• Solar HDH desalination system combined with PVT

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Abstract

This work presents the integration of a photovoltaic thermal system (PVT) with a humidification dehumidification desalination (HDH) system. The heat extracted from the PVT collector can be used to preheat seawater or air for its posterior use in the HDH desalination system, while the cooling achieved of PV cells increases their efficiency. The combination of both technologies has the potential of increasing the energy efficiency of the whole system and provide a better desalination solution.

Keywords: HDH, Desalination, PVT, Solar

1. Introduction

Photovoltaic PV electrical production is a function of PV panel technology, solar radiation, and cell temperature (Skoplaki and Palyvos, 2009; Kasaeian et al., 2013). Nowadays typical PV module efficiencies sit between 17% and 20% at standard testing conditions; hence, the rest of the absorbed energy is converted to heat, increasing the temperature of the PV panel. If the rate of heat removal is kept high, a low cell temperature can be obtained. The action to producing electricity and useful heat for a process from a PV panel is called PVT. Hot water or hot air may be produced for another process (Fudholi et al., 2014). This study explores the combination of PVT with a humidification dehumidification desalination (HDH) system to provide the heat and electricity source required by the process.

The literature available on HDH-PVT seems to be limited, with few studies related to this combined process. Giwa et al. (2016) developed an air-cooled PV system integrated with a HDH desalination system without an additional heating system. The system produced a daily average of 2.28 liters per m^2 of PVT collector. Anand and Srinivas (2017) studied a PVT water system which used the warmed water for the humidifier of the HDH system. The dehumidifier was cooled down using chilled water from an external source. The maximum PV efficiency was around 16.6% and a mass flow rate of 110 kg/h, while the maximum HDH efficiency was 43% using a mass flow rate of 30 kg/h. For both cases the solar radiation was reported as 800 W/m^2.

Elsafi (2017) presented a mathematical model to evaluate a concentrated photovoltaic-thermal collectors CPVT coupled with a HDH system. The CPTV warmed the air flux coming from the humidifier to the dehumidifier. The CPVT configuration had an area of collection of 9 m^2 and a PV area of 4.5 m^2. The annual production of freshwater was estimated in 12 m^3 and the annual electricity production in 960 kWh considering an accumulated annual solar irradiance of 1.88 MWh. Mahmoud et al. also propose a different configuration including CPVT. The CPTV is combined system with a solar still desalination and a two stage HDH system. In this configuration, the CPVT is placed between the two humidifiers and it is used to warm air and water. The proposed configuration increased the production of the system from 9 to 12 liters per square meter. Gabrielli et al. (2019) described a HDH desalination system that is power only using PVT as a heat source. This work found that the optimal working condition for their system is a function of the ambient temperature. For the proposed configuration, the outlet temperature of the PVT should be kept over 40°C to produce fresh water.

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This work analyses the integration of PVT and a HDH desalination system. It proposes the PVT collector in two ways, to preheat seawater and/or to preheat air. It will be evaluated the trade off to cool PV panels and increase their efficiency as well as increasing the energy efficiency of the HDH desalination system.

2. System description.

Fig. 1 shows a one stage solar HDH desalination unit with an open seawater loop and a closed air loop CAOW. The seawater (blue line) is pumped to the condenser where it is pre-heated. In a plate heat exchanger, the warmed seawater is heated by hot water from the solar thermal collector loop (red line). The heated seawater is then sprayed in the humidifier. A counterflow stream of air is in contact with the water and is warmed up and wetted due to heat and mass transfer process. The humid air is cooled down in the condenser while the seawater is warmed up producing distillated water in the process. The air moves in a close loop indicated with green line.

PVT are studied in two configurations and the combination of these two setups. The first configuration is considering the PVT to preheat the air coming from the condenser, shown with a dash line green in Fig. 1. The air leaving the condenser is cold but saturated. The addition of heat, recovered from the PV panels, will increment the capacity of air to carry water, improving the efficiency of the HDH process. The second option is to use PVT to preheat seawater between the condenser and the thermal solar collector loop, as indicated with the dash line blue in Fig. 1. In addition, it could be evaluated the option of using only the PVT as a heat source for the seawater without the thermal solar collector loop. The benefit to install PVT panels in this circuit is the chance to increment the seawater temperature in the humidifier; consequently, the efficiency of the HDH unit. Also, it can reduce the capital cost of the system because less thermal solar collector may be necessary for the HDH unit.

