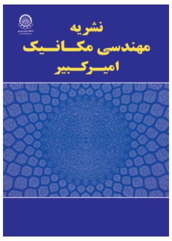

Amirkabir Journal of Mechanical Engineering

Amirkabir Journal of Mechanical Engineering, 49(3) (2017) 231-234
DOI: 10.22060/mej.2016.765

Performance Assessment of a Humidification-Dehumidification Desalination Unit Connected to Photovoltaic Thermal Collectors

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ABSTRACT: Present paper has investigated the performance assessment of a humidification-dehumidification (HDH) desalination system connected to photovoltaic thermal (PV/T) collectors. The main components of the system include humidification, dehumidification and PV/T collectors. Problem governing equations are obtained by writing the energy balance for the system various components and solved numerically. The simulation results of the present study are in fair agreement with the experimental data of previous literatures. Paper results show that at least three PV/T collectors with total area 2.3 m2 is needed to supply the minimum solar energy for the startup of system. Also, there is a desired mass flow rate for brackish water and air which maximize the system energy efficiency. The desired values of mass flow rate of brackish water and air and the maximum energy efficiency are 0.025 kg/s, 0.03 kg/s and 65%, respectively. Furthermore, the increase of PV/T collectors number increases freshwater productivity and output electrical power and decreases the energy efficiency due to the increase of consumed pumping power. Due to the negative influence of the temperature increase of inlet brackish water on the performance of dehumidifier and PV/T collectors, it causes the decrease of freshwater productivity, electrical power and energy efficiency.

Review History:

Received: 10 December 2015
Revised: 26 August 2016
Accepted: 4 September 2016
Available Online: 5 September 2016

Keywords:

Fresh water
Humidification
Dehumidification
Solar collector
Photovoltaic thermal

1- Introduction

Nowadays, requirement to drinking water is grown whereas the sources of potable water are limited and decreased. Only one percent of potable water sources is available for human kind [1]. Production of potable water in universe appropriates the remarkable amount of fossil fuels consumption, annually. Solar stills are the simplest and cheapest desalination technology. However, their efficiency is very low. Humidification-dehumidification (HDH) systems in small and medium scale can be used for the production of potable water in domestic applications [2]. The input thermal energy to HDH systems can be supplied from solar energy by photovoltaic/thermal (PV/T) collectors. Also, PV/T collectors provide the needed electrical power to establish brackish water and humid air flow in HDH system. Many theoretical and experimental researches have been carried out on the performance evaluation of HDH systems and PV/T collectors in the past 30 years [1-5]. However, in the previous literatures [1-5] the performance assessment of a HDH desalination unit connected to PV/T collectors has not been investigated. The present study is based on numerical simulation. First, governing equations on mass and heat transfer of hybrid HDH system are introduced. Then the validation of numerical simulation is carried out. Finally, parametric studies are done.

2- Governing Equations of Problem

Fig. 1 shows the general control volume of HDH system connected to PV/T collectors. The problem assumptions include steady state flow, fully developed flow, logarithmic average temperature in HDH, and etc. The proof of governing equations are not mentioned to have brief note [3-5].

Mass and heat transfer equations on dehumidifier [4,5]:

$$\dot{m}_{w}C_{p,w}(T_2-T_1)+0.5U_{loss}A_{unit}[0.5(T_5+T_6)-T_a]=\dot{m}_a(fh_6-h_5) \quad (1)$$

$$\dot{m}_{w}C_{p,w}(T_2-T_1)=\frac{eU_{cond}A_{cond}[(T_6-T_2)-(T_5-T_1)]}{\ln\left(\dfrac{T_6-T_2}{T_5-T_1}\right)} \quad (2)$$

Mass and heat transfer equations on humidifier [4,5]:

$$\dot{m}_{w}C_{p,w}(T_3-T_4)-0.5U_{loss}A_{unit}[0.5(T_5+T_6)-T_a]=\dot{m}_a(fh_6-h_5) \quad (3)$$

$$\dot{m}_a(fh_6-h_5)=\frac{eKaV\ [(h_3-fh_6)-(h_4-h_5)]}{\ln\left(\dfrac{h_3-fh_6}{h_4-h_5}\right)} \quad (4)$$

Thermal energy balance on the general control volume of HDH system [4,5]:

$$Q_u=U_{loss}A_{unit}[0.5(T_5+T_6)-T_a]+\dot{m}_wC_{p,w}(T_4-T_1) \quad (5)$$

The coefficient KaV for force convection mode is defined as follows [4,5]:

$$KaV=\dot{m}_w\left[0.53-0.22\log\left(\frac{\dot{m}_w}{\dot{m}_a}\right)\right],\quad 0.1\le\dot{m}_w/\dot{m}_a\le 2 \quad (6)$$

