (0.5 m x 2 m) with a wall height of 25, 10 cm on high-side and low-side, respectively. Black paint is coated in the absorber plate to enhance the absorption of heat from the sun. Thermocol (polystyrene) sheets of 5 cm thickness are utilized to insulate the basin to reduce the heat losses. A glass sheet of 3 mm thickness is utilized to cover the basin, at a point of 10 ° on a level plane that is the latitude of Virudhunagar, Tamilnadu, India.

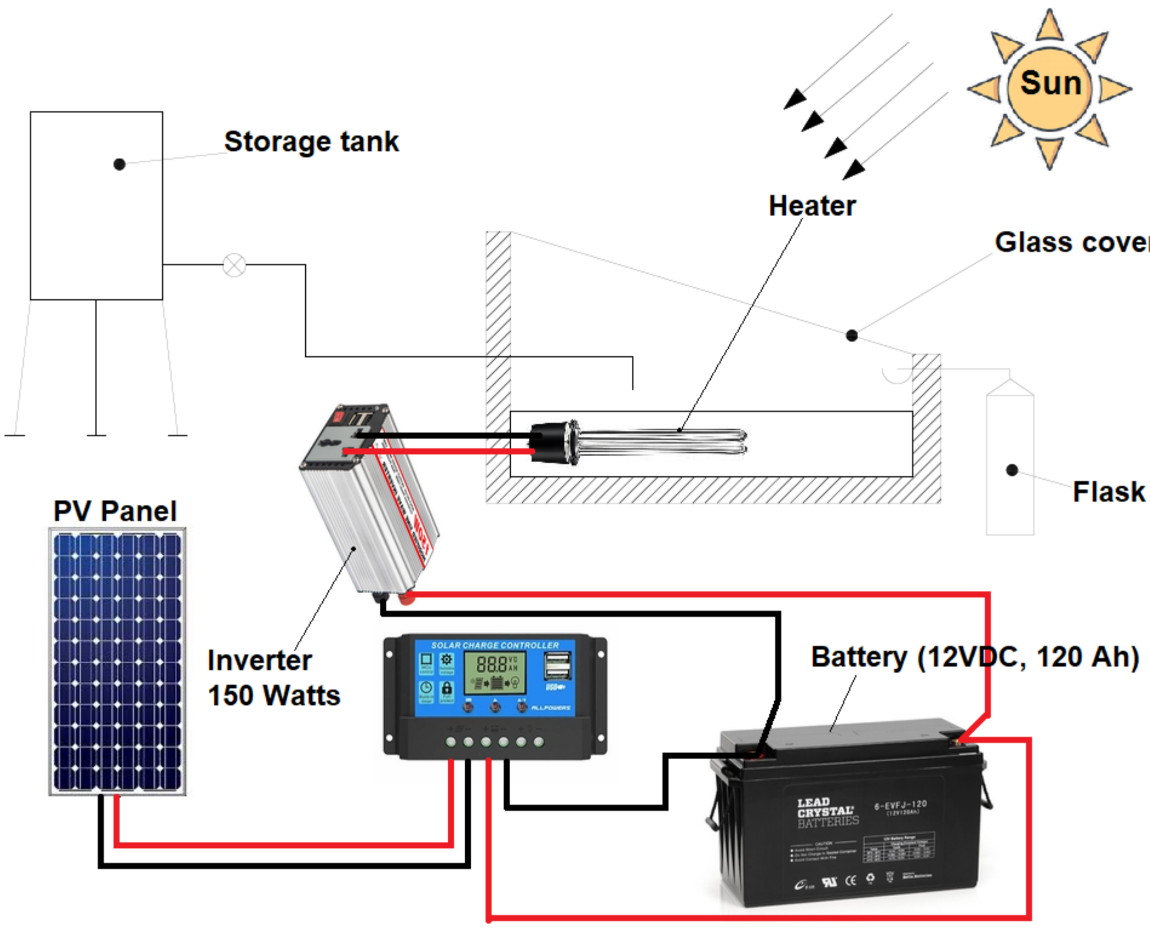

Figure 1. Schematic diagram of a proposed research work

3 RESULTS AND DISCUSSION

3.1 Variations of solar irradiance and atmospheric temperature

Diurnal changes in solar intensity and climatic temperature during the exploration day is plotted in Fig. 2. From the figure, it is found that solar intensity and the climatic temperature has an incremental trend during the before noon time and reached its maximum values at 2 o' clock and thereafter it has a decreasing trend. The maximum hourly solar intensity during the testing are recorded as 870, 850 and 830

W/m^2 on 20.4.2018, 23.4.2018 and 25.4.2018, respectively. It is calculated that the daily average solar intensity during the experimental day was found to be as 716.67, 726 and 718.11 W/m^2 on 20.4.2018, 23.4.2018 and 25.4.2018, respectively.

