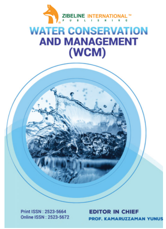
ZIBELINE INTERNATIONAL™ PUBLISHING

Water Conservation & Management (WCM)

DOI: http://doi.org/10.26480/wcm.01.2021.46.52

ISSN: 2523-5664 (Print)
ISSN: 2523-5672 (Online)
CODEN: WCMABD



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RESEARCH ARTICLE

AUGMENTATION OF SOLAR WATER DISTILLER PERFORMANCE WITH PV/T

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ARTICLE DETAILS

Article History:

Received 20 June 2021
Accepted 23 July 2021
Available online 27 July 2021

ABSTRACT

Recently, due to global warming and urbanization, there are many major cities that may face the challenge of day zero next decades. Obviously, water is an indispensable component for maintaining life on the earth. Although portable water is required of the hour, the quantity of available freshwater is impacted significantly by sea-level rise and pollution from industrialization. As a consequence of the global water crisis, different methods for clean water production from brackish water have been studied and developed in practice, however, the solar distillation of water is the most economical and desirable approach due to this method utilize solar energy that is the environmentally friendly and economical resource. Over the last 15 years, the impressive price drop of the photovoltaic solar collector (PV/T) makes them popular and easy to access. As a result, the employment of PV/T in solar stills is emerging as a potential device for water distillation. Therefore, in this paper, an active solar distiller combined with a photovoltaic panel has been reviewed for improvement of the distillate yield and effectiveness of solar photovoltaic. This review work presents a variety of studies on various types of solar still (for example conventional solar still (CSS), double slope solar still (DSSS), stepped solar distiller, and cascade solar still) couples with different solar water collectors (such as flat plate collector (FPC) and evacuated tubes collector (ETC)) and solar photovoltaic modules. It is obtained that the hybrid PV/T active solar still improves the distillate yield, energy efficiency, and exergy efficiency as compared to passive mode. The cooling method enhances the performance of the photovoltaic solar collector as well as the productivity of solar still. Moreover, the environmental economic estimation reveals that the solar still coupled with the PV/T mitigated considerably the amount of CO_2. It can be stated that it is suitable to commercialize the hybrid PV/T active solar still for supplying not only electricity but drinking water also. Finally, this review paper also suggests the scope for the research in the future.

KEYWORDS

solar energy, solar still, photovoltaic solar collector, freshwater production, distilled yield.

1. INTRODUCTION

Water is the need of the hour and an indispensable resource for the living on the earth. The requirement for freshwater is soaring for drinking, industry, irrigation, domestic usages, etc. because of population explosion as well as quick urbanization (Nizetic et al., 2021; Hoang, 2022). Water is used not only for drinking aim, but it also has a vital role in the industrial and agricultural fields. However, if we gather all water on Earth, 97% of it is saltwater, 2% is in the ice state at the poles and only 1% is available to serve for humankind to survive (Le et al., 2020; Le et al., 2021). All the corner of the world could face their own day zero in the coming decades. Besides that, worldwide energy consumption has increased dramatically which lead to degradation of environmental quality (Ganesana et al., 2022; Chen, 2021). Industrial/ technological growth along with population explosion deplete natural resources, cause environmental pollution, global warming as well as depletion of the ozone layer, etc. (Vinayagam, 2021; Tran et al., 2020). As the water crisis becomes one of the global issues, seawater is a potential alternative source for producing potable water (Tri Le et al., 2020). It is evident that desalination of water is necessary for the clean water scarcity situation. Water distillation utilizing solar energy is a good solution to produce fresh water on terms of small scale in regions suffering water crisis (Le et al., 2021).

