IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Experimental investigation on a vacuum still integrated with concentrating PVT hybrid system

To cite this article: X X Guo *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **188** 012066

IOP Conf. Series: Earth and Environmental Science **188** (2018) 012066 doi:10.1088/1755-1315/188/1/012066

Experimental investigation on a vacuum still integrated with concentrating PVT hybrid system

X X Guo[1], H Zhang[1,2] and H P Chen[1]

[1]School of Energy, Power and Mechanical Engineering, North China Electric Power University, No. 2 Beinong Road, Beijing, 102206, China

E-mail: zhangchongheng@hotmail.com

Abstract. A vacuum still integrated with concentrating photovoltaic/thermal (VSICPVT) hybrid system for desalination is proposed in this paper. This system consists of a vacuum still, a concentrating photovoltaic/thermal (CPVT) module and a solar collector thus can produce freshwater and electricity simultaneously. Its prototype was established in North China Electric Power University (NCEPU), Beijing, China. In order to study the performance of this hybrid system with different inlet temperature of the vacuum still but with constant flow rate of saline water in the CPVT module, the experiments were conducted. And the electric efficiency, power, vaporization rate and freshwater yield of the system were analyzed.

1. Introduction

Nowadays, fossil energy crisis and freshwater shortage have been global issues. As an inexhaustible and available everywhere renewable energy, solar energy draws increasingly attentions all around the world. Many researchers [1-6] investigated how to utilize solar energy efficiently. And quite a few scholars [7-9] studied how to desalt sea water by using solar energy. Ong *et al* [10] studied a high-CPVT combining with membrane desalination system. Outlet saline water temperature of the CPVT could reach to 75-80°C, and the entire system converted the 85% of the solar irradiation on the CPVT to valuable energy. Meanwhile, the freshwater yield was 4.87 L/m^2. Srithar *et al* [11] experimentally studied the performance of a stand-alone solar desalination system, consisting of solar still, cooling arrangement, and CPVT module. And the daily freshwater yield could obtain the maximum 16.94 kg/m^2. Kumar *et al* [12] conducted experiments on an active PVT incorporating with a solar still system. And a comparative experiment with a conventional passive PVT-solar still system was also carried out. The results indicated that the total efficiency of the active one was approximately 25% higher than the passive one. Gude *et al* [13] proposed a solar desalination system operating at vacuum pressure but closely ambient temperature. Abutayeh and Goswami [14] established a model based on a sustainable sea water flash distillation process. And thermodynamic relations in the process were developed in the model. Since CPVT can receive higher solar radiation intensity than flat-plate PVT, it has higher overall efficiency and thus provides greater saline water temperature to desalinate efficiently. Beside, solar still operating at vacuum pressure has higher distillate yield and lower vaporization temperature than that operating at ambient pressure. To boost the freshwater yield of desalination and utilize solar energy efficiently, a novel vacuum still integrated with concentrating PVT (VSICPVT) hybrid system is proposed in the paper. It not only can generate electricity, but also produce considerable freshwater for domestic use.

2. VSICPVT system

The VSICPVT system mainly consists of CPVT module, solar collector, vacuum still and condenser. The schematic diagram of the VSICPVT system is presented in figure 1. And the working processes and principles of the system are as follows:

