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Exergy Analysis of a Simple Solar Still Augmented with a Flat-Plate Solar Collector

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ABSTRACT

A single-stage basin solar still augmented with flat-plate solar collector was investigated to examine the effect of the available amount of exergy on still production. For different temperatures, solar intensities, and distilled water production, the quantity of exergy was computed. Calculations were performed based on experimental measurements and readings for various weather and operational conditions. The total distilled water produced from the collector augmented still is found to be 1807 ml/day which is 77 % larger than that when the still worked without collector (1016 ml/day).

1. INTRODUCTION

Solar distillation is a water purification process powered by solar irradiance. The solar still working principle is to take advantage of the sun's energy by vaporizing water (from a brackish or salty source) and then re-condensing it on the cool glass. The amount of condensed distilled water, which is salt-free, depends on the energy input from the sun. The process of passing the brackish water through a flat plate-type solar collector before entering the solar still will raise the water's temperature and thus accelerate the evaporation process inside. This process leads to an improvement in solar still efficiency and productivity.

To service a rising global population that will experience increased water shortages in the future, desalination will grow in importance. Desalination is a procedure that uses a lot of energy and currently relies on fossil fuels, which increases the world's water problems and contributes to global warming. Desalination's environmental impact may be minimized by using solar energy, which has a minimal carbon footprint [1].

In distant and dry parts of Jordan, the impact of the water depth in the basin solar still, design, and operating characteristics on the water production were examined. At Mutah University, samples of brackish water at various depths (from 0.5 to 4 cm) with 5000 ppm total dissolved solids were examined. Six-month of research revealed that the climatic, design, and operating circumstances had a significant impact on the still production. The acquired findings revealed a significant link between increased water production and the reduced water depth, while the performance characteristics revealed a significant correlation between water productivity and incident irradiance [2].

Passive solar desalination performance has been greatly enhanced by the construction of a passive vapor production system with interfacial solar heat localization [3]. Incorporating a salt-free thermally localized multi-stage solar still design into a low-cost system, they obtained a record-breaking 385% efficiency of solar-to-vapor conversion at a rate of 5.78 (L/m^2/h). More than 75% of the production was recovered by condensation [3].

Many solar-based desalination technologies have been studied to identify the key elements that affect their effectiveness [4]. The variables that impact performance might vary depending on the kind of solar desalination. One of the most crucial elements affecting the output of the systems is solar radiation [4].

Velammal Engineering College in Chennai tested a 0.49 m^2 galvanized iron sheet single-slope and single-basin solar still to evaluate how initial basin pressure affects solar still production. A reciprocating pump was used to control the initial basin pressure of the solar still. At 25, 50, 75, and 101.32 kPa, the still's freshwater production was tested. Compared to atmospheric pressure operation, solar yield rose by 67.53, 34.49, and 10.72%, respectively. The reduced pressure within the solar system still enhances evaporation and condensation, resulting in better production [5].

The thermos-economic performance of a solar still by means of a RT58 (PCM) phase-change material with superior thermophysical characteristics has been examined. According to the data, the RT58-PCM produced a higher yield than a standard solar still (SSS) that did not include RT58-PCM as an energy storage medium. RT58-PCM increases solar energy production by 46% in comparison to CSS. In terms of cost/liter of fresh water generated and payback period, economic study found that solar still with RT58-PCM is more economically feasible than SSS [6].

A modified double-stage vertical distiller with a moving disc was used by Diab et al. [7] to test the effects of altering water depth at the optimal disc rotation speed on vertical distillers' thermal productivity. To determine the ideal depth, several water depths were examined at 1.5 rpm. The findings showed that using moving discs increased the production of the distillers. Moreover, at 5 cm depth and 1.5 rpm, the distiller's best performance was attained. Additionally, modified single-stage vertical distillers and modified double-stage vertical distillers both saw 350 and 617.4% increases in output, respectively, in comparison to the productivity of the standard tilting distiller, which was 2.3 L/m^2 day [7].

