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A Study on Heat and Mass Transfer Analysis of Solar Still

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Abstract— To evaluate the performance of solar still, it is very important to know about the energy balance and heat transfer. Heat transfer phenomena occur inside the still through three variable modes convection, evaporation, and radiation. As the temperature of water increases, the evaporation rate also increases. Therefore, many modifications have been done to increase the evaporation rate of basin water by the researchers, such as using nanoparticles, photovoltaic module, flat plate collector, heat exchangers, and phase change materials etc. The heat and mass transfer study on different parts of SS along with energy balance is presented in the paper. The reader will get information about the quantity of heat absorbed and the heat released inside the basin. Modification made on SS to increase productivity in the last 4-5 years has also been presented. The study found that the productivity of modified solar still gives 53.95% higher than the conventional solar still after adding external devices and energy storage materials.

Keywords: Heat and mass transfer, energy balance, distilled water, passive solar still, active solar still.

I. INTRODUCTION

Water is a necessary component for the animal and humans life. 71% of the Earth is covered with water. 1.6 % of the water is available as underground water and 0.001% is in the form of vapor and clouds. Out of 97% is in the seas and oceans, which is salty and cannot be used for drinking [1]. Only 3% of water is drinkable, of which 2.4 % is placed in glaciers and the North and South Pole and only 0.6 percent is in rivers, lakes and ponds that can be used, so it is required to such a device which converts the saline water in portable water. With the increasing population, the demand for fresh water is also increasing.

Requirements of fossil fuels are rapidly increasing in present time; due to this the environment is becoming polluted. In this situation, it is necessary to use a device that reduce the damage to the environment; this will only happen if we work more on a renewable energy based devices. That is, such devices should be made which operate with renewable energy. SS is a device that operates by the solar radiation. Researchers are constantly making such devices which are entirely dependent on renewable energy. SS has been used to convert salt and impure water into potable water. But due to the population growth, demand of clean water is increasing, but the productivity rate of SS is very low, so it is not used on a large scale. Therefore, several methods are constantly being used by researchers to enhance the yield of SSs, and many experiments are being done to understand its heat and mass transfer. To increase the productivity of SS it is very important to understand the heat transfer analysis. Because by heat transfer, it can be known that how much energy is absorb and release from different part of SS. Energy, exergy and heat transfer of SS have been intensively studied by many researchers, as well as various types of modification have been made which can increase the productivity of SSs.

A comprehensive review was prepared by Panchal and Mohan [2], they studied the effect of fins, heat storage material and multi-basin, on the distillate yield of SS. Kabeel et al. [3] describes the various heat exchange mechanisms adopted by the researchers on different modified SSs. External and internal reflectors have been used by Tanaka [4] to increase the productivity of SSs, as well as study the heat transfer of modified SS. An Experimental study was done by Raju and Narayan [5], in which they have added different number of flat plate collector (FPC) to simple SS. They found that when single FPC was added to the setup, its distilled efficiency was 6.82% and when two FPCs were added to the setup, the distilled efficiency was 7.29%.

P. Pounraj at al. [6] developed a peltier based hybrid active solar still with PV/T system is attached. Their efficiency is 30% higher than the convention solar still and produce 6.5 times more water than conventional SS. Solar still acts in the presence of the sun, but solar steel can be used at night to increase productivity. Researchers have obtained water through Solar Still at the night time by using of PCM in Solar Still. In this way, day & night continuous use of solar steel can increase the daily productivity. M.shalaby et al. [7] Using PCM in single basin solar still and attached v-corrugate on the basin liner. The paraffin wax is filled inside the v-corrugate, which works as an absorber; the water productivity was 72.7% increased at night in compared to conventional solar still. Dyes [8] and charcoal pieces [9] are placed inside the basin, So that the absorbing capacity of the basin could increase and the amount of solar radiation can be absorbed in excess quantity. By increasing the absorption capacity of basin surfaces, it absorbs extra energy during the cloudy weather and night time; this will increase water

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productivity, In this way different types of wick, PCM and various types of energy-storing materials have been used in the basin [10-14]. Nano fluids use in solar still [15-16], when graphite and copper oxide Nano-particles are used in the solar still it enhance the water productivity of 53.95% and 44.93% than the conventional SS respectively [17]. For increasing the performance of solar still, different water preheating process are used by the researchers like external solar collector [18] and solar pond [19-22]. The inclined external reflector enhanced the productivity of the SS by approximately 16% larger than that with the vertical external reflector [23]. For increasing the radiation incident on the solar still Deniz. [24] Study an experimental work on the inclination and tilt angle of the glass and consider various parameters for increase the productivity, like angle of the glass cover, cooling system of the glass surface and distance between the glass cover and water surface.

