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Experimental investigation on hybrid PV/T active solar still with effective heating and cover cooling method

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ABSTRACT

A hybrid photovoltaic/thermal (PV/T) active solar still and a conventional passive solar still with single slope were designed, fabricated and experimented at three different water depths (0.05 m, 0.10 m, and 0.15 m). For the higher production of distillate water, a nickel-chromium (NiCr) heater powered by solar photovoltaic (PV) was incorporated in the proposed hybrid active still. Solar PV module was cooled by the saline water which increases the efficiency of the solar PV as well as the distillate water production. The daily yield from the proposed hybrid active (PV/T) solar still is 6 times more than the conventional passive still. This new system of renewable energy based power and distillate water production is highly self-sustainable in the remote areas. From the experimental study it is clear that, the proposed hybrid active (PV/T) solar still gives an enhanced overall thermal and electrical efficiency, that is nearly 25% higher than the conventional passive one.

1. Introduction

Electrical energy and potable water are the essential needs for the life of the human in the present world scenario. The conventional energy resources are degrading day by day which leads to the turning in the use of renewable energy resources. Industrialization in the present world pollutes the nature of the environment, mainly the potable water available below and above the ground level. Over one billion people in the globe, lack access to drinking water. About 80% of all diseases in the developing world happens because people consume unsafe water and without an adequate sanitation [1]. The most effective renewable energy source is the solar photovoltaic (PV). Even though solar PV is effective, the effect of high temperature acts as one of the main challenges to rise above. Increase in temperature of the solar PV causes the decrease in the efficiency.

The brackish or saline water (salinity ~10,000 ppm) can be purified by solar still. It may be either active solar still or passive solar still. The passive solar still is a natural slow evaporation process does not need any external source to heat the saline water in the basin. But in the case of active solar still, it uses an external heat source to heat the basin saline water to evaporate. The yield of the active solar still (more than 7 L/day) is comparatively high than the passive solar still (around 2 L/day). A lot of researchers have done many designs in the passive solar still ([2,3,4,5,6,7], multi-basin [8], regenerative [9], inverted trickle [10], multi-effects [11], having reflectors [12], triangular shaped [13], pyramid-shaped [14] and hemispherical [15] type solar still). On the other side, the active solar still also have many ways to heat the basin water but the highly recommended method is the integration of panel with the basin either through the heat exchanger [16,17,18] or directly [6,7]. A. E. Kabeel analysed techniques for quicker evaporation of water by using certain wick materials to absorb the heat other than basin absorption heat [25] and the recent review literature were studied regarding the performance enhancement techniques of the solar still. Integration of solar PV and solar thermal system by various methods were studied in a mini literature [26] and a review of solar collector integration was studied [27]. The heat exchange mechanism [19–24,28], and heat energy storage techniques [29,30] for improving fresh water production were observed. A hybrid active solar still integrated with porous fins [31], acrylic finned [47] and flat plate collector [38] was studied to know the design, fabrication and analysing

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methods of hybrid solar PV/T still. Evaporation [41,42,48] and condensation [43,44,45] processes of the basin saline water can be enhanced by many techniques, which were studied from recent literature.

For converting the waste or brackish water into potable water single basin solar still is the simplest and very easy to fabricate with the available materials [32] tested by A. E. Kabeel. From the literature, it is very clear that the active solar still is better in performance than the passive solar still. The yield per day of 1 m^2 of the solar still area mainly depends on the rate of evaporation and the rate of condensation of the corresponding surface area. So, to increase the vaporization of water, the saline water from the storage is preheated before fed into the basin by flowing it over the hot solar PV panel in a regulated time interval using solenoid valve. At the same time, condensation of the water vapour is also important so that glass cover cooling is made by the water from the PV panel. Then the maximum power from the solar PV is used to heat the basin saline water by a heating process explained in Section 4. The two main advantages of this process are (i) the saline water is preheated which is easy to evaporate and (ii) the solar PV panel is cooled i.e., the temperature of the PV cell is reduced because of the absorption of heat by saline water which increases the efficiency of the solar PV panel. Since the proposed method uses a battery for power storage, the distilled water can be produced at any time.

The aim of this paper is to present high energy efficient active hybrid (PV/T) active solar desalination system in which the efficiency of the solar PV is improved by cooling the PV cell using saline water. Therefore, the intention of the proposed experimental study is to get better performance in the solar still as well as to improve the efficiency of the solar PV panel.