In the literature, there are several designs and adaptations for solar stills, all of which aim to boost their performance. Updates include a solar distiller with a revolving wick and improved vaporization techniques [8], copper-stepped tilted solar still [9], revolving-drum solar distiller with improved evaporation and condensation procedures [10], rotating discs solar still [11], mirror-equipped hemispherical distiller with energy-saving materials [12], phase-change material combined with Al_2O_3 nanoparticles in a plate solar distiller [13], an external condenser redesigned still using nanofluids [14], utilizing response surface approach, a pyramidal solar still with various nanoparticles [15], artificial neural network wick-solar still [16], corrugated absorber solar distiller with wick and reflectors [17], reactive distillation modelling [18], solar stills with corrugated absorbers and fins [19], corrugated absorbers and a half-barrel modifications for a wicked-solar still [20], and nanomaterials with corrugated surfaces [21].

Exergy is a thermodynamic quantity reflecting the peak work obtained theoretically from a system's interaction with its surroundings as both achieve equilibrium. A system's exergy is a joint property with the reference environment, not only a thermodynamic attribute [22]. An evacuated glass tube solar collector with a single end was investigated to examine the net exergy-exergetic efficiency and exergy destruction of wet-type evacuated tube solar collector. The findings indicate a 65.88% exegetic efficiency, a consistent value despite the rising temperature differential between water entering and exiting the collection, based on the average annual Jordan solar irradiance [23].

Energy and exergy analysis were conducted to evaluate the performance of a simple flat plate solar collector using water-based Al_2O_3 nanofluids of different diameters and deionized water. Nanoparticles were 13 nm and 20 nm, with a volume percentage of 0.1%. Experiments used a stable nanofluid. The findings show how each parameter affects collector energetic and exergetic efficiency [24].

Exergetically, a water-lithium bromide single-effect absorption system of 1 kW and 10 kW was examined. Calculations are made for each component's to find the exergetic coefficient of performance, and exergy losses. COP ranged from 80 to 90℃ for 10 kW cooling load. ECOP ranged from 100 to 90℃ generating temperature. Generators lost 40% of system exergy. At 80℃ generator temperature and 10℃ evaporator temperature, the absorber loses the least exergy with 1 kW cooling load. Both 1 kW and 10 kW cooling capabilities had a maximum COP at 5℃ evaporator temperature. ECOP peaked at 1.5℃ evaporator temperature [25].

On the basis of experimental research, noncorrosive, nontoxic, and eco-friendly green thermal fluid was studied to examine how well flat plate solar collectors work. With increasing heat flux, mass flow rate and nano-concentration, the collector's thermal efficiency improved; but, as the temperature at the collector's entry increased, its efficiency will decrease. Based on the results of tests, 0.0188 kg/s with a 0.1% nanofluid fraction increased energy efficiency by 30.8% compared to basic fluid [26].

The literature demonstrates an energy crisis and its environmental repercussions, the importance of increasing energy efficiency, and the emergence of distillation systems as one of the most vital sectors of energy applications. Energy and exergy studies provide additional data regarding the design, development, optimization, and performance improvement of these energy and distillation systems. Using energy and exergy analyses, this research aims to answer the current critical challenges in the analysis of better and novel distillation systems. Also, to the best of our knowledge, this work constitutes a pioneering effort in employing exergy analysis for the solar still supplemented with a solar collector, as no comparable research has been discovered.

2. METHOD AND SYSTEM DESCRIPTION

The current study investigates the effects of integrating a typical flat-plate solar collector into a single basin solar still under Jordan climates, as seen in Figure 1. The outcomes of this enhancement, productivity and efficiency, based on energy and exergy analysis was reported and discussed. Also, the energitec and exergitec efficiency of passive still was compared to that of the flat-plate collector in conjunction with a solar still (active still), and makes comparison between produced quantities of distilled water in each case.