A separate condenser chamber and nanoparticles was used by Kabeel et al. [25] to increase the thermal conductivity and evaporation rate of the basin water. Productivity increased by 53.2% when an external condenser was added to the setup and productivity increased by 116% when the nanoparticle was added to the basin water of the condenser-based setup. Refalo et al. [26] has studied the effect on the productivity of SS due to solar chimneys and condensers and it was found that when the chimney was added to the SS, the setup produced 5.1 liters/m^2 of distilled water in a day and when the external condenser was added to the setup, the productivity of setup was 4.7 liters/m^2 in single day. Dwivedi and Tiwari [27] compared performance in double-slope active and passive SSs, in which they found that active double-slope SS had higher exergy efficiency and lower energy efficiency. A rectangular sponge of rubber was used by the Rashidi et al. [28] and studied the exergy analysis. Modified SS achieved 17.35% higher distillate as compared to conventional SS. Paper presents the heat and mass transfer study on different parts of modified SS with the help of energy balance.

II. HEAT AND MASS TRANSFER IN SS

Thermal analysis of different components of the setup has been shown below and also the energy balance on different parts of the setup such as condensing cover, saline water, basin liner and surrounding of setup is shown. Heat transferred through conduction, convection, and radiation, from outer surface of the SS, while heat transferred through convection, radiation and evaporation within the basin. The distilled water production of the setup depends on the evaporation rate of basin water from per unit area in a day. The distilled output of SS can be managed through energy and mass balance of different parts of the setup.

III. ENERGY BALANCE ON DIFFERENT COMPONENTS OF SS

Solar radiation (Is) initially incident on the top of the glass cover, where certain radiation is reflected and some radiation is absorbed and transfer inside the SS. Heat energy is transfer from upper glass surface to the ambient through three modes radiation, convection and conduction. The radiation is transfer in the SS basin through the condensing cover, after that the radiation reached at the basin water, small amount of radiation is reflected by the water surface and the rest radiation is absorbed by the basin water. Finally, the radiation reaches to the basin liner where the maximum radiation is absorbed, causing the basin water to warm. Fig. 1 shows the heat transfer of different parts of a single slope SS.

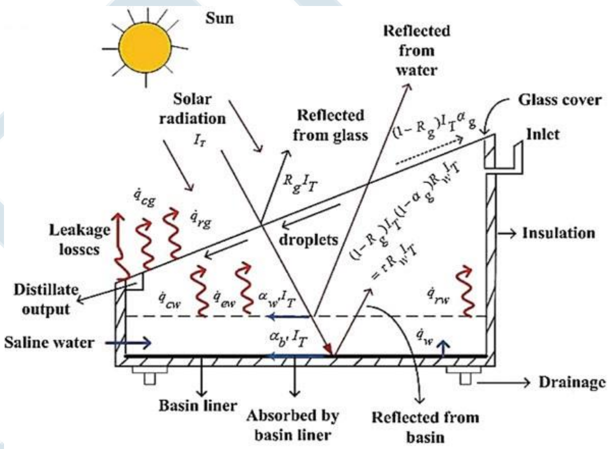

Fig. 1. A schematic diagram of a single slope SS showing the heat transfer of various parts [29]

A. EB on outer glass surface

Radiation incident on the outer surface of condensing cover and transmitted inside the cavity area of SS. Heat is transfer from outer glass cover to ambient and inner surface of glass cover is received heat energy from the hot basin water in the mode of convection, evaporation and radiation [30].

$$\frac{dT_{go}}{dt} = \frac{1}{(\rho_g \times C_{pg} \times D_g)}\left(q^{cd} - q^{rd}_{g-at} - q^{cn}_{g-at}\right) \quad (1)$$