The most acceptable and suitable alternative energy for distilling seawater is solar energy that can minimize operating costs. The advantages of the sun are undeniable, which are not only for individuals but for the planet as a whole also (Aboushi et al., 2021; Liu et al., 2019). The energy of the sun is considered as a potential energy resource replaced unrenewable sources in the world. The benefits of the sun's energy over traditional electricity productions are not dependent on fossil fuels, mitigate air and water pollution, utilize global warming without any negative effect and be a preferable option for many (Nguyen et al., 2021). Solar devices operate with an available natural source, while power generation procedure harms the natural environment (Hoang, 2021; Nguyen, 2020). Fossil fuels will be finally exhausted, but solar radiation won't, which makes solar energy highly reliable. In addition, whereas fossil fuels spend the high cost for mining and usage, there is no cost to employ sun's energy. Furthermore, fossil fuel with annual consumption of 11 billion tonnes, is predicted to deplete soon (Nayak et al., 2021; Ragupathi and Mani, 2021). As a consequence, green technologies have emerged as an excellent solution for eliminating the harms due to environmental degradation, that may create a clean, safe, and sustainable society for future generations (Nguyen et al., 2020; Hoang, 2018). There is a surprising number of forms of alternative energy that are studied recently including wind energy, biofuel, biomass energy, hydrogen gas and wave energy (Chen et al., 2021; Derse and Yilmaz, 2021; Nizetic et al., 2021; Hoang, 2019; Bui et al., 2020; Nguyen et al., 2021; Chen, 2022; Pham, 2020; Bui et al., 2020; Bui et al., 2021; Zhang et al., 2016). All need is the capital cost for installing solar devices and then reaps the benefits. The popular solar thermal application is a solar photovoltaic collector that has been commercialized in practice (Nizetic et al., 2021; Tang et al., 2019). PV can be set up on the ground, rooftop, wall, and floating (Marudaipillai et al., 2020). The PV cell normally has layers of semi-conducting medium. As photovoltaic absorbed solar intensity, an electric field is created across the layers that lead to the flow of electricity (Krishna et al., 2018). The more solar irradiation is, the more power is produced, however, the effectiveness of the PV is an important factor that most researchers are interested in its enhancement. The voltage of the PV cell is decreased as its temperature increase that causes the reductant of the efficiency (Mustafa et al., 2020; Pham and Nguyen, 2021).

Applying the sun's energy for distilling seawater has been studied and developed historically. Solar energy can be used as a driving force for the thermal processes or to generate the requested power for the membrane distillation system. Solar still is a desalination system that directly employs the energy of the sun to separate portable water from either salts or contaminants. It normally takes place in a closed system and applies the greenhouse effect for the evaporation of seawater (Le et al., 2021). It is noted that it is effective to use solar still to supply usable water in the agricultural field and domestic applications due to its simple fabrication and there is no need for laborers with special skill and maintenance. Nevertheless, low distilled yield is the major drawback of solar stills in comparison to other desalination methods. As a result, there are efforts to improve the daily productivity of these devices. Passive and active solar still is generally its main two types. The evaporation process acts in passive solar still is driven directly by the solar irradiation. Various still designs have been proposed for the aim of the productivity increment still design. The focus in the solar-assisted distillation of water research is daily distillate productivity. Obviously, solar intensity mainly influences the distilled yield, however, it is an uncontrolled parameter.

The control parameter that can be improved is the temperature difference between brackish water and the surface of the condenser. The improvement of this parameter can be processed into two directions. The first way is to increase the temperature of brackish water because the amount of vapor is proportional to the water's temperature. There are some methods that have been conducted to achieve this aim such as increasing solar radiation absorption by using internal or external reflectors, applying different shapes of the absorber and top cover, and preheating seawater by coupling with solar external heater (solar water collector, solar pond). The second approach is to decline the temperature of the condenser which can be done by force air or low-temperature fluid. The lower temperature of the condenser enhances the condensation rate. Additionally, another method to overcome the intermittence of the sun is to store excess sun's energy and then use it after sunset. As a result, sensible storage materials and phase change materials received the attention of many researchers over the last years. In this review article, a complete analysis of the incorporation of solar still and PV modules has been presented. The rest of the paper is organized as follows. In Section 2, integration with PV/T for preheating basil water and enhancing PV/T efficiency have been presented. This is followed by a solar distiller integrated with the PV/T panel for supplying power to other devices in Section 3. Finally, a concluding remark has been made in Section 4.

2. Application of PV/T Panel for Purpose of Preheating Brackish Water and Improvement of Pv/T Efficiency

Single slope solar still is known as a simple and traditional one that can produce about 2-5 liter of fresh water per day depending on the weather condition. As a consequence, it is not commercialized in practice to provide fresh water. Therefore, Various efforts to enhance the productivity of solar still by coupling with other devices like many types of solar water collectors, and photovoltaic.