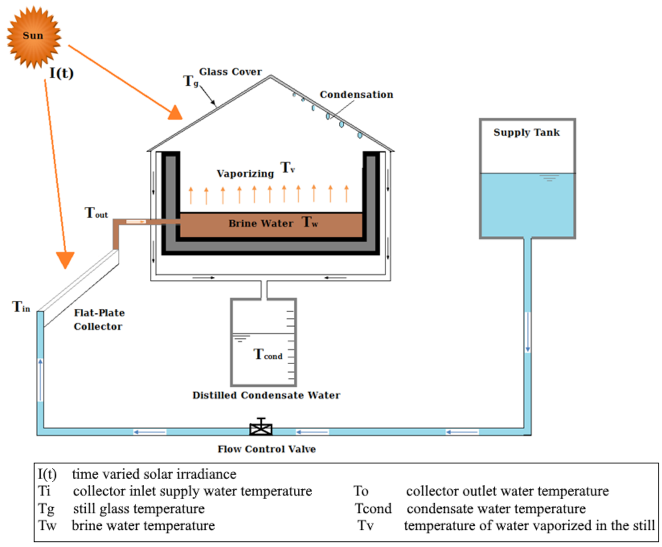

Figure 1. Solar collector augmented still schematic diagram

3. EXERGY ANALYSIS OF THE STILL WITHOUT COLLECTOR (SIMPLE STILL)

Heat is a form of disorganized energy. Therefore, heat transfer is always accompanied by exergy transfer. Following the solar still examination in conjunction with a flat-plate collector done by Badran and Al-Tahaineh [27] the exergy due to heat transfer may be written as:

$$X_{heat} = \left(1 - \frac{T_{wo}}{T_w}\right) Q \tag{1}$$

The transfer of heat Q is given by:

$$Q = (mc)_w (T_{wo} - T_{wi}) \tag{2}$$

The water's mass flow rate is m, and its specific heat is c; T_{wo} is the temperature of basin water. Water temperature, T_w, as a function of time average *f(t)* for time interval Δt is given by the research [27]:

$$\frac{dT_w}{dt} + aT_w = f(t) \tag{3}$$

Solving the differential equation for T_w yields to:

$$T_w = \left[\frac{f(t)}{a}(1-(-at)) + T_{wo} \times e^{-at}\right] \tag{4}$$

The differential coefficient a is given in terms of loss coefficient U_l as:

$$a = \frac{U_l}{(mc)_w} = \frac{U_b+U_t}{(mc)_w} \tag{5}$$

U_b is the bottom loss coefficient. The top loss coefficient U_t is given by:

$$U_t = \frac{h_{1w}h_{1g}}{h_{1w}+h_{1g}} \tag{6}$$

where, h_{1g} is the glass cover-to-ambient heat transfer coefficient, and h_{1w} is the water-to-glass heat transfer coefficient.

The time average function *f(t)*, may be written as a function effective product of absorptivity and transmissivity $(\alpha\tau)_{eff}$, solar irradiance *(I(t))*, overall loss coefficient (U_l=U_b+U_t), ambient temperature (T_a), and water heat capacitance $(mc)_w$ as:

$$f(t) = \frac{(\alpha\tau)_{eff}I(t)+U_lT_a}{(mc)_w} \tag{7}$$

where, the product of absorptivity and transmissivity $(\alpha\tau)_{eff}$ depends on the radiative heat transfer coefficients of basin liner, convective heat transfer coefficients of water, and glass (h_b,h_w, h_g) respectively and the fractions of solar energy absorbed by basin liner, water, and glass (α_b,α_w, α_g) respectively.

$$(\alpha\tau)_{eff} = \alpha_b\frac{h_w}{h_w+h_b} + \alpha_w + \alpha_g\frac{h_{1w}}{h_{1w}+h_{1g}} \tag{8}$$