Temperature of upper glass cover surface (T_{go}) can be calculated through following equation [31]

$$T_{go} = \frac{(K_g/D_g)T_{gi} + h_{go-am}T_{am}}{(K_g/D_g) + h_{go-am}} \quad (2)$$

B. EB on inner glass surface

$$\frac{dT_{gi}}{dt} = \frac{1}{(\rho_g \times C_{pg} \times D_g)}\left(\alpha_g I_{sg} + q^{rd}_{w-gi} + q^{cn}_{w-gi} + q^{ep} - q^{cd}\right) \quad (3)$$

Temperature of upper glass cover surface can be calculated through following equation [31] [32]

$$T_{gi} = \frac{\alpha_g I_{sg} + h_{w-gi} \times T_w + U_{gi-ab} \times T_{ab}}{h_{w-gi} + U_{gi-ab}} \quad (4)$$

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C. EB on basin water

$$\frac{dT_w}{dt} = \frac{1}{(\rho_w \times C_{pw} \times D_w)}\left(\alpha_{bl} I_{sw} + q_{b-w}^{cn} - q_{w-gi}^{rd} - q_{w-gi}^{cn} - q^{ep}\right) \quad (5)$$

$$T_{bw} = \frac{\overline{f(t)}}{a}\left[1 - e^{-at}\right] + T_{bw0} \times e^{-at} \quad (6)$$

Where $f(t) = \frac{\alpha_{eff} I(t)_{rs} + U_H T_{air}}{m_w C_w}$ and $a = \frac{U_H}{m_{w,} C_{bw}}$

D. EB on basin liner

$$\frac{dT_{bl}}{dt} = \frac{1}{(\rho_{bl} \times C_{pbl} \times D_{bl})}\left(\alpha_{bl} I_{sbl} - q_{b-w}^{cn} - q_{lost}\right) \quad (7)$$

Temperature of basin water can be calculated through following equation:

$$T_{bl} = \frac{\alpha_{bl} I_{sbl} + h_{bl-w} T_w + h_{b-sn} T_{air}}{h_{bl-w} + h_{b-sn}} \quad (8)$$

IV. CALCULATION OF HEAT TRANSFER COEFFICIENT (HTC) INSIDE THE SS

HTC inside the setup is occurs through the evaporation, radiation and convection modes. The moist air inside the basin is composed by the mixture of dry air and water vapor, which travels from the water surface to the inner glass surface. The mass of dry air travels ($\dot{m}_a$) through the natural convection mode from the per unit area of the basin and per unit time, which can be obtained by following equation.

$$\dot{m}_a = \frac{q_{w-gi}^{cn}}{C_{pa}(T_w - T_{hd,a})} \quad (9)$$

Where,

$$q_{w-gi}^{cn} = h_{w-gi}^{cn}\left(T_w - T_{gi}\right) \quad (10)$$

Where, h_{w-g}^{cn} is the convective HTC which can be obtained as [33]:

$$h_{w-gi}^{cn} = 0.884\left[T_w - T_{gi} + \frac{(P_w - P_{gi})(T_w + 273)}{268.9 \times 10^3 - P_w}\right] \quad (11)$$

Where,

P_w - Vapor pressure on water

P_{gi} – Vapor pressure on inner glass, it can be evaluate by following relation:

$$P_w = exp\left(25.317 - \frac{5144}{T_w + 273}\right) \quad (12)$$

$$P_{gi} = exp\left(25.317 - \frac{5144}{T_{gi} + 273}\right) \quad (13)$$

The mass flow of the water vapor is from the water surface to the dry air, where the vapor meets the dry air and converts into a humid air. Mass of water vapor ($\dot{m}_{vp}$) travels through the evaporation mode from the unit area of the basin and per unit time, it can be calculated by following equation.

$$\dot{m}_{vp} = \frac{q^{ep}}{L_{wg}} \quad (14)$$

Where L_{wg} is the latent heat of vapor, it is obtained by following equation:

$$L_{wg} = 3.1615 \times 10^6\left[1 - 7.6166 \times 10^{-4}(T_w + 273.15)\right] \quad (15)$$

$$q^{ep} = h^{ep}\left(T_w - T_{gi}\right) \quad 16)$$

"h^{ep}" is the evaporation HTC, it is obtained by following equation [34]:

$$h^{ep} = 16.27 \times 10^{-3} h_{w-gi}^{cn}\left(\frac{P_w - P_{gi}}{T_w - T_{gi}}\right) \quad (17)$$