Enthalpy and relative humidity of humid air are given as follows [4,5]:

$$h=0.00585T^3-0.497T^2+19.87T-207.61 \quad (7)$$

$$\omega=2.19\times10^{-6}T^3-1.85\times10^{-4}T^2+7.06\times10^{-3}T-0.077 \quad (8)$$

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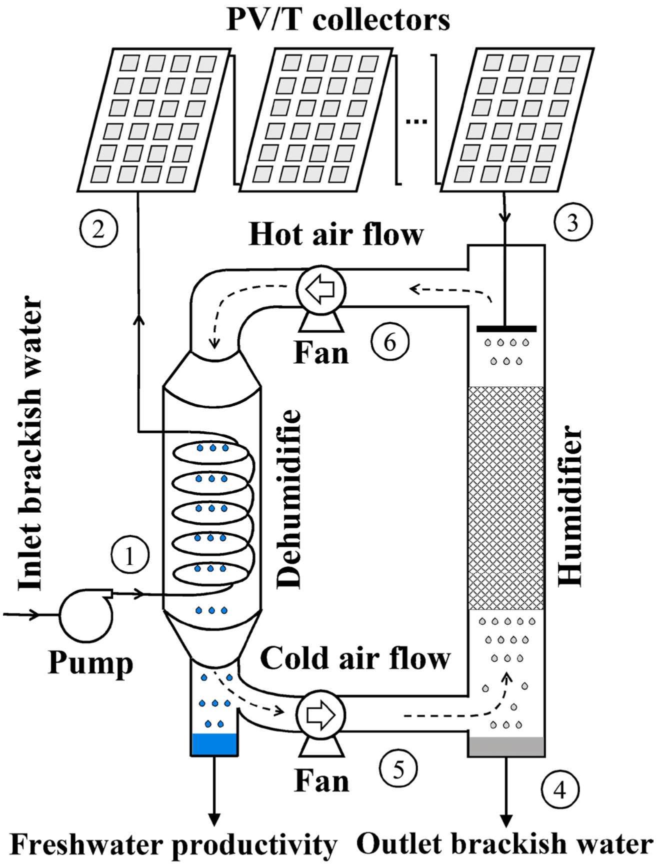

Figure 1. Schematic view of HDH system connected to PV/T collectors

The mass flow of fresh water and evaporative heat transfer rate are given as follows [4,5]:

$$\dot{m}_{\mathrm{d}} = \dot{m}_{\mathrm{a}}(\omega_6 - \omega_5) \tag{9}$$

$$q_{\mathrm{evp}} = \dot{m}_{\mathrm{d}} h_{\mathrm{fg}} \tag{10}$$

The useful absorbed heat transfer rate by PV/T collectors is given as follows [3]:

$$Q_{\mathrm{u}} = \sum_{\mathrm{i=1}}^{\mathrm{N}} q_{\mathrm{u,i}} = \mathrm{N} F_{\mathrm{R}} A_{\mathrm{c}}[h_{\mathrm{p1}} h_{\mathrm{p2}} (\alpha\tau)_{\mathrm{eff}} G - U_{\mathrm{L}}(T_2 - T_{\mathrm{a}})] - \frac{F_R A_{\mathrm{c}} U_{\mathrm{L}}}{\dot{m}_{\mathrm{w}} C_{\mathrm{p,w}}} \sum_{\mathrm{i=1}}^{\mathrm{N}} (\mathrm{N-i}) q_{\mathrm{u,i}} \tag{11}$$

The output electrical power of PV/T collectors and the consumed electrical power of pump and fan are given as follows [3]:

$$q_{el} = \eta_{el,ref} G N A_c [1 - 0.0045(T_c - T_{a,ref})] \tag{12}$$

$$q_{\mathrm{p}} = \dot{m}_{\mathrm{w}} \Delta P_{\mathrm{w}} / (\rho_{\mathrm{w}} \eta_{\mathrm{p}}) \tag{13}$$

$$q_{\mathrm{f}} = \dot{m}_{\mathrm{a}} \Delta P_{\mathrm{a}} / (\rho_{\mathrm{a}} \eta_{\mathrm{f}}) \tag{14}$$

The energy efficiency of hybrid HDH system is defined as the ratio of net (desired) output energy rate to net input energy rate.