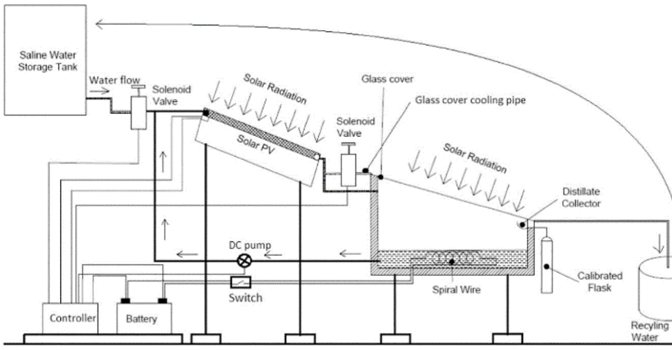

Figure 1: Schematic view of the hybrid (PV/T) solar still with NiCr spiral wire heater (Kumar et al., 2018).

Hybrid PV/T active solar still was proposed which then was compared to a conventional solar still (CSS) performance under weather conditions in India at three water levels of 0.05, 0.1 and 0.15 m (Kumar et al., 2018). Figure 1 describes the schematic diagram of the hybrid PV/T solar still. Nickel chromium wire was used as a heater and operated by electricity from the solar photovoltaic panel. In their system, saline water was provided from the water tank to cool PV cells and to preheat there before going to solar still. Their findings revealed that the average temperature of basin seawater was 50% higher than that in the CSS. This still produced 8.54 litter while the conventional still distilled 3.42 litter. Moreover, the hybrid solar still used PV/T had the greater overall thermal efficiency that is 25% higher than that of passive solar still under the same conditions. The payback of their system was estimated to be about 104 days.

N-identical photovoltaic thermal-compound parabolic concentrator (PVT-CPC) solar distiller with the cooling method was investigated by Joshi and Tiwari (Joshi and Tiwari, 2018). The main components of their system consisted of a passive solar still (PSS), semitransparent photovoltaic module or flat plate collector (FPC), and a helically coiled copper heat exchanger placed in the PSS. There were three configurations that were experimented in their work. In the first case PV module and FPC was arranged at the lower and upper position of the receiver part, respectively. While case 2 used only PVT-CPC and case 3 applied only FPC. They indicated that to maximize energy and exergy of the three configurations, the optimized mass flow rates flowing through the collectors was 0.04 kg/s and that of cooling water was 0.025 kg/s, the best length of the heat exchanger was 1.97 m and the amount of basin water was 280 kg that is shown in Figure 2. Additionally, the highest daily productivity was 37.9 kg belonged to case 3. In addition, case 2 had the highest electrical module efficiency that was obtained to be 13% in January. They also indicated that the estimation of the energy payback time was 2 years.

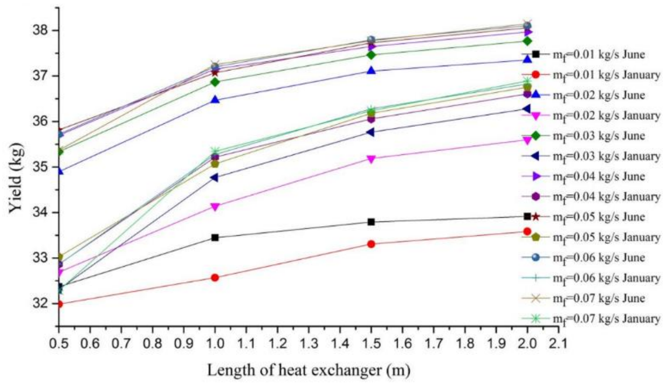

Figure 2: Variation of yield with the length of the heat exchanger at various mass flow rates for case 3 (Joshi and Tiwari, 2018).

A thermal model was developed to investigate the solar still integrated with the evacuated tube collector (ETC) along with the semitransparent photovoltaic module (Yari et al., 2016). The task of their system was to produce electricity and distilled brackish water also. Their system was operated in the natural mode. The semitransparent PV module was set up on the top of the solar still with the inclined angle of 30°. The PV module absorbed a part of solar irradiation and generate power while some were received by basin water. Their findings obtained that the distilled yield increased with the increment of tubes number. The daily productivity was improved from 2.3 to 4.76 kg/m^2/day when the number of tubes rose from 10 to 30 at the optimum water depth of 0.07 m. The whole day electrical energy is achieved for the HIT-type PV module was 483.2 W/m^2. The highest energy was 16.65% and that of exergy efficiency was 6.86%.