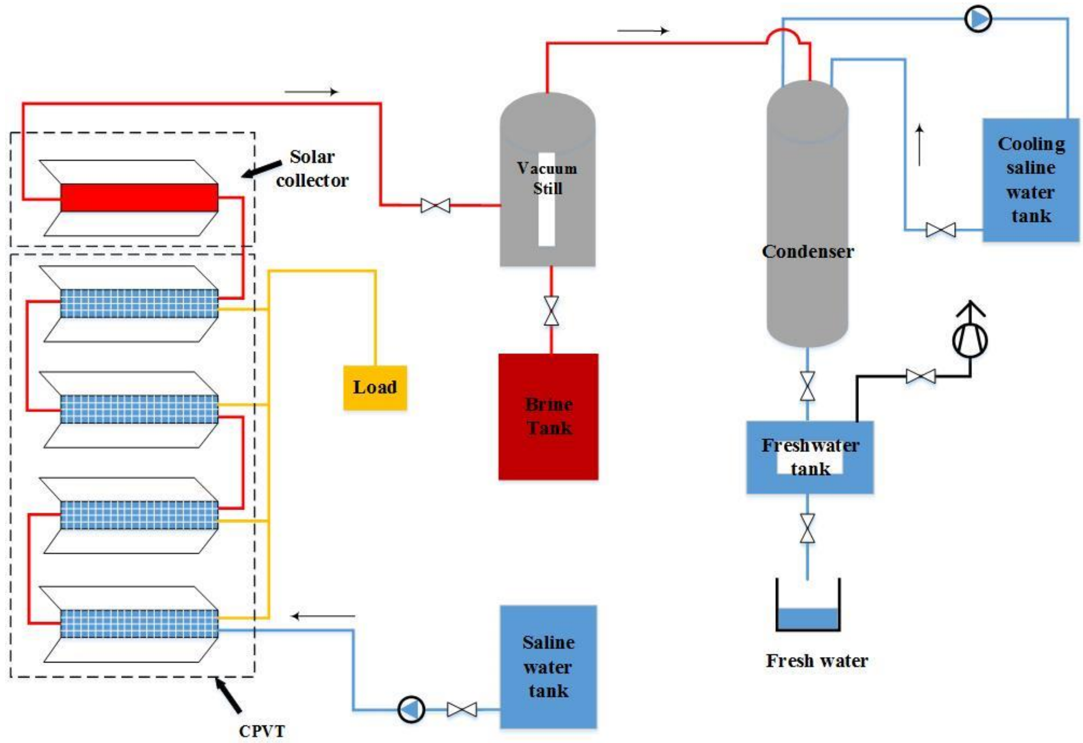

Figure 1. Schematic diagram of the VSICPVT system.

The CPVT module coupling PVT with compound parabolic concentrator (CPC) concentrates solar lights on the photovoltaic (PV) panel located at the bottom of the CPC so that the PV cells generate electric power and partial heat coming from the PV cells is absorbed by saline water for preheating. Then the preheated saline water is further heated to a desirable temperature by flowing through the solar collector before entering the vacuum still. When the heated saline water flows into the vacuum still, since the temperature of the inlet saline water higher than the saturation temperature at the experimental vacuum pressure (15 kPa), partial water in the vacuum still vaporizes rapidly, transforming from liquid to vapor. The generated vapor then enters into the condenser to be condensed to distillate. The cooling medium used in the condenser is cooling saline water. Eventually, the freshwater is collected by a fresh tank and its yield is measured by a measuring cup every half an hour. Meanwhile, the generated electricity from the system is used for the load (light and storage battery).

3. Analysis and discuss of experiment results

The experiment was carried out on May 24, 2017 at a building roof in NCEPU, Beijing, China (N38°52′32.75″, E115°29′56.14″), and the flow rate in the LCPVT module and the flash pressure in the vacuum still were stable at 120 L/h and 15 kPa, respectively.

The solar radiation intensity, ambient temperature, inlet saline water temperatures of CPVT module and vacuum still, were measured every half hour that day and were depicted in figure 2. As presented in figure 2, the solar radiation intensity initially ascends, reaches the maximum 969.85 W/m^2 at 11:00, and then declines to the minimum 270.86 W/m^2 at 16:00. The variation trend of the radiation intensity dramatically decreases at 14:00 and 15:00 due to cloudy weather. Both ambient temperature and inlet saline water temperature of the CPVT module increase slightly. The inlet saline water temperature of the CPVT module is less sensitive to the ambient factors due to keeping basically stable but a little increases from 15:30 to 17:00 with the maximum 40.8°C occurring at 17:00. Meanwhile, the inlet saline water temperature of the vacuum still shows the similar variation trends as that of the solar radiation intensity after 16:00. Therefore, the probable reason for the inlet water temperature increment is that the pipe for feedwater was right exposed to the sun after 16:00 due to its location at the east corner of the fence on the roof, while the pipe was shadowed by the fence at the rest of the time.