The climatic temperature during the exploration day also has the same trend as like solar intensity variations. The maximum climatic temperature during the testing has reached at 2 o' clock. The maximum hourly climatic temperature of 38, 39 and 37 ° C has measured on 20.4.2018, 23.4.2018 and 25.4.2018, respectively. It is calculated that the daily average climatic temperature during the experimental day was found to be as 34.86, 35.92 and 34.09 ° C, respectively.

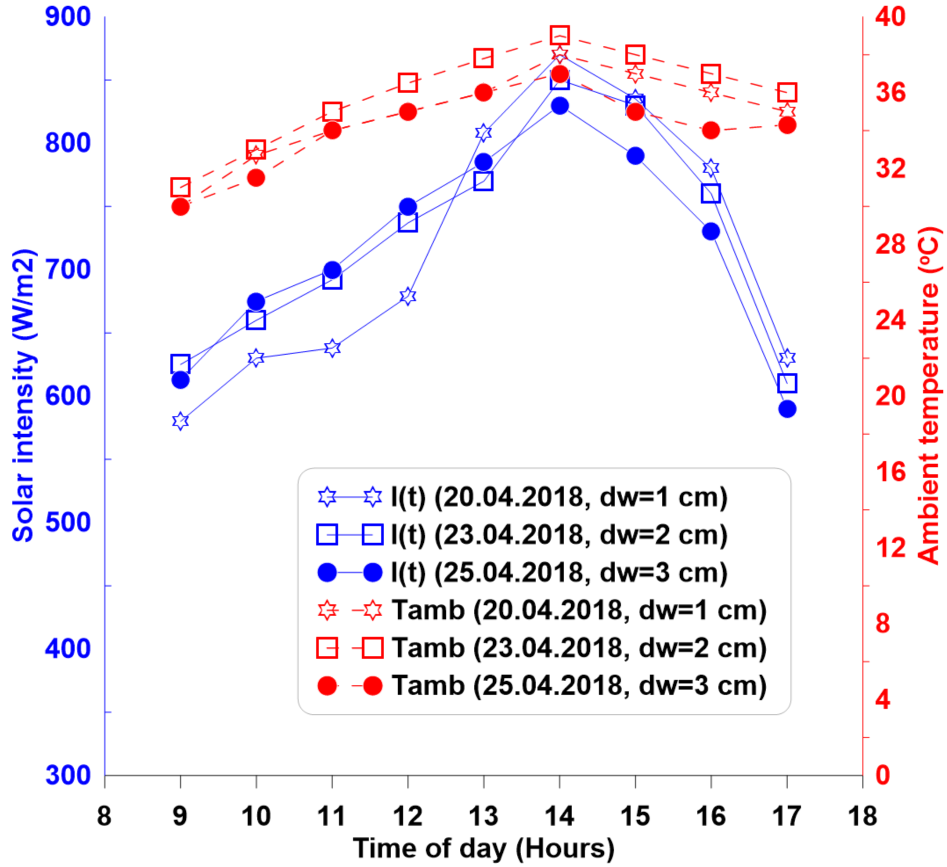

Figure 2. Variations of solar intensity and ambient temperature every hour

3.2 Variations of water temperature and the EHTC

Diurnal changes in water temperature and the EHTC for the PSS at different W_d are plotted in Fig. 3. From the graph, it is identified that water temperature reached its maximum temperature at 3 o clock. The maximum hourly water temperature of the PSS at 1, 2 and 3 cm is 67, 60 and 50 ° C, respectively. The daily average water temperature of the PSS at a W_d of 1 cm is 52.72 ° C, 2 cm is 47.89 ° C and 3 cm is 40.67 ° C. It is calculated that when the W_d is increased from 1 to 2 cm and from 1 to 3 cm, the daily average water temperature of the PSS has decreased up to 9.17 and 22.87%, respectively. At minimum W_d condition, the water mass inside the basin is minimum so it was easy getting heated and enhances its temperature.