Experimental and theoretical investigation of a low concentrating photovoltaic thermal system (LCPV/T) assisted the conventional solar distiller was carried out (Xinxin et al., 2019). Three conventional solar distillers with different inclined angles of glass cover (25°, 35°, and 45°) were estimated in their study. The absorber of solar still was made from stainless steel. There were four LCPV/T units integrated into the series. An LCPV/T unit comprised a flat-plate PV/T panel and two compound parabolic concentrators (CPCs). The CPC was majorly made of a curved mirror. Glass cooling channel was designed to attach to the backplane of the PV to ensure electrical efficiency. Additionally, a tracking subsystem was installed to help LCPV/ T subsystem absorb solar energy as much as possible in which a photosensitive probe was set for detection of sun rays. They discovered that the rise of the inclined angle of glass cover increased the daily yield of a solar still, hence, the maximum distilled yield was 2.653 L/m^2 at the optimum glass slope of 45°. The average power generated by their system was 2097.15 W and the average electrical efficiency was obtained to be 10.98%. The highest overall exergy efficiency reached 15.50% and the average was 14.02%.

A numerical simulation was developed by Saeedi et al. [41] for optimizing PV/T solar still in terms of the production of fresh water (Saeedi et al., 2015). Energy balance equations were written for thermal analysis. Their numerical results were validated with the experimental data and they found a fair agreement with the error of 36.98% (Kumar and Tiwari, 2008). After that, they carried out parametric studies to investigate the impact of parameters on efficiency. The obtained findings showed that the rise of collector quantity increased the amount of distilled freshwater, however, the number of collectors over 30 did not have significant raise in daily yield. The highest efficiency was observed to be 21.56% at an optimized flow rate of 0.0044 kg/s and seven collectors. The increment of surrounding air temperature and mass of basin water declined the energy efficiency.

An effort for augmentation of daily distillate output of hybrid PV/T conventional slope solar still system was conducted (Balchandran et al., 2020). The concept of their work for productivity enhancement was the use of cooling effect on the glass cover and employment of hybrid natural fiber composite (HNFC) for insulation purposes. 6% of natural fiber, 1% of nano-silica, and polyester resin were prepared to make composite insulation which then was compared to the performance of single slope solar still insulated by thermocol (Polystyrene-styrofoam). They concluded that the highest increase in the daily distilled yield was 35% was obtained by using cooling water and HNFC, compared to still with thermocol at a water level of 0.5 cm while at a water level of 1 cm, the rising rate was 21%. In addition to their finding, the energy efficiency of their system was 60.82 and 58.65% at water levels of 0.5 cm and 1 cm. To address the water and electrical scarcity problems assessed the performance of integration between the PV panel and solar still (Manokar et al., 2018).

Their system consisted of a basin of a polycrystalline PV panel organized to an inclined solar still. In the solar cell, cotton threads were attached at the gap between the rows and columns, which could improve the rate of evaporation. In the experiment, water was supplied from the storage tank to the basin through a PVC pipe that had equal holes for the uniform distribution of the water to the distiller. The mass flow rate was controlled at 0.0023 kg/s. High-temperature water leaving from the still was circulated back to the water storage tank. The system was tested under the condition with sidewalls and bottom insulation (case 1), with side walls insulation (case 2), and without insulation (case 3). They investigated their system based on various aspects like still output, thermal efficiency, electricity generation, the efficiency of PV panels, and exergy efficiency. It is revealed that the inclined PV panel solar still produced the highest amount of freshwater of 7.3 kg in case 1. The maximum recorded daily efficiency was 71.2% belonged to case 1. The highest exergy efficiency was also obtained by case 1 (4.5%), followed by case 2 (2.3%), and case 3 (1.3%).

The comparison of passive and active mode of an inclined solar panel basin solar distiller was taken place (Manokar et al., 2018). In the active mode, they applied a flat plate collector that was installed between the storage tank and inclined PV solar still. It meant that in active mode, water was preheated before flowing to the still. In both active and passive mode, the mass flow rate was remained unchanged at 0.0013 kg/s. The results observed that the daily distilled yield of active mode (7.9 kg/day) increased by 44.63% compared to passive mode (4.3 kg/day). The energy efficiency recorded by active mode was 24.91% higher than by passive mode. The daily exergy effectiveness of the active and passive mode was 2.9% and 6.6%, respectively. The combination of PV panel and stepped solar distiller with the bottom channel was studied that is shown in Figure 3 (Xiao et al., 2019). The water was pumped from the tank to the PV/T panel to preheat here and to cool the PV/T collector also. After that, preheated water continued to flow into the bottom channel which was designed under the absorber of solar still. After water exited the bottom channel, it went down the steps and create a thin layer of water. The effect of depth of the bottom channel (H) was investigated.