Temperature of humid air ($T_{hd,a}$) can be obtained by following equation:

$$T_{hd,a} = \frac{(T_w + T_{gi})}{2} \quad (18)$$

Heat transfer fluxes ($\boldsymbol{q_{w-gi}^{rd}}$) and radiative HTC ($\boldsymbol{h_{w-gi}^{rd}}$) from water surface to inner glass surface can be obtained by following equation [33] [35]:

Heat transfer fluxes:

$$q_{w-gi}^{rd} = h_{w-gi}^{rd}\left(T_w - T_{gi}\right) \quad (19)$$

Radiative HTC:

$$h_{w-gi}^{rd} = \varepsilon_{eff} \times \sigma \times \left((T_w + 273.15)^2 + (T_g + 273.15)^2\right) \times \left(T_w + T_g + 546.3\right) \quad (20)$$

Where "ε_{eff}" is the effective emissivity, it can be obtained by following equations:

$$\varepsilon_{eff} = \left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right)^{-1} \quad (21)$$

The total HTC inside the SS (h_t) can be extracted through the following operations:

$$h_t = h_{w-gi}^{cn} + h_{w-gi}^{rd} + h^{ep} \quad (22)$$

V. HEAT LOSS FROM THE SS

The heat losses through the convection and radiation mode in the atmosphere from condensing cover of SS and from the bottom of the SS between the basin liner and the atmosphere. Radiation and convection heat transfer fluxes between the glass cover and the atmosphere are written below [36].

A. Top heat loss

Radiation heat transfer fluxes: (23)

Where "h_{g-am}^{rd}" is the radiation HTC, it is obtained by:

$$h_{g-am}^{rd} = \frac{\varepsilon_g \sigma\left[(T_{go} - 273)^4 - (T_{sky} + 273)^4\right]}{T_{go} - T_{am}} \quad (24)$$

ε_g = Emissivity of the glass cover,

σ = Stephan − Boltzman constant = (5.669 × 10^{-8} W/m^{2}K^4),

T_{sky} = Temperature of the sky = $T_{am} - 6$

Convection heat transfer fluxes:

$$q_{g-am}^{cn} = h_{g-am}^{cn} \times \left(T_{go} - T_{am}\right) \quad (25)$$

Where "h_{g-am}^{cn}" is the convection HTC, it is obtained by:

$$h_{g-am}^{cn} = 5.7 + 3.8 \times v \quad (26)$$

Where

v - Wind velocity

B. Bottom heat loss

In case of SS bottom heat loss is assumed to be negligible, as the basin area is covered with insulated material, which prevents heat loss. Heat flux from basin area to ambient ($q_{lost,bl}$) can be evaluated through following equations:

$$q_{lost,bl} = h_{bl-am}^{cd} \times (T_{bl} - T_{am}) \quad (27)$$

Where "h_{bl-am}^{cd}" is the conductive HTC, it is given by:

$$\frac{1}{h_{bl-am}^{cd}} = \sum \frac{t_{ins}}{k_{ins}} + \frac{1}{h_{bl-am}} \quad (28)$$

Where t_{ins} & k_{ins} is the insulation thickness and insulation thermal conductivity respectively, h_{bl-am} is the HTC from basin surface area to ambient which can be calculate as similar to the Eq.20.

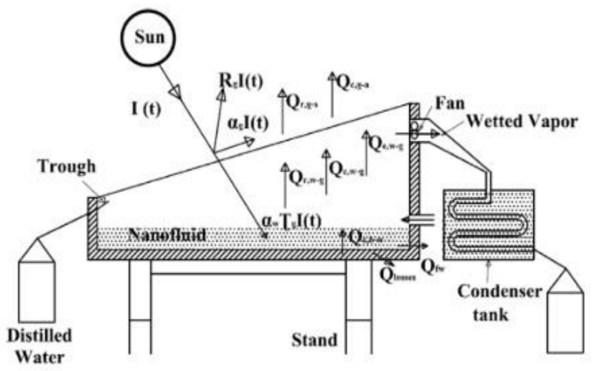

Fig. 2. Schematic diagram of external condenser integrated SS [37]

VI. PREVIOUS WORK ON HEAT & MASS TRANSFER

Over the several decades, many researches have been done related to heat transfer. Energy analysis of the experimental setup has been studied by the many authors and at the same time many mathematical modeling has been developed on the basis of energy balance. Based on energy balance many researches done in the last few years and various new modification have been developed in the field of heat transfer of SS, which are shown in Table 1.