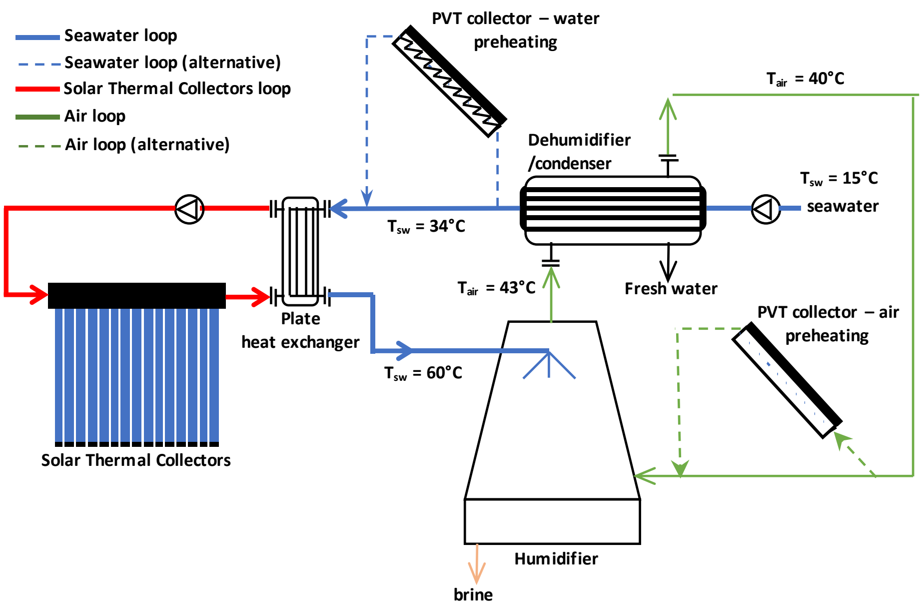

Fig. 1: Solar HDH system with the option to integrate PVT as water preheater and/or air heater.

The main purpose of the HDH desalination unit is producing distillate (M_d); however, it is relevant to understand the efficiency of the desalination system. The traditional overall performance parameter for desalination units is known as Gained Output Ratio (GOR), which is calculated using eq. 1.

$$GOR = \frac{M_d \lambda}{Q_u} \qquad \text{(eq. 1)}$$

GOR is the standard thermal desalination parameter that relates the heat necessary to evaporate M_d and the thermal heat provided to the desalination unit Q_u, which in Fig. 1 is the heat transferred to the seawater in the plate heat exchanger. Therefore, GOR is only considering the desalination process and not the solar collector process. This could lead to incorrect conclusions about the operational performance of the solar desalination unit. Therefore, it is proposed to use the Solar Irradiation-Distillate Ratio SIDR as the key performance parameter, as it reflects properly the performance behavior of solar desalination systems. This overall parameter considers both the collection and desalination processes, as shown in Eq. 2.

$$SIDR = \frac{G_T A_C}{M_d} \qquad \text{(eq. 2)}$$

The HDH unit is considered to be autonomous and completely solar (electricity and heat). It means that the thermal energy is provided by solar thermal collectors as well as PVT, and the electricity required by the fan (air loop) and pumps (seawater and thermal solar collector loops) is also provided by the PVT collector. A_C corresponds to the sum of the areas of the solar thermal and PVT collectors. For all the configurations proposed it will be studied which conditions minimize SIDR and maximize M_d production.

3. Numerical Model

The one stage solar CAOW HDH desalination unit presented by Hernandez et al. (2018) is used as a reference system. In this study, the system is modeled in the TRaNsient System Simulation Tool TRNSYS (2013). Each component of the system is represented by an element or a "Type" that calculates the outputs using the inputs that receive from other elements and they are validated against the data reported by Hernandez. Fig. 2 shows the Solar HDH CAOW system.

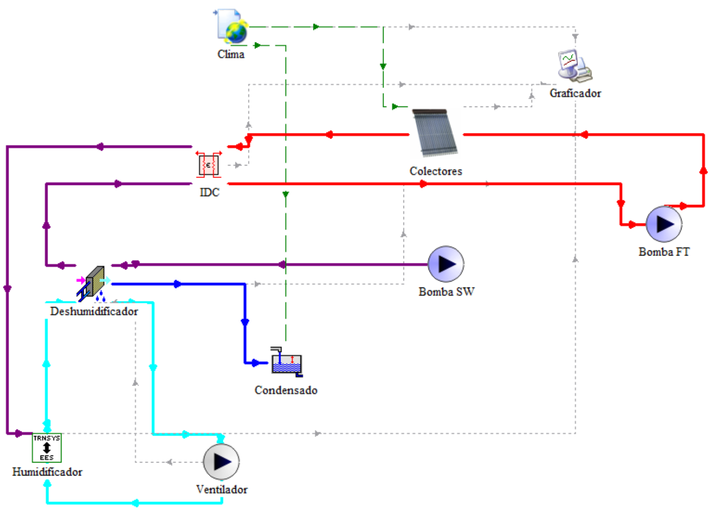

Fig. 2: Solar HDH CAOW system.