The daily yield of their system at H = 1 cm was 3.99 kg/day that increased by 51.7% compared to traditional still. They discovered that the daily production of freshwater was reduced when the depth of the bottom channel increased from 1 cm to 3 cm. The overall thermal efficiency increased 17% whereas, the power efficiency was unchanged. The exergy efficiency was 10% under the optimum H= 1 cm. Numerical and experimental analysis of stepped type solar still integrated to PV/T panel was carried out (Naroei et al., 2018). The saline water was flowed into photovoltaic thermal (PVT) with the support of a pump and preheated here. Preheated water continuously absorbed solar energy and evaporated in the stepped solar still. Their results obtained that the accumulated yield was about 5.71 kg/m^{2}day, which was 20% higher than that of traditional stepped type. The electrical efficiency was constant at 9.5%. The application of the PV/T made the energy efficiency increase 2 times.

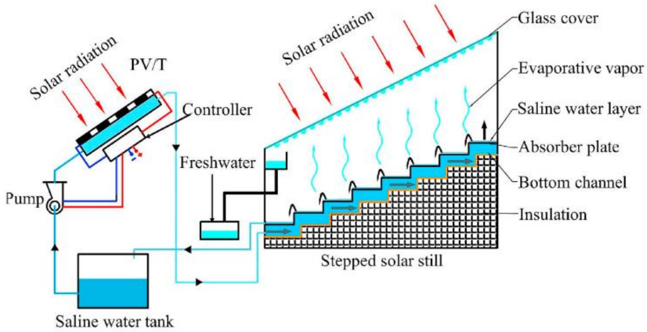

Figure 3: Schematic diagram of stepped solar still integrated with PV panel with the bottom channel (Xiao et al., 2019).

A studied experimentally an inclined PV panel solar still with phase change material (PCM) and cooling method for condenser surface (Kabeel et al., 2019). Their system comprised a PV pane with an area of 1.6 m^2, that was covered by the glass at the top. There were two storage tanks in that one supplied water to cool glass cover, whereas another feed water to the solar still. There were three modes of operation for cooling water included fully closed, partially open, and fully open. The effect of different mass stream rates of water (7.35, 13.32, and 17.72 kg/h) to inclined PV panel solar still was investigated. 10 kg of PCM was set up under the basin to absorb excessed heat and utilize them at off-sunshine hours. They discovered that the growth of mass stream rates of water declined distillate yield while increasing electricity production. At the mass flow rate of 7.35 kg/h and fully open mode of cooling water, the maximum distilled productivity was obtained to be 14.17 kg/m^2.

Moreover, the maximum hourly thermal efficiency was 97% for fully opened conditions at the noontime. The integration of cascade solar still and PV /T collector was studied by Sarhaddi [49] in terms of exergy analysis and in terms of energy analysis (Sarhaddi, 2018; Hedayati-Mehdiabadi et al., 2017). Both studies developed the numerical analysis that was evaluated to the study (Tabrizi et al., 2010). Sarhaddi found that the use of two PV/T panels increase possibly freshwater yield by 27%, even achieved to raise by 56.8% if the power generated from PV/T panels heat the water in the basin. The further finding showed that the exergy efficiency of cascade solar still can be doubled by employing two PV/T panels. Meanwhile in some study found that the use of PV/T collector enhanced the cascade solar distiller by 20% in daily productivity and by 26% in daily energy efficiency (Hedayati-Mehdiabadi et al., 2017).

A **c**ombination of double slope solar still (DSSS) and solar photovoltaic have been performed by several researchers. A DSSS coupled to a photovoltaic integrated flat plate collector was built and tested (Singh et al., 2011). Natural and forced convection mode with FPC arranged in series and parallel was investigated. Their system received 7.54 kg/day of daily freshwater productivity. Additionally, 3 years was the energy payback time. Comparative analysis between DSSS and CSS when they were integrated with PVT integrated partially covered CPC was carried out that is illustrated in figure 3 (Singh and Tiwari, 2017). The schematic diagram of their system is illustrated in Figure 3. There were N identical water flat plate collectors with CPC on that 25% area of each collector was partially covered by PVT to create the self-sustainable system. The insulated pipes help the integration between the PVT-CPC water collector and solar still in a closed circulation. The absorbers of solar stills were made of aluminum. They stated that the performance of their system was optimized at 0.04 kg/s of water mass flow rate, a water depth of 0.7 m, and a number collector of 7. As shown in figure 4, it was interesting to note from their work that at a water depth of less than 0.31 m, the DSSS showed the better performance than the CSS based on average daily energy efficiency, overall energy efficiency, and average daily yield while it was opposite at water level of more than 0.31 m. Based on the hourly production of freshwater, the DSSS was higher than the CSS at all water depths.