Glass to ambient convective-radiative heat transfer coefficient (h_{1g} = h_{cg} + h_{rg}) could be calculated as a function of wind speed (V) using the following relation (h_{1g}=5.7 +3.8V) [27]:

Substituting Eqns. (2) and (4) into Eq. (1), then the still exergy may be written as:

$$X = \left(1-\frac{T_{wo}}{\left[\frac{f(t)}{a}(1-(-at))+T_{wo}\times e^{-at}\right]}\right)\times \left((mc)_w\left(\left[\frac{f(t)}{a}(1-(-at))+T_{wo}\times e^{-at}\right]-T_{wo}\right)\right) \tag{9}$$

4. EXERGY ANALYSIS OF THE AUGMENTED STILL (STILL WITH COLLECTOR)

When the simple solar still is augmented with a flat-plate collector as shown in Figure 1, exergy of the collector augmented still becomes:

$$X = \left(1-\frac{T_{wo}}{\left[\frac{\overline{f(t)}}{a}(1-e^{-at})+T_{wo}\times e^{-at}\right]}\right)\times \left((mc)_w\left(\left[\frac{\overline{f(t)}}{a}(1-e^{-at})+T_{wo}\times e^{-at}\right]-T_{wo}\right)\right) \tag{10}$$

where, $\overline{f(t)}$ is corrected time average function to include the effect of adding solar collector to the system and is given as follow:

$$\overline{f(t)} = \frac{((\alpha\tau)_{eff}\overline{I(t)}+F_R(\alpha\tau)A_c\overline{I_c(t)})+(U_l+U_lF_RA_c)\overline{T_a}}{(mc)_w} \tag{11}$$

where, $I_c(t)$ is solar irradiance incident on the augmented solar collector, and the factor represents heat removal F_R is the practical energy gain ratio result if the absorber temperature of the collector being at the temperature of local fluid. The solar radiation absorptivity (α) is given by:

$$\alpha = \frac{U_l+F_RU_l\acute{A}_c}{(mc)_w} \tag{12}$$

where, $\acute{A}_c$ represents the of collector-basin still area ratio.

$$\acute{A}_c = (A_c/A_s) \tag{13}$$

Applying the input parameters shown in Table 1 into the governing equations, the results were presented.

Table 1. System input parameters

Local time (hr)	T_{amb} (°C)	I (W/m²)	T_{out} (°C)	T_{in} (°C)	T_w (°C)
9	16	400	23	18	16
10	17	590	40	23	30
11	19	780	52	30	42
12	22	950	56	36	52
13	24	1000	58	45	66
14	22	870	60	48	76
15	19	700	60	43	75
16	17	510	52	40	68
17	15	290	35	30	57

5. RESULTS AND DISCUSSION

Figure 2 shows how the sun irradiance and surrounding temperature vary for the research site in relation to local time. The peak solar flux (about 1000 W/m²) and ambient temperature (about 24°C, respectively) were measured around 13 local time.

The variation of temperatures at different locations of investigation setup were presented in Figure 3. The results show a maximum value of temperature out of the solar collector to be around 65°C. Theoretical temperatures inside the solar still was found to be around 76°C. The Maximum temperatures was found to be around 13 local time.