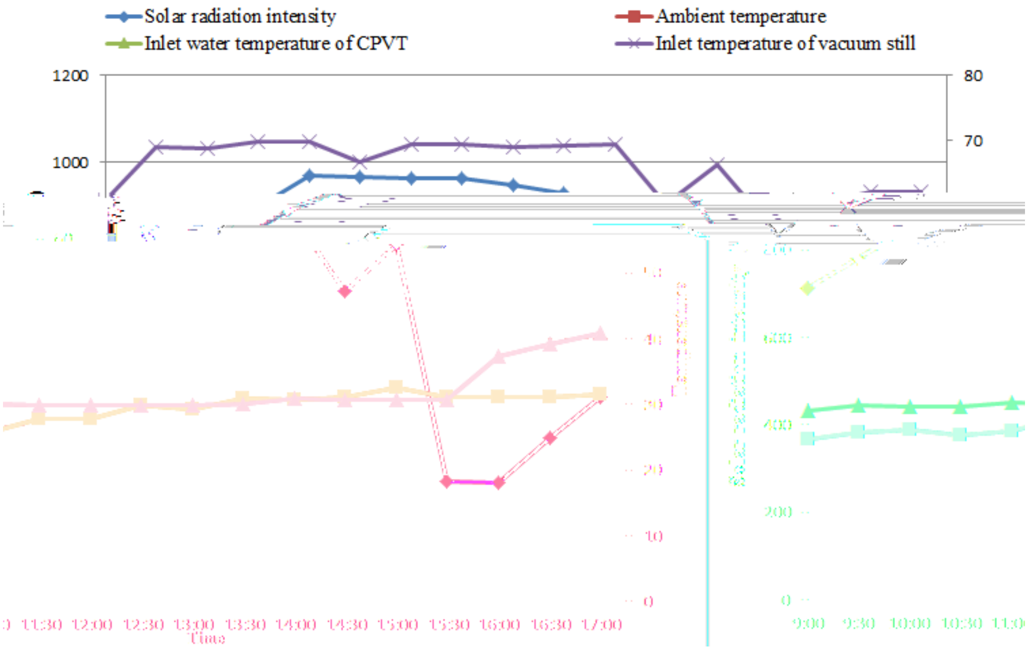

Figure 2. Variations of the solar radiation intensity, ambient temperature, inlet saline water temperatures of the CPVT module and vacuum still with time.

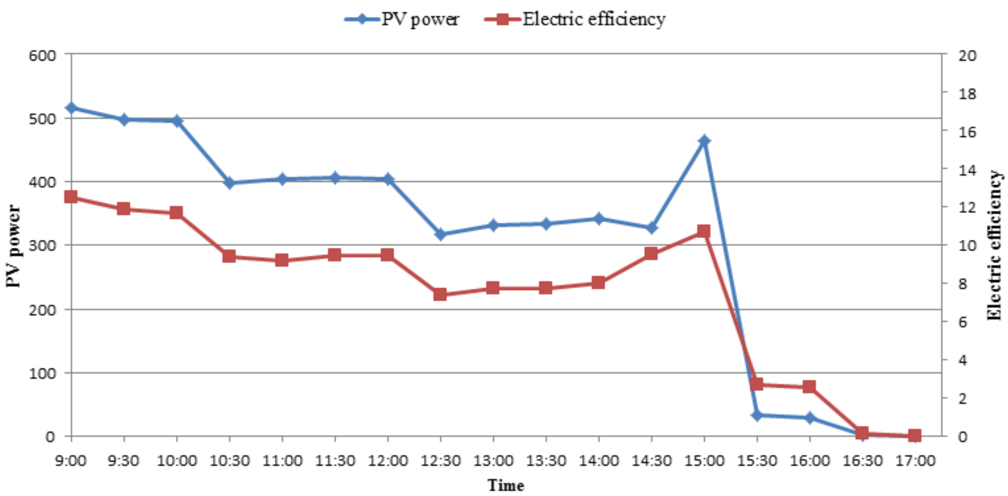

Figure 3. Variations of the electric efficiency and PV power with time.

Figure 3 indicates that the PV power and electric efficiency have the alike variation trend, achieving the maximum 516.3 W and 12.5%, respectively. Both the PV power and electric efficiency go down as the solar radiation intensity reduces from 15:00 to 15:30. The reason of it is that when the solar radiation intensity is low, the PV panel cannot receive enough photon energy to drive electrons move, hence the generated current is small. It is notable that the when the solar radiation intensity reaches the maximum at 11:00, neither of the maximum electric efficiency and power occurs at 11:00. It may be because that not only the solar radiation intensity plays a role on the performance of the PV cell, but the temperature of the PV panel has influences on it since increasing PV panel temperature leads to its electric efficiency decreased.