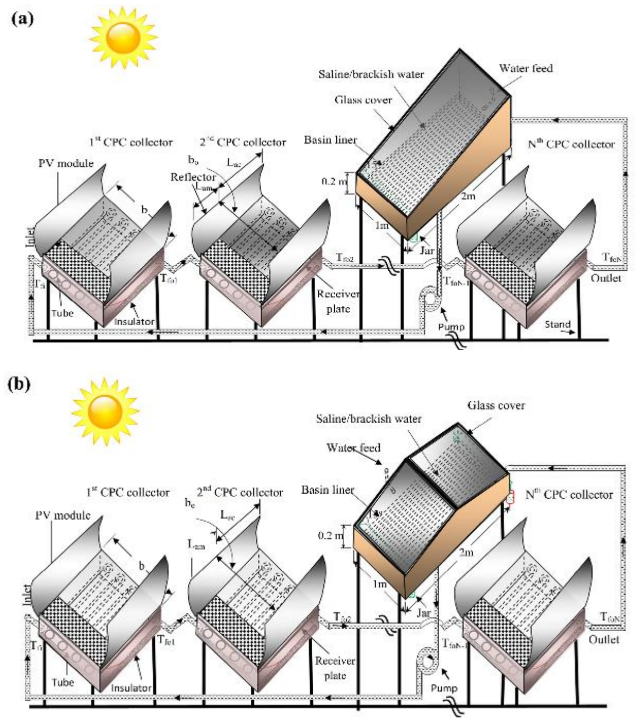

Figure 3: Integration of single slope solar still and N identical partially covered PVT-CPC collectors (Singh and Tiwari, 2017).

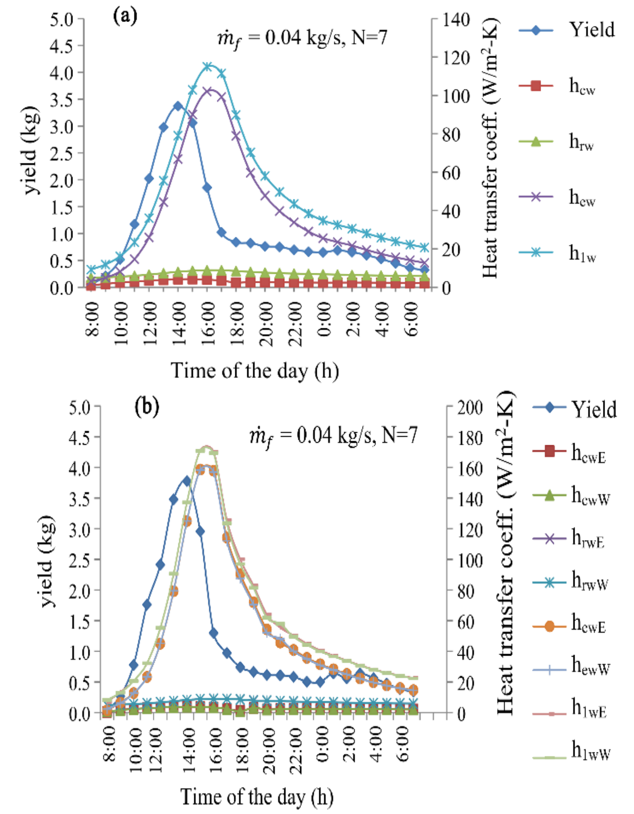

Figure 4: Hourly productivity and heat transfer coefficients of single slope (a) and double slope (b) active solar still integrated with N partially covered PVT-CPC collector integrated in series.

A group researchers developed numerical analysis was built to estimate the exergy performance of a DSSS assisted with PV/T collector and phase change material (Hedayati-Mehdiabadi et al., 2020). The numerical result observed that the daily yield was estimated to be 6.5 kg/m^2 in the summertime. There was a rise of 10.6% in daily distilled yield and an increase of 27% in exergy efficiency when there was a growth of the mass flow rate from 0.001 to 0.01 kg/s. Sahota and Tiwari [55] investigated the performance of DSSS with partially covered N PV/T-FPC without heat exchanger (System A), with heat exchanger (System B), and only DSSS (system C) (Sahota and Tiwari, 2017). The different nanofluid was tested in three systems included TiO_2, Al_2O_3, and CuO. The PV modules provided power to a pump to circulate water in the system. They discovered that the best yearly performance belonged to system A according to overall thermal energy and exergy, and productivity compared to the rest systems with all water-based nanofluids. Additionally, the use of CuO nanoparticles showed better effects on systems A and B in terms of yearly performance; exergoeconomic and enviroeconomic. They concluded that with the usage of nanofluid the annual mitigation of CO_2 of system A was 14.95 and 3.17 tones, while that of system B was 24.61 tones and 2.36 tones.