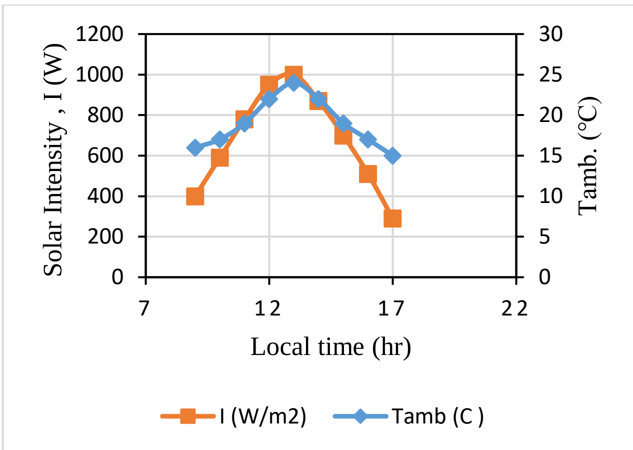

Figure 2. Ambient temperature-solar intensity variation with local time

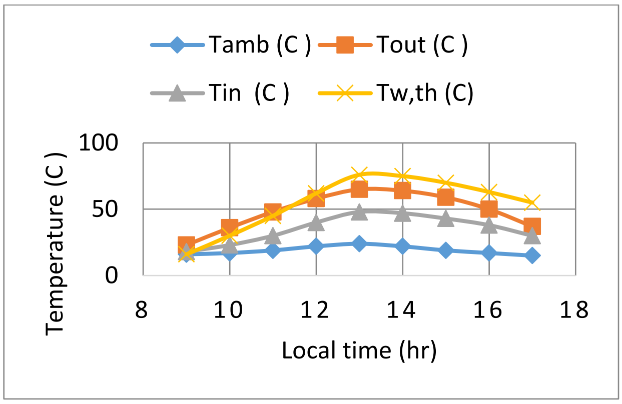

Figure 3. Variation of temperature with local time

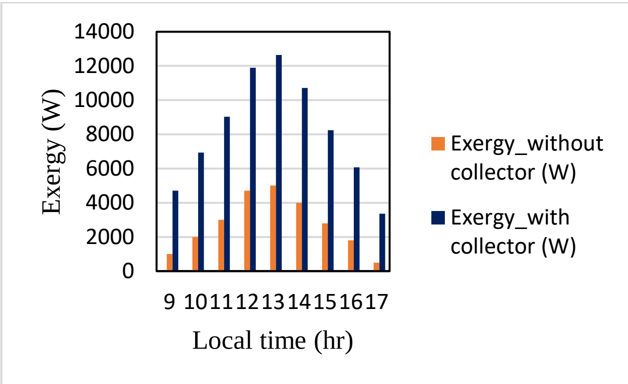

Figure 4. Variation of solar intensity and exergy with local time (with/without collector)

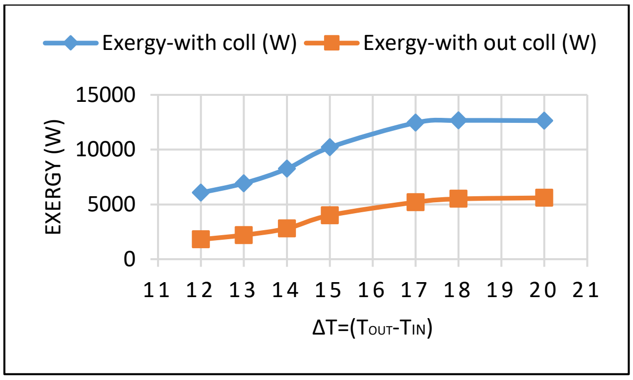

Figure 5. Effect of collector temperature difference on system exergy

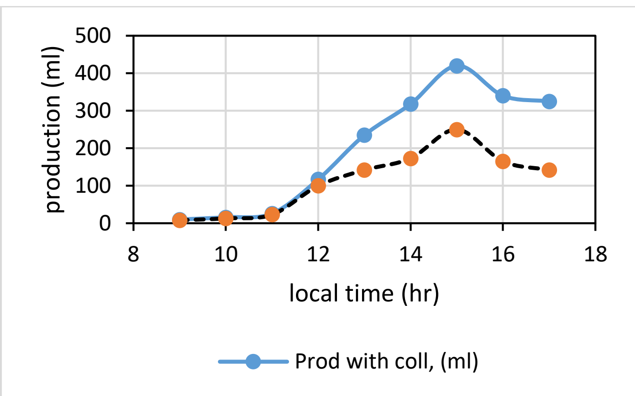

Figure 6. Variation of water production with local time (with and without collector)

The benefit of solar collector augmentation was shown clearly in Figure 4. The temperature of water entering the still increases by about 30% with adding collector to the system and these results in increasing distilled water production. Augmenting the flat plate collector with the solar still enhances the overall system exergy. Results presented in Figure 4 show that the solar collector increased the system average exergy by more than 190%. At 13 local time, the time with maximum exergy, 12647 W is the exergy available of solar still coupled with solar collector while it was 5000 W for still alone with more than 150% increase.

