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Impacts of Environmental Factors on the Performance of Photovoltaic-Thermal Panels with Wavy Channels

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Abstract. Cooling photovoltaic (PV) panels is essential for maintaining their electrical performance at optimal levels. Photovoltaic-thermal (PVT) technology, which is a hybrid system of PV cells and thermal loops, is widely used in which the PV panel can be cooled through the channel. In addition, wavy surfaces can improve heat transfer between the working fluid and the wall of the channel due to increasing turbulence intensity and improving the mixing of fluid flows. As a result, in this study, the impacts of the variation of solar heat flax and ambient temperature on the electrical efficiency and the thermal performance of a PVT applying wavy channels under certain wavelength and amplitude ratios and Reynolds number are investigated. The total efficiency of the PVT including a wavy channel has an increase of 14.8% with the increase in the surrounding temperature from 28 ºC to 38 ºC, while the power generation efficiency decreases from 10.5% to 10.3%. Results of numerical simulations demonstrated that both solar irradiation intensity and ambient temperature are highly impactful in the performance of the wavy channels in the cooling of the PVT cells and thus affecting their power generation and total efficiencies.

Keywords. PVT cells, wavy channel, power generation efficiency, thermal efficiency, cogeneration.

1. Introduction

Carbon dioxide pollution is the main reason behind climate change, and its magnitude reached globally above 36.8 Gt in 2022 [1]. In the power sector, CO_2 emissions had a

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decrease by 3.3% in 2020 using renewables in which Low-carbon technologies especially solar PV panels and wind turbines had a contribution of up to 20% [2]. The applications of PV systems range from building integrated systems and PVT systems to power stations, transport, and telecommunication. PV systems convert directly solar energy into electricity.

Increment of PV cell's temperature causes the increase in the circuit resistance and a decrease in power output. There are many techniques for cooling PV systems including active, passive, phase change material (PCM), and PCMs with additives cooling methods. In active cooling techniques, forced air flow, forced water flow, and PVT systems can be applied [3].

In PVTs, using nanofluids has received much attention in academia and many pieces of articles in this area could be found in the literature. Using nanofluids, the efficiency of the system increases due to their high thermal conductivity but has technical issues such as particle agglomeration, corrosion, etc. The electric efficiency of a PVT system picked up from 27.3% to 34.8% and 39.5% when Al2O3 and CuO were used in the cooling water of the system instead of pure water [4]. Researchers have also shown that the power and heat supply efficiencies of PVTs may be enhanced by about 3-5% and 20-30%, respectively, using PCMs. More importantly, their CapEx and payback period can decrease by about 15-20% and 6 years, respectively [5]. Applying flat heat pipes and PCM named RT21 in a PVT system decreased the payback period to 13.4 years which was 18 years in a conventional one [6]. The electrical efficiency of a PV system increased from 17.4% for a PV system to 19.8% for a PVT system using water as a cooling flow [7]. Although the results on the technical performance enhancement of PVTs using PCMs look promising, these have their own challenges such as supercooling and low thermal conductivity making them difficult to be effectively applied [8]. Bayrak et al. [9] examined the effects of the length, size, and arrangements of aluminum fins on PVTs, and showed a total energy efficiency of 8.7%, 9.5%, and 10.4% for the system without fins, with fins of 12 mm, and 7 mm, respectively. The PVT system using a staggered-vertical configuration of fins had more efficiency than that using a sequent-vertical configuration of those. Zhao et al. [10] used five and ten fins under the PV panel. The electrical efficiency increased from 15.7% to more than 16% when fins were applied on the backside of the PV panel. Chibani et al. [11] utilized both RT35HC PCM and metal fins made of graphite, Cu, TiO_2, and steel under the PV module. A decrease of 3 ^{o}C at the temperature of PV was obtained using graphite and Cu material compared to using TiO_2 and steel.