From the graph, it is found that the value of the EFTC reached the maximum at 2 o' clock for 1 cm W_d and maximum value at 3 o' clock for 2 and 3 cm of W_d. The maximum EHTC for the PSS at 1, 2 and 3 cm W_d is 51.75, 43.47 and 31.66 W/m^{2}k, respectively. The daily average EHTC of the PSS at a W_d of 1, 2 and 3 cm is 29, 16 and 10 W/m^{2}k, respectively. It is calculated that when the W_d is increased from 1 to 2 cm and from 1 to 3 cm, the daily average EHTC of the PSS has decreased up to 45.53 and 67.42%, respectively.

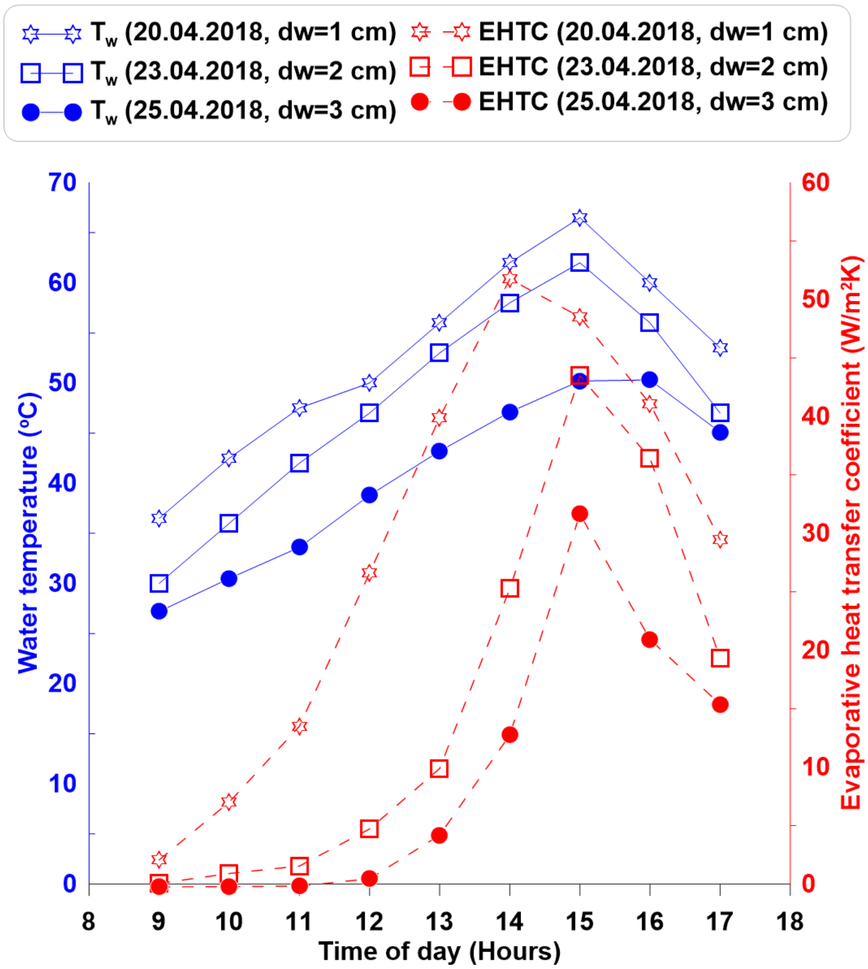

Figure 3. Variations of water temperature and EHTC every hour

3.3 Variation of the distilled water production and Energy efficiency

Diurnal changes in distilled water production and Energy efficiency for the PSS at different W_d are plotted in Fig. 4. The distilled water production is directly proportional to the EHTC. The maximum yield from the PSS at 1 cm W_d reaches at 2 o' clock, whereas the maximum yield from the PSS at 2 and 3 cm reaches at 3 o' clock. The maximum hourly yield from the PSS at 1, 2 and 3 cm W_d is 1.26, 0.95 and 0.68 kg, respectively. The daily freshwater production from the PSS at 1, 2 and 3 cm is 6.91, 5.02 and 3.27 kg, respectively. It is calculated that, when the W_d is increased from 1 to 2 cm and from 1 to 3 cm, the daily average freshwater production from the PSS has decreased up to 27.28 and 52.71%, respectively.