The overall system exergy increases with increasing temperature differences of water entering and exiting the still since the water heat capacity rises with heating. Figure 5 depicts the influence of water temperature differential on the still's available exergy in both cases (with and without augmenting solar collector). Results show that for both cases, the system exergy continues to rise until the temperature difference approaches 20°C, at which point the exergy reaches a steady state condition (12647 W for still with collector and 5600 W for still alone). The explanation for this is that, at this temperature difference, the system reaches equilibrium with the surrounding environment (i.e., the rate of energy flux gained by the solar system equals the rate of heat loss from the system to the environment).

When the collector is added to the still, it produces a distilled water of about 1807 ml/day, which is 77% more than when the still operated alone (1016 ml/day). Figure 6 clearly illustrates the difference between the two cases, with and without the collector, under the same average solar intensity and exergy of Figure 4. This is due to the fact that the collector still gains more thermal energy when it is added than when it operates alone, and that the water-glass temperature grew at night was primarily caused by the release of heat that has been trapped in the water due to the thermal heat capacity effect. Production peaks at 3:00 pm (420 ml with collector, 250 ml without collector), with a 68% local increase.

6. CONCLUSION

The influence of the available quantity of exergy on the production of a single-stage basin solar system still augmented with a flat-plate solar collector was explored. The amount of energizing exergy and its effect on distilled water production were calculated for various temperatures and solar intensities. Calculations were made based on experimental measurements and readings under different operating and meteorological conditions. With installing a solar collector to the system, the temperature of the water entering the still increases by about 30%, increasing the system's average exergy by more than 190%. In turn, the collector-augmented still produces about 1807 ml of distilled water per day, which is 77% more than the still's output when it operates without a collector (1016 ml per day).

REFERENCES

[1] Delgado, W.R., Beach, T., Luzzadder-Beach, S. (2020). Solar desalination: Cases, synthesis, and challenges. Wiley Interdisciplinary Reviews: Water, 7(3): e1434. https://doi.org/10.1002/wat2.1434

[2] Tarawneh, M.S.K. (2007). Effect of water depth on the

performance evaluation of solar still. Jordan Journal of Mechanical and Industrial Engineering (JJMIE), 1(1): 23-29.

[3] Xu, Z., Zhang, L., Zhao, L., Li, B., Bhatia, B., Wang, C., Wilke, K.L., Song, Y., Labban, O., Lienhard, J.H., Wang, M.R., Wang, E.N. (2020). Ultrahigh-efficiency desalination via a thermally-localized multistage solar still. Energy & Environmental Science, 13(3): 830-839. https://doi.org/10.1039/C9EE04122B

[4] Mostafa, M., Abdullah, H.M., Mohamed, M.A. (2020). Modeling and experimental investigation of solar stills for enhancing water desalination process. IEEE Access, 8: 219457-219472. https://doi.org/10.1109/ACCESS.2020.3038934

[5] Murugana, D.K., Elumalai, N., Subramani, S. (2021). Experimental investigation on the effect of basin pressure in a single basin solar still. Desalin. Water Treat, 229. https://doi.org/10-16. 10.5004/dwt.2021.27385

[6] Sahu, S.K., Natarajan, S.K., Suraparaju, S.K. (2022). Experimental investigation of a solar still combined with phase change material (RT58) in southern India climatic conditions. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 09544062221139986. https://doi.org/10.1177/09544062221139986