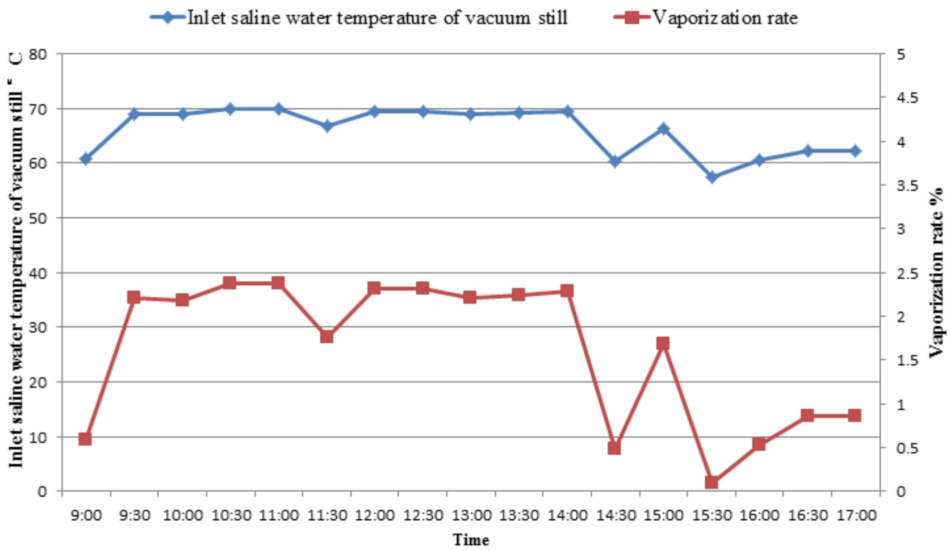

Figure 4. Variations of the vaporization rate and inlet saline water temperature of the vacuum still with time.

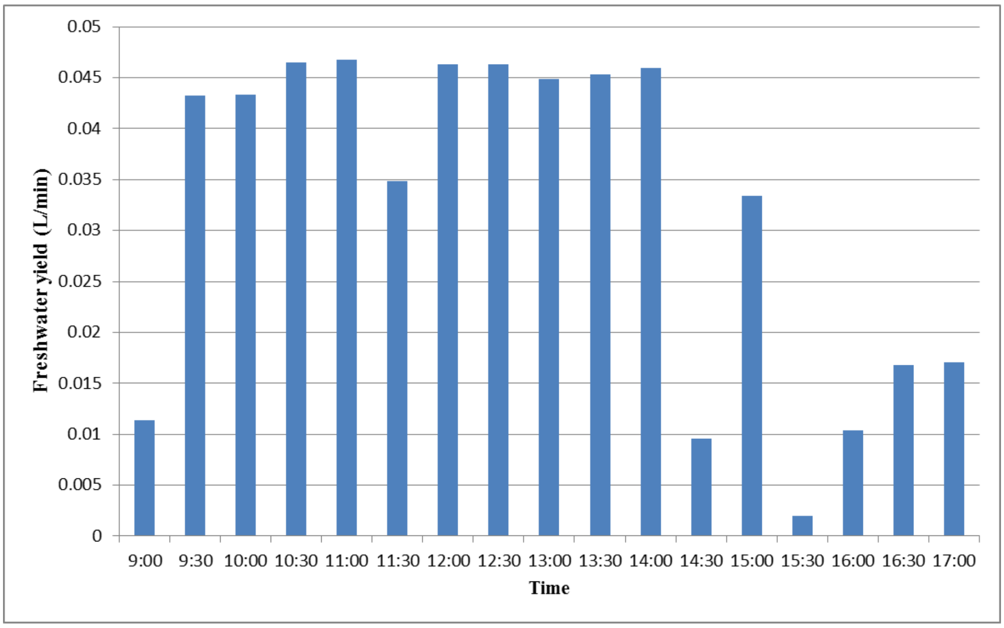

Figure 5. Data summary of freshwater yield rate every half hour.