$$\eta_{\mathrm{en}} = \frac{q_{\mathrm{desired}}}{q_{\mathrm{in,net}}} = \frac{\dot{m}_{\mathrm{a}}(\omega_6 - \omega_5) h_{\mathrm{fg}}}{G N A_{\mathrm{c}}} + \frac{\eta_{\mathrm{el,ref}}[1 - 0.0045(T_{\mathrm{c}} - T_{\mathrm{a,ref}})]}{C_{\mathrm{f}}} - \frac{\frac{\dot{m}_{\mathrm{w}} \Delta P_{\mathrm{w}}}{\rho_{\mathrm{w}} \eta_{\mathrm{p}}} + \frac{\dot{m}_{\mathrm{a}} \Delta P_{\mathrm{a}}}{\rho_{\mathrm{a}} \eta_{\mathrm{f}}}}{G N A_{\mathrm{c}} C_{\mathrm{f}}} \tag{15}$$

3- Validation

The validation of numerical simulation of HDH system in present study has been carried out with the experimental results of Hermosillo et al. [4]. Fig. 2 shows the comparison between the numerical results of present study and the experimental results of Hermosillo et al. [4] for HDH system.

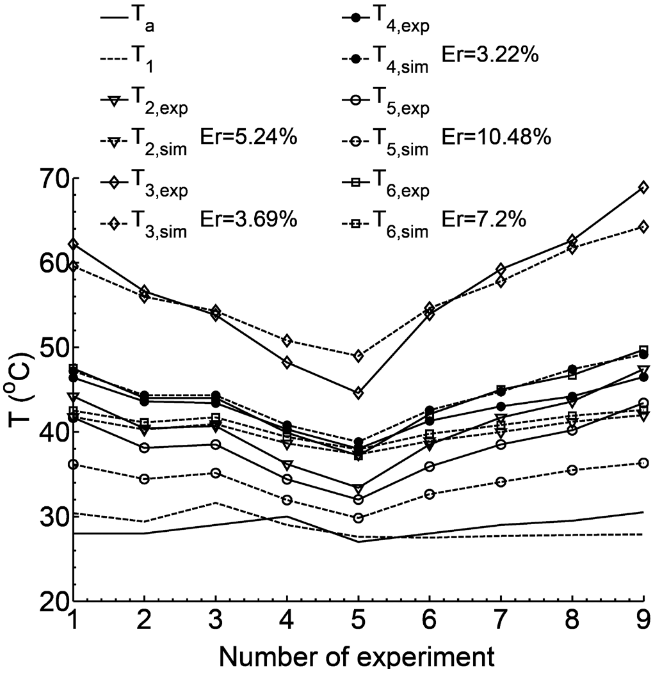

Figure 2. Comparison between the numerical results of present study and the experimental results of Hermosillo et al. [4] for HDH system

4- Results and Discussion

Fig. 3 shows the variations of energy efficiency with respect to brackish water mass flow rate and humid air mass flow rate. According to this figure, it is observed that there is one global maximum point for the energy efficiency. The coordinate of this point corresponds with the optimum value of brackish water mass flow rate and humid air mass flow. The calculated values of global maximum point are $\dot{m}_w$=0.025 kg/s, $\dot{m}_a$=0.03 kg/s and $\eta_{en,max}$=65%.

5- Conclusions

Main conclusions of the present study are as follows:

- The numerical simulation results of the present study are in fair agreement with the experimental measurements of Hermosillo et al. [4];
- It is observed that there is an optimum value for brackish water mass flow rate and humid air mass flow in HDH system which maximizes the energy efficiency of the system.

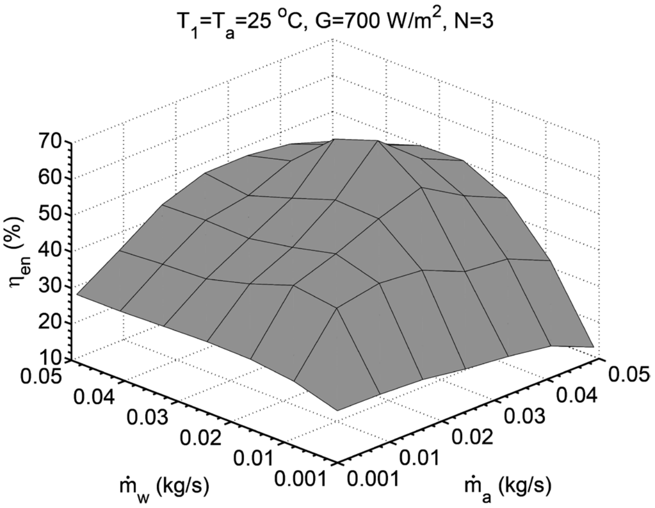

Figure 3. Variations of energy efficiency with respect to brackish water mass flow and humid air mass flow

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Please cite this article using:

M. A. Hosseini and F. Sarhaddi, “Performance Assessment of a Humidification-Dehumidification Desalination Unit Connected to Photovoltaic Thermal Collectors” *Amirkabir J. Mech. Eng.*, 49(3) (2017) 653-662.

DOI: 10.22060/mej.2016.765