One of the conventional methods to increase heat transfer between working fluid and the wall in contact with it is applying wavy or corrugated surfaces which cannot only increase the contact area but also generate secondary flow and disturbance close to walls [12]. To investigate the impact of wavy channels on the rate of heat transfer in PVT cells, researchers conducted both numerical and experimental studies were conducted and observed thermal performance enhancement of the channel as the Reynolds number increased from 1386 to 4203 and the height of the channel decreased [13]. Rashidi et al. [14] used an SST $k-\omega$ model to conduct a numerical simulation on the impacts of wavy channels with wavelength (λ) and wave amplitude ratios (α) of 1-3 and 0.1-0.3, respectively. The Re number was in the range of 5,000 to 50,000. The entropy generation had its optimal level at Re=20,000. The effects of skewness angle

(0^o-50^o) and α (0.1H-0.3H) on the thermal performance of a wavy channel were analyzed numerically in Ref. [15], in which the maximum thermal performance factor was obtained at the skewness angle of 45 and α=0.1H. Dormohammadi et al. [16] found that in a wavy channel using Cu/water, the optimum α for a wavy channel with $\lambda = 1\ and\ 2$ was 0.2. To reach an optimum design of a wavy channel, α, phase shift, and number of waves were changed 0.2H-0.6H, φ =0^o-180^o, and N=5-15 by Nakhchi [17]. The best case was observed at α=0.54, φ =0^o, N=11, and the Re=2530.

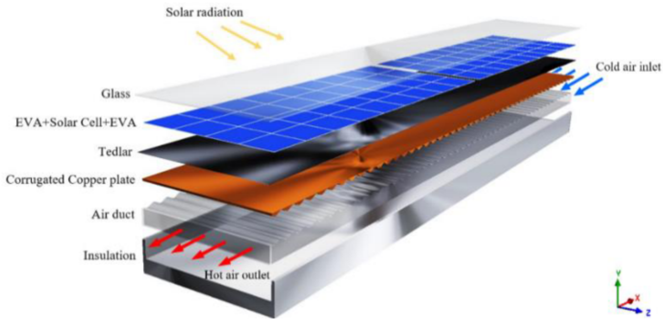
According to the literature, many studies have been carried out to reach an optimum design for wavy channels. In our previous study, the impacts of Re number (5,000-160,000), wavelength ratio (1, 2, and 3), and wave amplitude ratio (0.1, 0.2, and 0.3) on the electrical and thermal efficiencies of a PVT system including air as a working fluid in the channel were investigated. The maximum overall thermal efficiency reached at α=0.1, $\lambda = 1$, and Re=40,000. In this study, the impacts of environmental factors such as solar radiation and ambient temperature on the power and heat generation of PVT panels equipped with wavy channels as the cooling mechanism are examined.

2. Problem Formulation and Solution Method

2.1. PVT System and Problem Specification

PVT panels usually consist of PV cells, a Tedlar, two EVA layers, and a cover (usually made of glass) as shown in Fig. 1.

(a)



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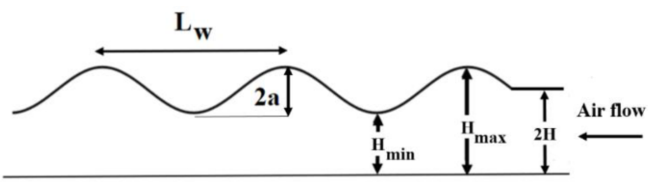


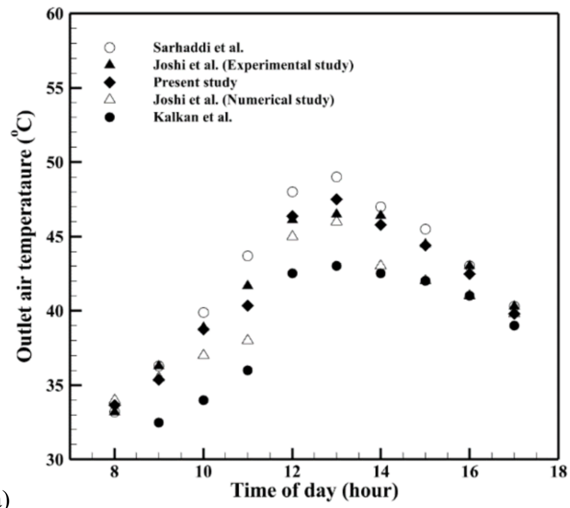
Figure 1. (a) The PVT systems including different layers, and (b) The wavy channel [18].