The selected location is Antofagasta, Chile. A TMY climatic data file for this location is used that contains hourly values for climatic data like radiation and ambient temperature. The solar thermal collectors are modeled using Type 538. The plate heat exchanger that connects the seawater flow and the water flow from the solar loop is modelled using the Type 91b. The humidifier is modeled with an EES module that connects both programs. The humidifier model assumes an ascending flux of air while water is being sprayed from the higher part to the bottom of the humidifier. The dehumidifier is simulated by a Type 508-2 that works as an in ideal heat exchanger of two fluids (water and humid air). Type 508-2 cools and dehumidificates the air mass flow rate as much as possible with the mass flow rate and energy provided by the seawater flow.

When the PVT is integrated to the HDH system, Type 560 is used. Type 560 models the PV panel with a serie of tubes bonded in the absorber plate behind the PV panel. The cooling fluid passes inside the tubes and absorbs heat from the PV panel. The fraction of the energy that is not converted into electricity or lost to environment is transferred to air or water.

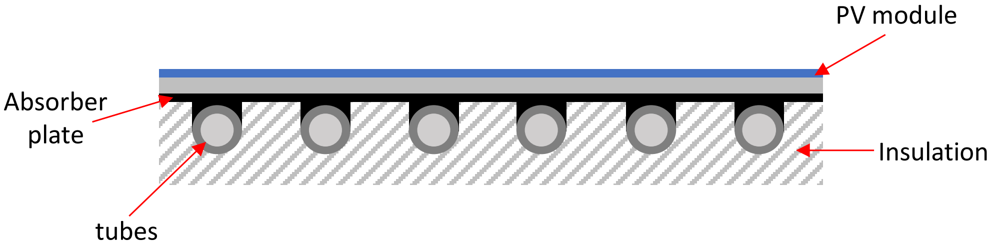

Fig. 3: Schematic of a PVT configuration

The parameters used for the PVT module are detailed in Table 1.

Table 1: Parameters used for PVT

Thermal Conductivity of the absorber	1386	kJ/h-m-K
Number of tubes	10	
Tube Diameter [m]	0.01	m
Bond Width [m]	0.01	m
Bond Thickness [m]	0.001	m
Bond Thermal Conductivity	1386	kJ/h-m-K
Resistance of Substrate Material	0.01	h m^2 K/kJ
Resistance of Black Material	3	h m^2 K/kJ
U-Value of Roof Material	0.667	kJ/h-m^2-K
Fluid Specific heat	1.05	kJ/kg K
Top Loss Convection Coefficient	20	
Fluid Heat Transfer Coefficient	200	

4. Results

The HDH desalination unit is formed by 8 m2 of solar thermal collectors to provide heat to the system, 8 m2 of PVT panels to drive the seawater pump (0.37 kW), the thermal solar collector pump (0.15 kW), and the air fan (0.06 kW), and to provide the rest of energy for common use. The air mass flow rate is set to 800 kg/h and the water mass flow rate is 288 kg/h. The inclination of the solar thermal collectors and the solar PV panels is set to be the latitude of Antofagasta (23°).

The results are shown for one day of march in Antofagasta. The solar radiation data at the solar thermal collector and solar PV panels are shown in Fig. 4. Also, the ambient temperature is shown for the same day and same location.