Table 1: Recent work on SS for heat transfer improvement

Type of still	Modification	Outcome	Ref.
Single slope single basin active SS	The FPCs have been added in series to the SS as shown in Fig.3.	When 2 & 3 FPCs were equipped with SS, its productivity was increased by 41% & 89% compare to single FPC based still respectively.	[5]
PV/T based hybrid active single slope SS	Saline water cooled PV module and a nickel-chromium wire is placed inside the basin.	Modified setup gives 6 times more daily productivity and 27% higher thermal efficiency than conventional still.	[38]
PVT based double slope hybrid active SS	PV module is installed in FPC; PVT-FPC based SS.	The productivity of the modified setup is 1.4 times higher than PVT based hybrid active SS and the daily energy efficiency of the new setup is 17.4%.	[39]
PTC based double and single slope SS	A parabolic trough collector integrated in the single and double slope SS as shown in Fig. 4.	Daily productivity of the PTC based double slope SS is 6% greater than the PTC based single slope SS.	[40]
Double slope passive SS	Al_2O_3 nanoparticles are mixed in the basin water.	At 0.12% concentration of Al_2O_3, the daily yields increases by 12.2% and 8.4%, at 35 and 80 kg of basin water respectively.	[41]
Single slope SS	To increase the condensing rate, a separate condensing cover is installed in the setup.	The daily productivity of the new setup is 3.015 kg/m², which was 25% higher than the conventional stills.	[42]
Multi basin active SS	FPCs have been added to the multi-stage setup as shown in Fig.5.	The single collector based still was giving 11.56 kg of distilled water in a day, while the productivity of the double collector was increased by 96% and by the third collector only by 23%.	[43]
Nanofluids and external condenser based Single slope SS	Al_2O_3 & CU_2O nanoparticles were mixed with the basin water and a separate condenser had been fitted. Schematic diagram is shown in Fig. 2.	The daily efficiency of Al_2O_3 and CU_2O nanoparticles based SS increased by 73.85% and 84.16% respectively.	[37]
Porous absorber based SS	Three different sizes of fine basalt stones are used as Porous absorbers in the basin.	The daily productivity of SS at 2cm, 1.5cm and 1cm stone size increased by 33.37, 27.86 and 19.81%, respectively as compared to traditional SS.	[44]
PVT and collectors based single slope SS	Two PV-modules, two collectors are integrated to the single slope SS. A schematic diagram is shown in Fig. 6.	It was found that the maximum thermal value and overall thermal efficiency of the modified setup was 75% & 69.06% respectively.	[45]
Low pressure maintained inside the SS	Reflecting mirrors was equipped with single slope vacuum solar SS. 0.4 bar pressure maintain inside the SS.	The mirror reflects the fallen solar intensity to the water surface of the basin; Hence the evaporation rate was increased. Daily distilled output was 1.2 L/m²	[46]

Fig.3. FPC added to the single slope SS [5].

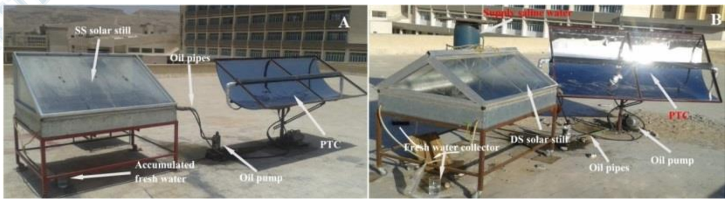

Fig.4. (A) PTC integrated to single slope SS, (B) PTC integrated to double slope SS [40].