3. Application of Pv/T Panel For Supplying Power for Other Purposes

A partially covered hybrid PV/T flat plate collector (FPC) solar distiller was designed, fabricated, and studied (Singh et al., 2016). The experimental setup included two FPC that were linked in series and a CSS. The conventional solar distiller consisted of an aluminum box with 1 m^2 of area, insulated by glass wool with 0.1 m of thickness. Each FPC has an area of 2 m^2, which was combined with the PV module on the lower side. The power from the PV module was used to operate the water pump which helped the brackish water to circulate through the system and avoided the pressure drop. The energy and exergy efficiency also were analyzed in their study. The maximum distillate productivity was 7.74 kg/day. The theoretical analysis was conducted to compare the experimental results. A good agreement was obtained for theoretical results. The highest thermal efficiency was 75% and the overall energy efficiency was 69.06%. Meanwhile, 20.74%, 28.53%, and 25% were obtained for thermal exergy efficiency, electrical exergy efficiency, and overall exergy efficiency, respectively.

A new integration was proposed on the basis of using a PV module to convert power into thermal heat for desalination of water in a solar still (Elbar et al., 2019). In their study, they accessed energy, exergy, exergoeconomic, and exgoenviromental perspectives. In their system, the PV module was arranged over a CSS. The basin was made of aluminum with an area of 1 m^2 that was covered by the glass at all sides. In their work, four cases are studied that were only CSS (case 1), still with photovoltaic (case 2), distiller with PV and black steel wool fiber (case 3), and distiller used PV as a reflector (case 4). Among these cases, case 3 had the highest distilled yield of approximately 3.2 kg/m^2, followed by case 2 (2.67 kg/m^2), case 4 (2.5 kg/m^2), and case 1 (2.42 kg/m^2). It is indicated that the energy efficiency was the highest with 59.75% achieved in case 3, followed by case 2 (55.75%), case 4 (40.9%), and case 1 (35.4%). The instantaneous exergy efficiency for all cases was 2.82% (case1), 3.25% (case 2), 3.88% (case 3), and 15.88% (case 4) respectively. The environmental benefits were estimated in their work in terms of carbon footprint which indicated that the yearly CO_2 was mitigated by 19, 20.9, 24.9, and 27.38 tons, corresponding to cases 1 to 4.

The influence of connecting PV with passive solar distiller on its temperature, daily output, energy efficiency, and the cost was done (Elbar and Hassan, 2020). A photovoltaic (PV) mono-crystalline panel was set up in a vertical position after the back of the solar still to reflect some solar energy into the distiller. A copper heater was embedded in the brackish water that was supplied electricity from the PV panel. They also studied the performance of solar still with the support of 0.6 kg of black steel wool fibers (BSWF). Through fine threads of BSWF, water went up under the capillary effect that leads to larger surfaces for evaporating seawater. Their system was tested under natural and forced convection air cooling. Their results obtained that the hybrid PV panel – solar still with the BSFW improved by 35% in daily distilled yield in comparison with CSS. The support of air cooling led to the enhancement of the daily productivity and energy efficiency by 30% and 35%, respectively.

Modified solar still with a stirrer was proposed (Rajaseenivasan et al., 2017). DC motor and electrical power generated by the solar photovoltaic panel were used for the stirrer mechanism. In this work, the capacity of the PV panel and motor was selected to be 4 W and 2 W. The stirrer was installed in a conventional solar still that consisted of an inner and outer galvanized iron sheet basin, a glass cover, and thermocol insulation. Charcoal and Paraffin wax was tested as thermal energy storage placed between inner and outer basins. The water depth of saline water was kept constantly at 1 cm. According to their results, the optimum average height between saline water and glass cover for conventional solar still was 0.15 m that could produce daily 3.19 kg of freshwater. According to figure 5, the use of stirrer and paraffin wax observed the highest daily yield and energy efficiency that were 5.23 kg/day and 58.63%, respectively.