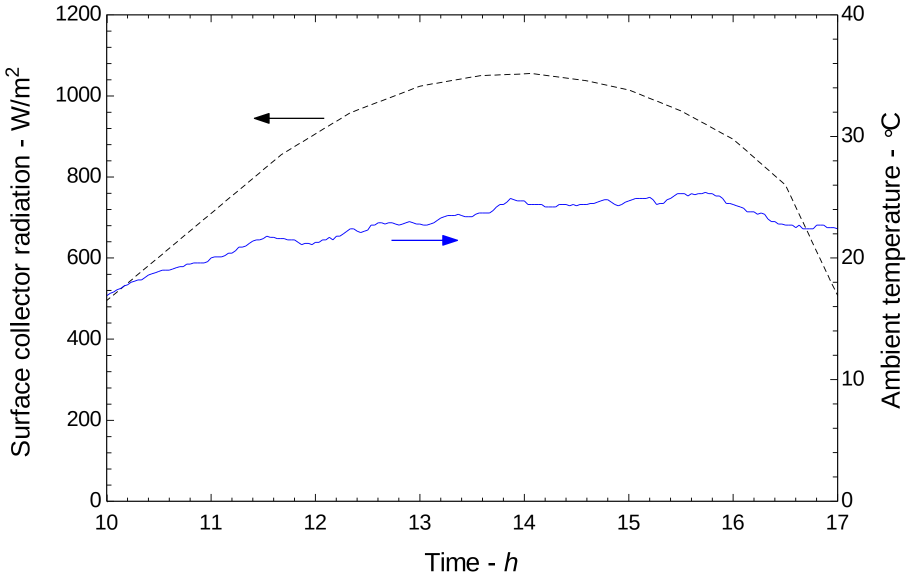

Fig. 4: Freshwater production of different PVT configurations

Fig. 5 shows the freshwater production for the HDH configuration (without PVT) that achieves around 15 kg of freshwater per day (in March). If a PVT is implemented to warm water after the dehumidifier and before the plate heat exchanger that provides the heat from the solar loop, a freshwater production is 50% greater than HDH configuration. The best results are obtained when the air coming from the dehumidifier is preheated before to enter to the humidifier, producing around 25 kg of freshwater per day.

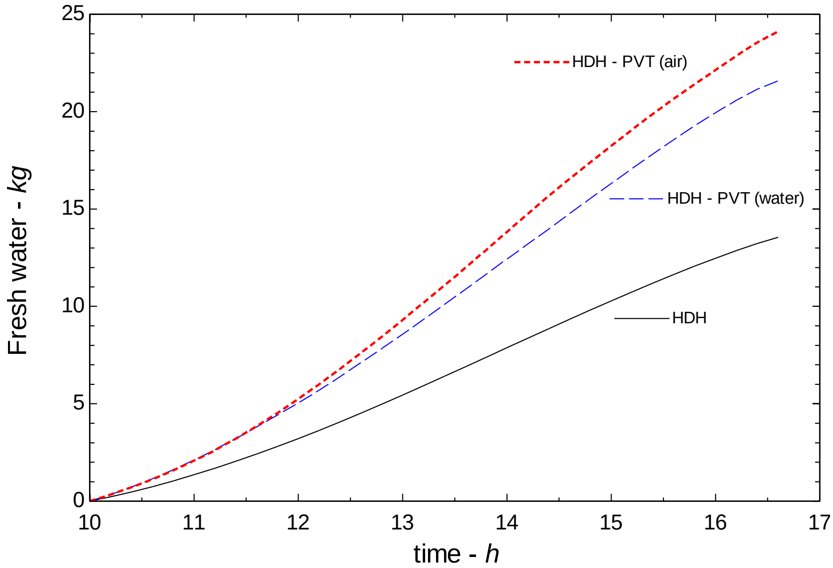

Fig. 5: Freshwater production of different PVT configurations

The performance of a HDH unit is driven by the air temperature difference between the outlet of the humidifier and the outlet of the dehumidifier. Also, it is clear the beneficial of using the residual heat of PV modules in HDH systems. In conclusion, it seems to be more effective to heat directly the air than to heat the water and expects that the water transferred heat and warm the air in the humidifier.

5. Conclusions

It has been demonstrated that the integration of a HDH system with PVT produces a performance improvement, this is shown in the increment of the distillate production of the system. The best results are the ones of the system with an air-PVT reaching a distillate production of 25 kg per day, more than the 50% increase than with the water-PVT system. Using PVT instead of PV in this kind of solar desalination system is a beneficial option, because the otherwise discarded thermal energy can be used to improve the desalination process, and also to better the efficiency of the electricity production by photovoltaic panel, with no need to use a wider space with further components and reducing the investment.

6. Outlook

These results show an opportunity to improve the future design of solar HDH desalination systems by incorporating this modification. In fact, including enough PVT modules could be an opportunity to reduce construction costs by reducing or replacing the solar collector field to use the thermal energy completely or partially from the PVT modules. In future studies, several configurations of integration HDH and PVT will be studied to have a more cost-effective and accessible solar water distillation technology.

7. Acknowledgements

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