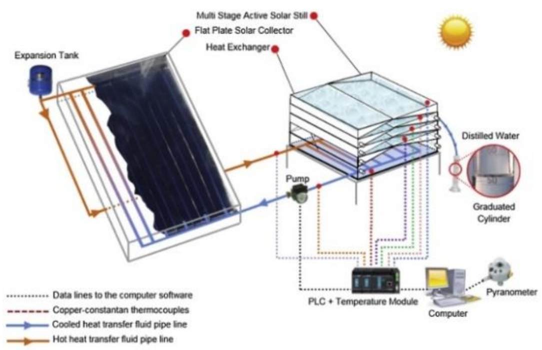

Fig.5. FPC integrated to multistage SS [43].

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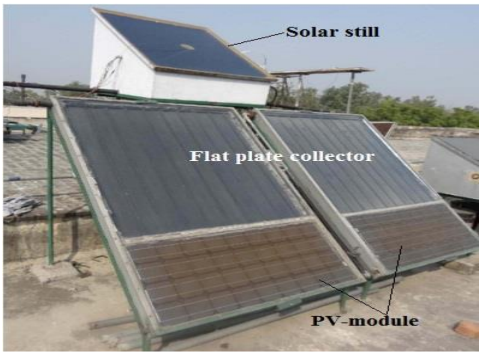

Fig. 6. Experimental setup of 2 PVT-FPC based hybrid active SS [45]

VII. CONCLUSIONS

The paper studied about the heat loss and heat absorption in different parts of solar still. Mass transfer of basin water has also been studied with the help of energy balance. To raise the efficiency and distilled output of solar still, it is necessary to understand the heat transfer. Various modifications have been done by many authors to increase the productivity of SSs which are shown in the table 1. Based on the present study, some conclusions are given below:

- External devices are helps to improve the evaporation rate and daily productivity of the solar still.
- Nanoparticles, phase change materials, and Porous Absorber material, etc. have been used in water to rise the thermal conductivity and evaporation rate of the basin water.
- Heat exchanger, flat plate collector, photovoltaic-module and PVT have been used to raise the thermal and overall efficiency of the setup.
- An external condenser has also been added to the setup, so that the water vapor can get large surface to be condensed, leading to faster distilled water productivity.

Nomenclature

m	Mass			
D_w	Basin water depth (m)	**Subscripts**		
h	Heat transfer coefficient (HTC) (W/m²K)		bl	Basin liner
C_p	Specific heat capacity(J/kg K)		am	Ambient
	Thickness of glass (m)		vp	Vapor
$\overline{f(t)}$	At 0 to t time interval average f (t) value		ins	Insulation
k	Thermal conductivity (W/m K)		sn	Surrounding
U_H	Overall heat loss co-efficient between basin water and atmosphere (W/m²°C).		at	Atmosphere
T	Temperature (°C)		w	Basin water
T_{bw0}	Initial water temperature when time t=0 (°C)		g	Glass
Is	Solar radiation(W/m²)		gi	Inner glass
q_{lost}	Bottom loss of heat transfer flux to atmospheres (W/m²)		go	Outer glass
q	Heat transfer flux (W/m²)			
a	Area (m²)	**Superscript**		
			rd	Radiation
Greek words			ep	Evaporation
α_g	Absorptivity of glass		cd	Conduction
			cn	Convection
Abbreviation				
FPC	Flat plate collector			
PVT	Photovoltaic thermal			
PTC	Parabolic trough collector			
SS	Solar Still			

REFERENCES

[1] Thakur, V. K., Gaur, M. K. & Sagar, M. K. Role of advance solar desalination technique for sustainable development. in Intelligent Computing Applications for Sustainable Real-World Systems (eds. Pandit, M., Srivastava, L., Rao, R. V. & Bansal, J. C.) 28–38 (Springer Nature Switzerland AG, ICSISCET 2019, PALO 13, 2020). doi:10.1007/ 978-3-030-44758-8_4.

[2] Panchal, H. & Mohan, I. Various methods applied to solar still for enhancement of distillate output. Desalination 415, 76–89 (2017).

[3] Kabeel, A. E., Arunkumar, T., Denkenberger, D. C. & Sathyamurthy, R. Performance enhancement of solar still through efficient heat exchange mechanism – A review. Appl. Therm. Eng. 114, 815–836 (2017).

[4] Tanaka, H. A theoretical analysis of basin type solar still with flat plate external bottom reflector. Desalination 279, 243–251 (2011).