The thermal efficiency of the PSS is directly proportional to the hourly distilled water production. The maximum thermal efficiency of the PSS at 1 cm W_d reached at 2 o clock, whereas the maximum thermal efficiency of the PSS at 2 and 3 cm reach at 3’ o clock. The maximum thermal efficiency of the PSS at 1, 2 and 3 cm W_d is 64.83, 51.45 and 36%, respectively. The daily average thermal efficiency of the PSS at a W_d of 1, 2 and 3 cm is 42, 26.52 and 19.62%, respectively. It is calculated that when the W_d is increased from 1 to 2 cm and from 1 to 3 cm, the daily average thermal efficiency of the PSS has decreased up to 36.8 and 53.24%, respectively.

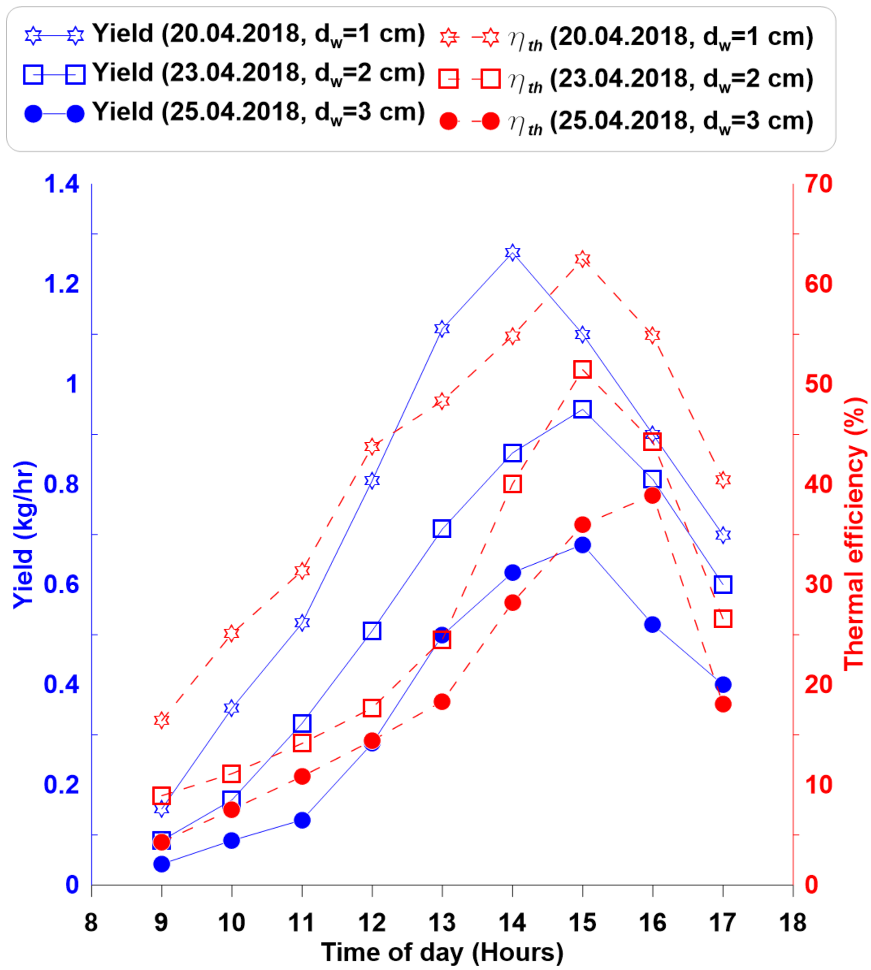

Figure 4. Variations of distilled yield and Energy efficiency every hour

3.3 Variation of the Exergy efficiency

Diurnal changes in exergy efficiency of the PSS at different W_d are plotted in Fig. 5. The exergy efficiency of the PSS mainly depends on the fresh water production rate and solar intensity. The exergy efficiency of the PSS is higher at minimum solar intensity input condition. The maximum exergy efficiency of the PSS at minimum W_d is 7.45% at 2’ o clock. Whereas the maximum exergy efficiency at 2 cm W_d is 5.57% at 3’ o clock and at 3 cm W_d is 3.19% at 4 o’ clock. The daily average exergy efficiency of the PSS at a W_d of 1, 2 and 3 cm is 4.5, 3.9 and 2.7%, respectively. It is calculated that, when the W_d is increased from 1 to 2 cm and from 1 to 3 cm, the daily average exergy efficiency of the PSS has decreased up to 50.45 and 80.61%, respectively.