2. Characteristics of solar PV (temperature effect) and heating element (nickel chromium)

A detailed review of the temperature effects on solar PV and solar still was studied [28,33,46]. The effect of temperature over solar PV is one of the major problems in East Asian countries. The average temperature in the research conducting location is 38 °C (Latitude 9.5680°N, Longitude 77.9624°E) which is 13 °C higher than the Standard Testing Condition (STC) temperature by IEC-61215 and IEC-61646. Also, Asia's largest solar PV power plant is located nearer to the location of research conducting place (Latitude 9.34757°N, Longitude 78.39216°E). The change in temperature is directly proportional to the change in voltage output of the PV and vice versa in the case of output current. STC includes the cell temperature of 25 °C, irradiance of 1000 W/m^2 and the air mass of 1.5 AM in the solar spectrum. Each degree temperature rise over the STC temperature in the solar cell leads to the decrease of the cell output voltage by 0.3% to 0.5% depending on the type of solar cell material (a-Si, c-Si, CdTe, GaAs, μc-Si, TFSC, m-Si & p-Si).

IEC-60904 series of standards provides the details of the performance of the solar PV by considering temperature and irradiance as a function. Temperature coefficient (C_v) and ambient temperature (T_a) decides the actual output of the solar PV panel. The temperature coefficient is a constant which may vary slightly for different cells manufacturers and the ambient temperature is the present atmospheric temperature at the panel. Eq. (1) gives the relation between the ambient temperature and the panel output.

$$Actual\ voltage = V_{mpp,rated} + [C_v \times (T_a - 25)] \quad (1)$$

For the proposed work, SES-450 J 50 W mono-crystalline type photovoltaic module is used. R. Santbergen et al. [34] found that the mono-crystalline PV cell absorbs more irradiance than other types of PV cells since it is made of pure silicon. Cells which absorb more irradiance can produce more power and also produce more heat. The temperature coefficient of this module is − 0.36%/°C of the open circuit voltage. Various types of solar cell have different temperature coefficients and efficiency which are given in Table 2. Therefore, for the 18 °C increase in the cell temperature may cause a loss of about 2 V in this module output. The panel specification of this module is given in Table 1.

Table 1
Specifications of used solar PV module at STC.

Electrical parameters	Specifications
Maximum power (P_{max})	50 W
Voltage at P_{max} (V_{mpp})	17.5 V
Current at P_{max} (I_{mpp})	2.90A
Short circuit current (I_{sc})	3.20A
Open circuit voltage (V_{oc})	21.8 V
Module efficiency (μ)	11.1%
Fill factor (FF)	0.72
Temperature coefficient of I_{sc}	0.105%/°C
Temperature coefficient of V_{oc}	− 0.360%/°C
Temperature coefficient of P_{max}	− 0.45%/°C

Table 2
Temperature coefficient and module efficiency values of different PV cell types.

Type of PV cell	Temperature coefficient, C_v (%/°C)	Module efficiency, μ (%)	Reference
a-Si	− 0.26	6.3	Yamawaki et al. [35]
CdTe	− 0.20	6.9	Nann and Emery [36]
CIGS	− 0.45	8.2	Nann and Emery [36]
m-Si	− 0.36	11.1	Rüther et al. [37]
p-Si	− 0.40	10.6	Nann and Emery [36]

Table 3
Properties and specifications of used NiCr wire.

Property	Specification
Electrical resistivity at room temperature	(1.0–1.5) × 10^{-6} Ω·m
Specific heat	450 J·kg^{-1}·K^{-1}
Thermal conductivity	11.3 W·m^{-1}·K^{-1}
Wire gauge	14 AWG 0.22 mm
Wire length	1 m
Resistance at room temperature (32.5 °C Ωm^{-1})	3 Ω·m^{-1}
Increase in resistance with temperature (20–315 °C)	0–3.3%
Power or heat produced per second w.r.t. panel ratings	40 W or 40 J·s^{-1}
Weight per meter	0.000276 kg·m^{-1}
Cross sectional area	0.0346 mm^2

From Table 2, it is clear that the increase in temperature increases the current to a smaller rate and decreases the voltage to a greater rate and that reduces the efficiency. In the case of irradiance, a decrease in irradiance decreases both the voltage and current. The increase in the irradiance level is possible but not always. So, increase in voltage is done by reducing the temperature of the PV cell i.e., cooling the PV cell using waste or saline water. This improves the overall efficiency of the solar PV panel and the saline gets preheated. This preheated water is used for the solar still and also for cooling glass cover (condensation of water).

A.E. Kabeel et al. [32] developed a solar still in which the production of pure water is augmented by a turbulence system powered by solar PV. They used an 18 W solar PV panel that drives a 12 W DC motor for the quick evaporation of basin saline water. This method is cost-effective and produces higher daily yield than the conventional still. From this work, it is seen that the initial saline water fed to the basin is at normal temperature and also the temperature of the solar PV increases gradually depending on the atmospheric condition. To improve the overall (both still and panel) efficiency, the panel is cooled periodically by the saline water (saline water gets preheated) as a part of the proposed work. In another part of the proposed work, DC motor