[7] Diab, M.R., Abou-Taleb, F.S., Essa, F.A. (2022). Effect of basin water depth on the performance of vertical discs' solar still—experimental investigation. Environmental Science and Pollution Research, 29(60): 91368-91380. https://doi.org/10.1007/s11356-022-22220-8

[8] Abdullah, A.S., Alarjani, A., Abou Al-sood, M.M., Omara, Z.M., Kabeel, A.E., Essa, F.A. (2019). Rotating-wick solar still with mended evaporation technics: Experimental approach. Alexandria Engineering Journal, 58(4): 1449-1459. https://doi.org/10.1016/j.aej.2019.11.018

[9] Abujazar, M.S.S., Fatihah, S., Kabeel, A.E., Sharil, S., Abu Amr, S.S. (2018). Evaluation quality of desalinated water derived from inclined copper-stepped solar still. Desalin Water Treat, 131: 83-95. https://doi.org/10.5004/dwt.2018.22958

[10] Abdullah, A.S., Essa, F.A., Omara, Z.M., Rashid, Y., Hadj-Taieb, L., Abdelaziz, G.B., Kabeel, A.E. (2019). Rotating-drum solar still with enhanced evaporation and condensation techniques: comprehensive study. Energy Conversion and Management, 199: 112024. https://doi.org/10.1016/j.enconman.2019.112024

[11] Essa, F.A., Abdullah, A.S., Omara, Z.M. (2020). Rotating discs solar still: New mechanism of desalination. Journal of Cleaner Production, 275: 123200. https://doi.org/10.1016/j.jclepro.2020.123200

[12] Attia, M.E.H., Essa, F.A., Abdelgaied, M. (2022). Effect of different basin materials on the performance of hemispherical distiller with mirrors and energy storage material. Research Square, 1-26. https://doi.org/10.21203/rs.3.rs-1170410/v1

[13] Saleh, B., Essa, F.A., Aly, A., Alsehli, M., Panchal, H., Afzal, A., Shanmugan, S. (2022). Investigating the performance of dish solar distiller with phase change material mixed with Al_2O_3 nanoparticles under different water depths. Environmental Science and Pollution Research, 29: 28115-28126. https://doi.org/10.1007/s11356-021-18295-4

[14] Kabeel, A.E., Omara, Z.M., Essa, F.A. (2014). Enhancement of modified solar still integrated with external condenser using nanofluids: An experimental approach. Energy Conversion and Management, 78: 493-498. https://doi.org/10.1016/j.enconman.2013.11.013

[15] Farouk, W.M., Abdullah, A.S., Mohammed, S.A., Alawee, W.H., Omara, Z.M., Essa, F.A. (2022). Modeling and optimization of working conditions of pyramid solar still with different nanoparticles using response surface methodology. Case Studies in Thermal Engineering, 33: 101984. https://doi.org/10.1016/j.csite.2022.101984

[16] Sharshir, S.S., Abd Elaziz, M., Elsheikh, A. (2022). Augmentation and prediction of wick solar still productivity using artificial neural network integrated with tree–seed algorithm. International Journal of Environmental Science and Technology, 1-16. https://doi.org/10.1007/s13762-022-04414-2

[17] Omara, Z.M., Kabeel, A.E., Abdullah, A.S., Essa, F.A. (2016). Experimental investigation of corrugated absorber solar still with wick and reflectors. Desalination, 381: 111-116. https://doi.org/10.1016/j.desal.2015.12.001

[18] Essa, F.A. (2022). Thermal desalination systems: From traditionality to modernity and development. In Distillation Processes. From Solar and Membrane Distillation to Reactive Distillation Modelling. Simulation and Optimization. https://doi.org/10.5772/intechopen.101128

[19] Omara, Z.M., Hamed, M.H., Kabeel, A.E. (2011). Performance of finned and corrugated absorbers solar stills under Egyptian conditions. Desalination, 277(1-3): 281-287. https://doi.org/10.1016/j.desal.2011.04.042