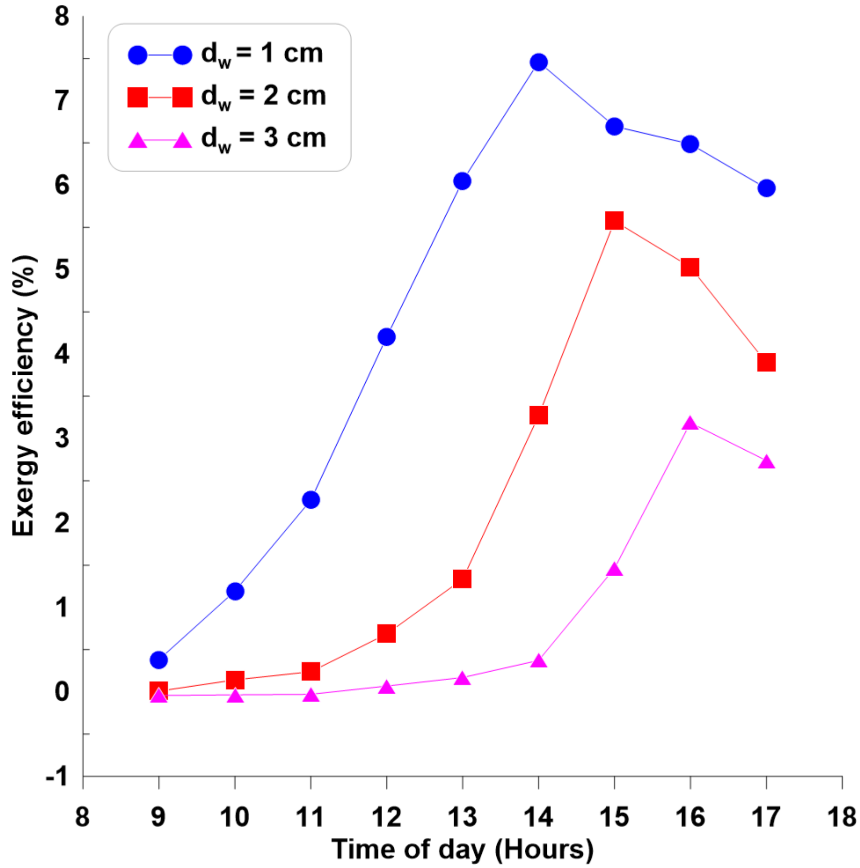

Figure 5. Variations of exergy efficiency every hour

4 CONCLUSIONS

From the experimental investigations on the CSS with Photovoltaic modules- AC heater the following conclusions have arrived.

- The maximum yield is produced at minimum water mass inside the basin.
- The daily fresh water yield of 6.91, 5.02 and 3.27 kg is obtained from the PSS at a W_d of 1, 2 and 3 cm, respectively.
- This system produced 43 to 71% higher yield as compared to the CSS (yield 2-4 kg/m^2)
- The thermal and exergy efficiency of the PSS is maximum at minimum water mass inside the basin.

REFERENCES

Al-Nimr, M. D. A., Al-Ammari, W. A., & Alkhalidi, A. (2019). A novel hybrid photovoltaics/thermoelectric cooler distillation system. *International Journal of Energy Research*, *43*(2), 791-805.

Elbar, A. R. A., & Hassan, H. (2019). Experimental investigation on the impact of thermal energy storage on the solar still performance coupled with PV module via new integration. *Solar Energy*, *184*, 584-593.

Kabeel, A. E., Manokar, A. M., Sathyamurthy, R., Winston, D. P., El-Agouz, S. A., & Chamkha, A. J. (2019). A Review on Different Design Modifications Employed in Inclined Solar Still for Enhancing the Productivity. *Journal of Solar Energy Engineering*, *141*(3), 031007.

Manokar, A. M., Murugavel, K. K., & Esakkimuthu, G. (2014). Different parameters affecting the rate of evaporation and condensation on passive solar still–A review. *Renewable and Sustainable Energy Reviews*, *38*, 309-322.

Manokar, A. M., Winston, D. P., Kabeel, A. E., El-Agouz, S. A., Sathyamurthy, R., Arunkumar, T., & Ahsan, A. (2018). Integrated PV/T solar still-A mini-review. *Desalination*. 435, 259–267.