Besides generating electrical power, the solar photovoltaic panel can play roles as absorbers in the distiller, preheat saline water, and support for the operation of other devices like the pump, heater, or stirrer. Table 1 shows the performance of solar photovoltaic active solar stills. The integration of PV/T module with solar still can improve the daily distilled yield. The daily productivity of PV/T solar still with water cooling method can increase 6 times compared to CSS (Kumar et al., 2018). The water-cooling method can enhance the efficiency of PV panels to 17% (Yari et al., 2016). The antieconomic analysis defines the yearly mitigation of CO_2 over the still life that had been investigated in the studies of [57] and [55] (Elbar et al., 2016; Sahota and Tiwari, 2017). Based on thermal energy, the amount of CO_2 mitigated annually was estimated to be 24.61 tones with DSSS-partially covered N PV/T- FPC - a heat exchanger and nanofluid (Sahota and Tiwari, 2017).

Table 1: Performance of different solar still integrated with PV/T module.

Ref.	Technique	I_{max}	T_{wmax}	$\dot{m}_{ew}$ (kg/m²day)	Compared to passive mode	$\eta_{PV/T}$	η_e	η_{ex}
(Kumar et al., 2018)	hybrid PV/T active solar still with water cooling method	838	66	8.542	↑6 times	11.4%	62.5%	-
(Joshi and Tiwari, 2018)	Integration of PVT-CPC and CSS with water cooling method + heat exchanger	510	68	3.58	-	13%	-	-
(Singh et al., 2016)	partially covered hybrid PVT-FPC solar distiller	500	62.4	7.74	-	-	69.06	25
(Yari et al., 2016)	CSS + ETC + semitransparent PV module	610	90.4	5.89	-	17	16.65	6.86
(Xinxin et al., 2019)	LCPV/T + tracking system + CSS	953	60.9	2.65	↑3.6 times	10.98	61.93	15.5
(Elbar et al., 2019)	CSS + PV/T+ BSWF + heater	850	64.4	3.2	↑31%	-	59.75	2.51
(Balachandran et al., 2020)	PV/T + CSS + Cooling effect + HNFC insulation	710	61	2.25	↑35%	-	60.82	
(Elbar and Hassan, 2020)	CSS + PV panel + BSWF + heater + FAC	900	66.7	3.25	↑34.6%	-	34.23	-
(Manokar et al., 2020)	inclined solar panel basin solar still + cotton threads+ Insulation	858	73.5	7.3	-	7.98	71.2	7.68
(Kabeel et al., 2019)	inclined solar panel basin solar still + PCM+cover cooling	-	-	14.7	↑36.25%	-	-	-
(Manokar et al., 2018)	inclined solar panel basin solar still + FPC	815	70	7.9	↑83.7%	7.68	66.49	6.6
(Xiao et al., 2019)	PV panel + Stepped solar still + bottom channel	818	68.52	3.99	↑51.7%	-	-	10
(Naroei et al., 2018)	PV panel + Stepped solar still	546	68	5.71	↑20%	9.5	33	-
(Rajaseenivasan, 2017)	CSS + Stirrer + Paraffin wax	900	-	5.24	↑63.95%	-	-	-
(Singh and Tiwari, 2017)	DSSS+ N identical partially covered PVT-CPC water collectors	1000	98	35	-	-	80	16
(Singh and Tiwari, 2017)	CSS+ N identical partially covered PVT-CPC water collectors	1000	94	38	-	-	83	14.5

Note: I_{max}: maximum solar irradiation; T_{wmax}: maximum basin water temperature; $\dot{m}_{ew}$: distilled yield; $\eta_{PV/T}$: effectiveness of PV/T; η_e: energy efficiency; η_{ex}: exergy efficiency.

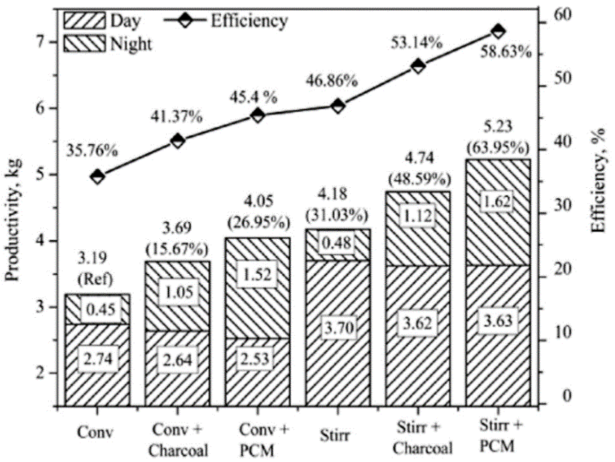

Figure 5: Production rate and efficiency of the solar still with stirrer arrangement and different energy storing materials.

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