[5] Raju, V. R. & Lalitha Narayana, R. Effect of flat plate collectors in series on performance of active solar still for Indian coastal climatic condition. J. King Saud Univ. - Eng. Sci. 30, 78–85 (2018).

[6] Pounraj, P. et al. Experimental investigation on Peltier based hybrid PV/T active solar still for enhancing the overall performance. Energy Convers. Manag. 168, 371–381 (2018).

[7] Shalaby, S. M., El-Bialy, E. & El-Sebaii, A. A. An experimental investigation of a v-corrugated absorber single-basin solar still using PCM. Desalination 398, 247–255 (2016).

[8] Rajvanshi, A. K. Effect of various dyes on solar distillation. Sol. Energy 27, 51–65 (1981).

[9] Okeke, C. E., Egarievwe, S. U. & Animalu, A. O. E. Effects of coal and charcoal on solar-still performance. Energy 15, 1071–1073 (1990).

[10] Hinai, H. Al, Nassri, M. S. Al & Jubran, B. A. Effect of climatic, design and operational parameters on the yield of a simple solar still. Energy Convers. Manag. 43, 1639–1650 (2003).

[11] Heidari, A. A. & Shiati, K. Using the novel technology of desalinating seawater by solar cell & lithium bromide absorption chiller in rural area. Desalination 183, 23–27 (2005).

[12] Alaian, W. M., Elnegiry, E. A. & Hamed, A. M. Experimental investigation on the performance of solar still augmented with pin-finned wick. Desalination 379, 10–15 (2016).

[13] Murugavel, K. K., Sivakumar, S., Riaz Ahamed, J., Chockalingam, K. K. S. K. & Srithar, K. Single basin double slope solar still with minimum basin depth and energy storing materials. Appl. Energy 87, 514–523 (2010).

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

[15] Sharshir, S. W. et al. Enhancing the solar still performance using nanofluids and glass cover cooling: Experimental study. Appl. Therm. Eng. 113, 684–693 (2017).

[16] Sahota, L. & Tiwari, G. N. Effect of nanofluids on the performance of passive double slope solar still: A comparative study using characteristic curve. Desalination 388, 9–21 (2016).

[17] Nguyen, C. T. et al. Viscosity data for Al2O3-water nanofluid-hysteresis: is heat transfer enhancement using nanofluids reliable? Int. J. Therm. Sci. 47, 103–111 (2008).