Muthu Manokar, A., Prince Winston, D., Kabeel, A.E., Sathyamurthy, R., & Arunkumar, T. (2018). Different parameter and technique affecting the rate of evaporation on active solar still-a review. *Heat and Mass Transfer*, 54: 593-630.

Manokar, A. M., Vimala, M., Winston, D. P., Ramesh, R., Sathyamurthy, R., Nagarajan, P. K., & Bharathwaaj, R. (2019). Different parameters affecting the condensation rate on an active solar still—A review. *Environmental Progress & Sustainable Energy*. Volume 38, Issue 1, Pages 286-296

Manokar, A. M., Taamneh, Y., Kabeel, A. E., Sathyamurthy, R., Winston, D. P., & Chamkha, A. J. (2018). Review of different methods employed in pyramidal solar still desalination to augment the yield of freshwater. *DESALINATION AND WATER TREATMENT*, *136*, 20-30.

Manokar, A. M., & Winston, D. P. (2017). Experimental analysis of single basin single slope finned acrylic solar still. *Materials Today: Proceedings*, *4*(8), 7234-7239.

Manokar, A. M., & Winston, D. P. (2017). Comparative study of finned acrylic solar still and galvanised iron solar still. *Materials Today: Proceedings*, *4*(8), 8323-8327.

Manokar, A. M., Winston, D. P., Kabeel, A. E., & Sathyamurthy, R. (2018). Sustainable fresh water and power production by integrating PV panel in inclined solar still. *Journal of Cleaner Production*, *172*, 2711-2719.

Moh'd A, A. N., & Al-Ammari, W. A. (2016). A novel hybrid PV-distillation system. Solar Energy, 135, 874-883.

Moh'd A, A. N., Kiwan, S. M., & Talafha, S. (2016). Hybrid solar-wind water distillation system. *Desalination*, *395*, 33-40.

Manokar, A. M., Winston, D. P., Kabeel, A. E., & Sathyamurthy, R. (2018). Sustainable fresh water and power production by integrating PV panel in inclined solar still. Journal of Cleaner Production, 172, 2711-2719.

Manokar, A. M., Winston, D. P., Mondol, J. D., Sathyamurthy, R., Kabeel, A. E., & Panchal, H. (2018). Comparative study of an inclined solar panel basin solar still in passive and active mode. Solar Energy, 169, 206-216.

Raj S.V., & Manokar, A. M. (2017). Design and Analysis of Solar Still. *Materials Today: Proceedings*, 4 (8), 9179-9185

Yari, M., Mazareh, A. E., & Mehr, A. S. (2016). A novel cogeneration system for sustainable water and power production by integration of a solar still and PV module. *Desalination*, *398*, 1-11.

Yari, M., Mazareh, A. E., & Mehr, A. S. (2016). A novel cogeneration system for sustainable water and power production by integration of a solar still and PV module. *Desalination*, *398*, 1-11.

APPENDIX

The following formulas were used to calculate the different parameters,
The EHTC from absorber to collector [17,18],

$$h_{e,w-g} = 16.273X10^{-3} x h_{c,w-g}\left[\frac{P_w - P_{gi}}{T_w - T_{gi}}\right]$$

Convective heat transfer coefficient from the absorber to the collector [17,18],

$$h_{c,w-g} = 0.884\left[(T_w - T_{gi}) + \frac{(P_w - P_{gi})(T_w + 273)}{(268.9X10^{-3} - P_w)}\right]$$

Partial vapour pressure at the basin water temperature [17,18],

$$P_w = exp\left(25.317 - \left(\frac{5144}{273 + T_w}\right)\right)$$

Partial vapour pressure at the collector cover temperature [17,18],

$$P_{gi} = exp\left(25.317 - \left(\frac{5144}{273 + T_{gi}}\right)\right)$$

The thermal efficiency of the PSS [17,18],

$$\eta_{passive} = \frac{\sum \dot{m}_{ew} L}{\sum I(t) A_s x3600} x100$$

The exergy efficiency of the PSS [17,18],

$$\eta_{overall,exe} = \frac{\sum Ex_{output}}{\sum Ex_{input}}$$

The hourly exergy output [17,18],

$$Ex_{output} = \frac{m_{ew} L_{fg}}{3600} \times \left[1 - \frac{T_a}{T_w}\right]$$

The hourly exergy input [17,18],

$$Ex_{input} = A_w I^{'}(t) \times \left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right]$$