[20] Younes, M.M., Abdullah, A.S., Essa, F.A., Omara, Z.M., Amro, M.I. (2021). Enhancing the wick solar still performance using half barrel and corrugated absorbers. Process Safety and Environmental Protection, 150: 440-452. https://doi.org/10.1016/j.psep.2021.04.036

[21] Omara, Z.M., Kabeel, A.E., Essa, F.A. (2015). Effect of using nanofluids and providing vacuum on the yield of corrugated wick solar still. Energy Conversion and Management, 103: 965-972. https://doi.org/10.1016/j.enconman.2015.07.035

[22] Dincer, I., Cengel, Y.A. (2001). Energy, entropy and exergy concepts and their roles in thermal engineering. Entropy, 3(3): 116-149. https://doi.org/10.3390/e3030116

[23] Al-Tahaineh, H., Damseh, R. (2013). Exergy analysis of a single-ended glass direct flow evacuated tube solar collector. International Journal of Advanced Research in Engineering and Technology (IJARET), 4: 1-9.

[24] Said, Z., Saidur, R., Rahim, N.A. (2016). Energy and exergy analysis of a flat plate solar collector using different sizes of aluminium oxide based nanofluid. Journal of Cleaner Production, 133: 518-530. https://doi.org/10.1016/j.jclepro.2016.05.178

[25] Al-Tahaineh, H., Frihat, M., Al-Rashdan, M. (2013). Exergy analysis of a single-effect water-lithium bromide absorption chiller powered by waste energy source for different cooling capacities. Energy Power, 3(6): 106-118. https://doi.org/10.5923/j.ep.20130306.02

[26] Amar, M., Akram, N., Chaudhary, G.Q., Kazi, S.N., Soudagar, M.E.M., Mubarak, N.M., Kalam, M.A. (2023). Energy, exergy and economic (3E) analysis of flat-plate solar collector using novel environmental friendly

nanofluid. Scientific Reports, 13(1): 411. https://doi.org/10.1038/s41598-023-27491-w
[27] Badran, O.O., Al-Tahaineh, H.A. (2005). The effect of coupling a flat-plate collector on the solar still productivity. Desalination, 183(1-3): 137-142. https://doi.org/10.1016/j.desal.2005.02.046

NOMENCLATURE

A_c	Collector area, (m^2)
A_s	Basin liner still area, (m^2)
h_{cg}	Convection heat transfer coefficient for glass cover, ($W/m^2.°C$)
h_b	Radiative heat transfer coefficient for basin liners, ($W/m^2.°C$)
h_{rg}	Radiative heat transfer coefficient for glass covers, ($W/m^2.°C$)
h_w	Basin liner-water convective heat transfer coefficient, ($W/m^2.°C$)
h_{1g}	Glass cover-to-ambient heat transfer coefficient, ($W/m^2.°C$)
h_{1w}	Water-to-glass heat transfer coefficient, ($W/m^2.°C$)
I	Solar irradiance, (W/m^2)
$(mc)_w$	Heat capacity of water mass per (m^2) in basin, ($J/m^2.°C$)
m_w	Hourly distillate water output, ($kg/m^2.hr$)
Q	Amount of heat transfer, (W)
q_b	Rate of energy convection from basin liner, (W/m^2)
T_a	Ambient temperature, (°C)
T_w	Still water temperature, (°C)
T_{wi}	Water that inlet to the still from the tank temperature, (°C)
T_{wo}	Water temperature at t=0, (°C)
t	Time (sec.)
U_b	Bottom overall heat lost coefficient, ($W/m^2.$ °C)
U_t	Side overall heat loss coefficient, ($W/m^2.°C$)
U_l	Overall heat transfer coefficient, ($W/m^2.°C$)

Greek symbols

α	Absorptivity
$(\alpha\tau)$	Absorptivity-transmissivity product
$(\alpha\tau)_{eff}$	Effective absorptivity-transmissivity product
τ	Transmissivity
ε	emissivity
Δt	Time interval (sec.)