[18] Tiris, C., Tiris, M., Erdalli, Y. & Sohmen, M. 98/03107 Experimental studies on a solar still coupled with a flat-plate collector and a single basin still. Fuel Energy Abstr. 39, 287 (2003).
[19] Velmurugan, V. et al. Integrated performance of stepped and single basin solar stills with mini solar pond. Desalination 249, 902–909 (2009).
[20] Chaichan, M. T. & Kazem, H. A. Using Aluminium Powder with PCM (Paraffin Wax) to Enhance Single Slope Solar Water Distiller Productivity in Baghdad – Iraq Winter Weathers. 5, 251–257 (2015).
[21] Velmurugan, V., Mandlin, J., Stalin, B. & Srithar, K. Augmentation of saline streams in solar stills integrating with a mini solar pond. Desalination 249, 143–149 (2009).
[22] Velmurugan, V. & Srithar, K. Solar stills integrated with a mini solar pond - analytical simulation and experimental validation. Desalination 216, 232–241 (2007).
[23] El-Sebaii, A. A., Ramadan, M. R. I., Aboul-Enein, S. & Salem, N. Thermal performance of a single-basin solar still integrated with a shallow solar pond. Energy Convers. Manag. 49, 2839–2848 (2008).
[24] Tanaka, H. & Nakatake, Y. Effect of inclination of external flat plate reflector of basin type still in winter. Sol. Energy 81, 1035–1042 (2007).
[25] Deniz, E. An Investigation of Some of the Parameters Involved in Inclined Solar Distillation Systems. Environ. Prog. 30, 1–5 (2011).
[26] Kabeel, A. E., Omara, Z. M. & Essa, F. A. Enhancement of modified solar still integrated with external condenser using nanofluids : An experimental approach. ENERGY Convers. Manag. 78, 493–498 (2014).
[27] Refalo, P., Ghirlando, R. & Abela, S. The use of a solar chimney and condensers to enhance the productivity of a solar still. 3994, (2015).
[28] Dwivedi, V. K. & Tiwari, G. N. Experimental validation of thermal model of a double slope active solar still under natural circulation mode. Desalination 250, 49–55 (2010).
[29] Rashidi, S., Rahbar, N., Valipour, M. S. & Esfahani, J. A. Enhancement of solar still by reticular porous media : Experimental investigation with exergy and economic analysis Abstract : Appl. Therm. Eng. (2017) doi:10.1016/ j.applthermaleng.2017.11.089.
[30] Tiwari G.N., S. L. (2017). History of Passive Solar-Distillation Systems. Adv. Solar-Distillation Syst. Green Energy Technol. 121–155 (2017) doi:10.1007/ 978-981-10-4672-8.
[31] Sarray, Y., Hidouri, N., Mchirgui, A. & Brahim, A. Ben. Study of heat and mass transfer phenomena and entropy rate of humid air inside a passive solar still. Desalination 409, 80–95 (2017).
[32] Joshi, P. & Tiwari, G. N. Energy matrices , exergo-economic and enviro-economic analysis of an active single slope solar still integrated with a heat exchanger : A comparative study. Desalination 443, 85–98 (2018).
[33] Sharshir, S. W. et al. Thermal performance and exergy analysis of solar stills – A review. Renew. Sustain. Energy Rev. 73, 521–544 (2017).
[34] Dunkle, R. V. Solar water distillation : the roof type still and a multiple effect diffusion still. in International Developments in Heat Transfer, ASME. Proceedings of International Heat Transfer, Part V, University of Colorado 895–902 (1961).
[35] Tiwari, G. N., Minocha, A., Sharma, P. B. & Emran Khan, M. Simulation of convective mass transfer in a solar distillation process. Energy Convers. Manag. 38, 761–770 (1997).
[36] J. Duffle, W. B. Solar Engineering of Thermal Processes. John Wiley Sons, New York. second ed., (1991).
[37] {{Watmuff}, J.~H. and {Charters}, W.~W.~S. and {Proctor}, D. . Solar and wind induced external coefficients - Solar collectors. Coop. Mediterr. pour l'Energie Solaire, Rev. Int. d'Heliotechnique. 2nd Quarte, 56 (1977).
[38] Kabeel, A. E., Omara, Z. M. & Essa, F. A. Theoretical with experimental validation of modified solar still using nanofluids and external condenser. J. Taiwan Inst. Chem. Eng. 75, 77–86 (2017).
[39] Praveen, B. et al. Experimental investigation on hybrid PV / T active solar still with e ff ective heating and cover cooling method. Desalination 0–1 (2017) doi:10.1016/j.desal.2017. 11.007.
[40] Al-sulttani, A. O., Ahsan, A., Rahman, A., Daud, N. N. N. & Idrus, S. Heat transfer coef fi cients and yield analysis of a double-slope solar still hybrid with rubber scrapers : An experimental and theoretical study. Desalination 407, 61–74 (2017).
[41] Hassan, H. Comparing the performance of passive and active double and single slope solar stills incorporated with parabolic trough collector via energy, exergy and productivity. Renew. Energy (2019) doi:10.1016/j.renene.2019.10.050.
[42] Sahota, L. & Tiwari, G. N. Effect of Al2O3 nanoparticles on the performance of passive double slope solar still. Sol. Energy 130, 260–272 (2016).
[43] Sandeep, Kumar, S. & Dwivedi, V. K. Experimental study on modified single slope single basin active solar still. Desalination 367, 69–75 (2015).
[44] Feilizadeh, M. et al. Year-round outdoor experiments on a multi-stage active solar still with different numbers of solar collectors. Appl. Energy 152, 39–46 (2015).
[45] Mohamed, A. F., Hegazi, A. A., Sultan, G. I. & El-Said, E. M. S. Augmented heat and mass transfer effect on performance of a solar still using porous absorber: Experimental investigation and exergetic analysis. Appl. Therm. Eng. 150, 1206–1215 (2019).
[46] Singh, D. B. et al. Experimental studies of active solar still integrated with two hybrid PVT collectors. Sol. Energy 130, 207–223 (2016).