Figure 4 demonstrates that the variations of the vaporization rate and inlet saline water temperature of the vacuum still with time. As illustrated in figure 4, the curve of the vaporization rate presents the same variation trend as that of the inlet saline water temperature of the vacuum still, obtaining the highest 2.38 % at 11:00 with the inlet saline water of the vacuum still at 69.83°C. Since based on figure 2, the inlet saline water of the vacuum is mainly affected by the solar radiation intensity, thus the greater the solar radiation intensity, the higher the vaporization rate. Figure 5 illustrates the freshwater yield rate recorded every half hour at the flow rate with constant of 120 L/h. It shows the same variation trend as the vaporization rate. The highest freshwater yield rate is 0.047 L/min, and daily average is 0.032 L/min. The daily freshwater yield was 15.36 L in the experiment.

4. Conclusions

Relying on the data measured in the experiments of the VSICPVT system, the freshwater yield and vaporization rate are significantly influenced by the solar radiation intensity, and they have the similar variation trend as the solar radiation intensity. Namely, the greater the solar radiation intensity is, the higher the vaporization rate and freshwater yield are. The highest freshwater yield rate is 0.047 L/min, the daily average is 0.032 L/min, and the daily freshwater yield was 15.36 L in the experiment. Besides, the electric efficiency and power show the same changing trend, reaches the maximum 516.3 W and 12.5%, respectively. Both of them are affected by solar radiation intensity and temperature of the PV panel, increasing temperature of the PV panel can still lead to the electric efficiency declined, though with great solar radiation intensity on the PV panel.

Acknowledgments

This work is financially supported by National Key R & D Program of China (2018YFB0604302), Beijing Municipal Science and Technology Project (Z151100003515002), and Key Research and Development Program of Hebei Province (18214318D).

References

[1] Zhang H, Chen H P, Han Y C, Liu H W and Li M J 2017 Experimental and simulation studies on a novel compound parabolic concentrator *Renew. Energy* **113** 784-94

[2] Zhang H, Li M J, Chen H P and Ye C T 2017 Experimental study of constant temperature operation and constant flow operation in concentrating PV/T system *8th Int. Conf. on Applied Energy* (Beijing 2016) vol 105 (Energy Procedia) ed Yan J *et al* pp 869-74

[3] Chemisana D, Rosell J I, Riverola A and Lamnatou C 2016 Experimental performance of a Fresnel-transmission PVT concentrator for building-facade integration *Renew. Energy* **85** 564-72

[4] Calise F, Figaj R D and Vanoli L 2017 Experimental and numerical analyses of a flat plate photovoltaic/thermal solar collector *Energies* **10** 4914

[5] Modrek M and Al-Alili A 2017 Thermal and electrical performance of a flat plate photovoltaic/thermal collector *Proc. of the ASME 11th Int. Conf. on Energy Sustainability* (Charlotte, North Carolina, USA, June 26–30, 2017) Paper No. ES2017-3462 pp V001T12A003

[6] Chen H P, Zhang H, Li M J, Liu H W and Huang J G 2018 Experimental investigation of a novel LCPV/T system with micro-channel heat pipe array *Renew. Energy* **115** 773-82

[7] Singh D B 2018 Improving the performance of single slope solar still by including N identical PVT collectors *Appl. Therm. Eng.* **131** 167-79

[8] Altarawneh I, Rawadieh S, Batiha M, Mkhadmeh L, Alrowwad S and Tarawneh M 2017 Experimental and numerical performance analysis and optimization of single slope, double slope and pyramidal shaped solar stills *Desalination* **423** 124-34

[9] Sivakumar V and Sundaram E G 2016 Experimental studies on quality of desalinated water derived from single slope passive solar still *Desalin Water Treat* **57** 27458-68

[10] Ong C L, Escher W, Paredes S, Khalil A S G and Michel B 2012 A novel concept of energy reuse from high concentration photovoltaic thermal (HCPVT) system for desalination

Desalination **295** 70-81
[11] Srithar K, Rajaseenivasan T, Karthik N, Periyannan M and Gowtham M 2016 Stand alone triple basin solar desalination system with cover cooling and parabolic dish concentrator *Renew. Energy* **90** 157-65
[12] Kumar B P, Winston D P, Pounraj P, Manokar A M, Sathyamurthy R and Kabeel A E 2018 Experimental investigation on hybrid PV/T active solar still with effective heating and cover cooling method *Desalination* **435** 140-51
[13] Gude V G and Nirmalakhandan N 2008 Desalination using low-grade heat sources *J. Energ. Eng.* **134** 95-101
[14] Abutayeh M and Goswami D Y 2010 Passive vacuum solar flash desalination *Aiche J.* **56** 1196-203