The impacts of solar radiation intensity and the surrounding temperature variations on the performance of a PVT system with wavy channels (characterized in our former study, Ref. [18]) are to be investigated numerically under a wavelength ratio of 1 and the amplitude ratio of 0.1.

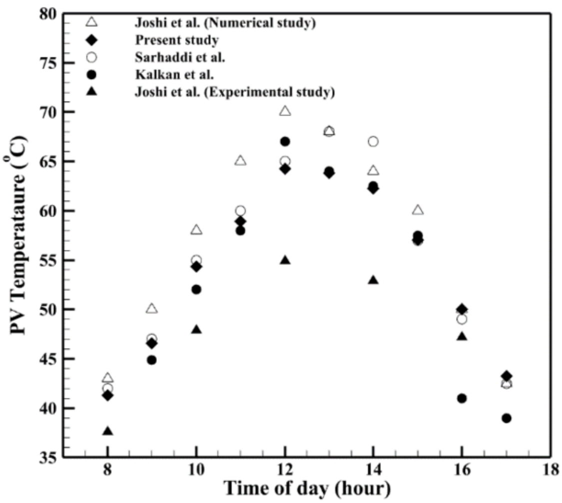
2.2. Numerical Results Validation

A numerical analysis is conducted using ANSYS CFX. The air flow is considered incompressible, and the properties of the material used in the structure of the PVT system are constant with the time and temperature variation. In addition, the SST k-ω turbulent model is applied to analyze the turbulent flow in the channel. The energy equation, momentum equation, convection, and radiation heat losses were presented in ref [18].

The results of this study for the PVT system including the plain channel were compared with those of Joshi et al. [19], Sarhaddi et al. [20], and Kalkan et al. [21]. There is good agreement with them as shown in Fig. 2.



(a)



(b)

Figure 2. (a) The outlet temperature, and (b) The temperature of the PV cells [18].

To validate the numerical results of this study for the PVT system applying a wavy channel, a comparison was made between the results of this simulation and those of Ahmed et al. [22]. A structural mesh was utilized which is shown in Fig. 3.

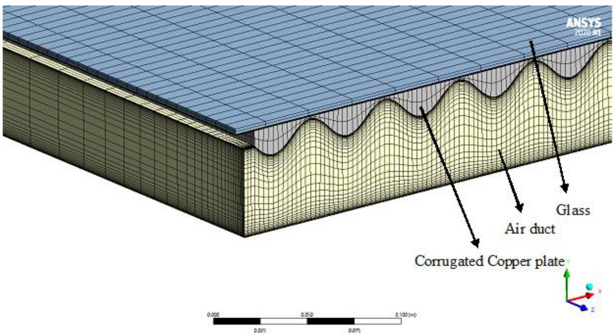


Figure 3. A structural mesh of the PVT system [18].

3. Results

In this study, the effects of solar irradiation intensity and surrounding temperature on the thermal performance of the PVT system including a plain channel and a wavy channel with a wavelength ratio of 1, an amplitude ratio of 0.1, and Re number of 40,000 are examined. The total (power+heat) efficiency can be calculated from [21]:

$$\eta_{overall} = \frac{P_{PV} + \dot{m}c_p\left(T_{out} - T_{in}\right)}{I_{solar}A_s + \dot{W}_{fan}} \tag{1}$$

The total generated power by the PV cells, P_{PV}, is given by [21]:

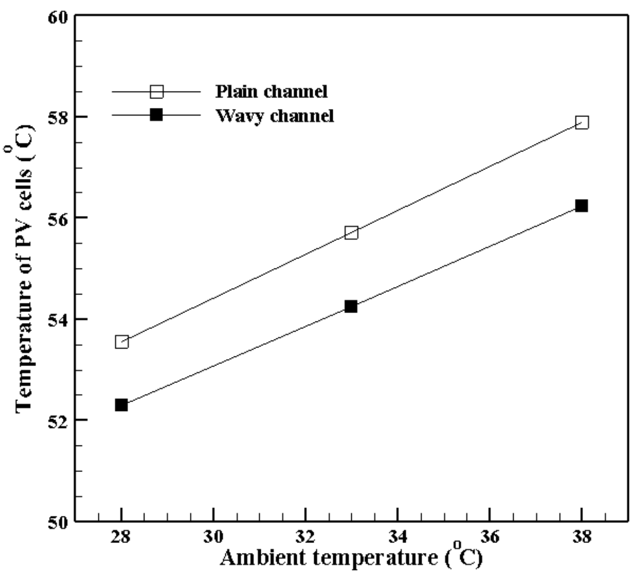
$$P_{PV} = P'''_{out} t_{PV} A_s \tag{2}$$

The fan power, $\dot{W}_{fan}$, is calculated from [21]:

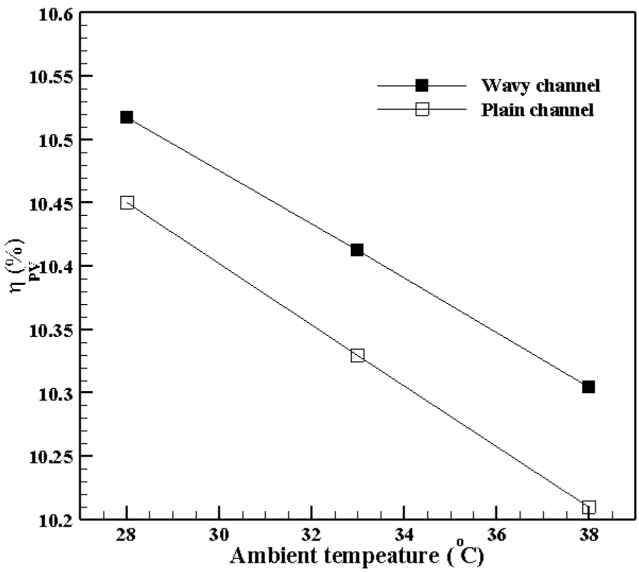
$$\dot{W}_{fan} = \left(\frac{\dot{m}}{\rho}\right)\Delta p \tag{3}$$

3.1. Surrounding Temperature's Impact

The increment in the surrounding temperature takes up the PV cells' temperature; as a result, the power production efficiency of the system drops (Fig. 4). The electrical efficiency decreased from 10.52% to 10.3% versus the ambient temperature. In addition, the PVT system including a wavy channel has more electrical efficiency compared to that including a plain channel due to increasing flow mixing and generating secondary flows.



(a)



(b)

Figure 4. (a) PV cell's temperature variation; and (b) PVT's total power production efficiency versus the surrounding temperature.

The PVT system's total (heat+power) efficiency increases from about 41% to about 56% with the growth of the surrounding temperature from 28 ºC to 38 ºC (see Fig. 5).

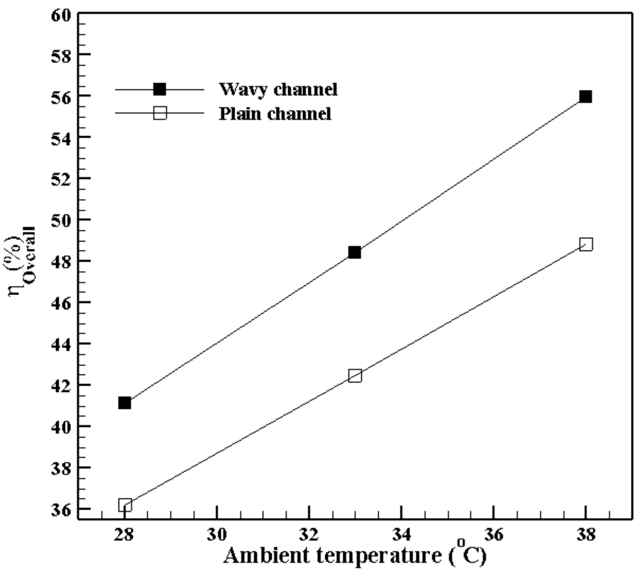
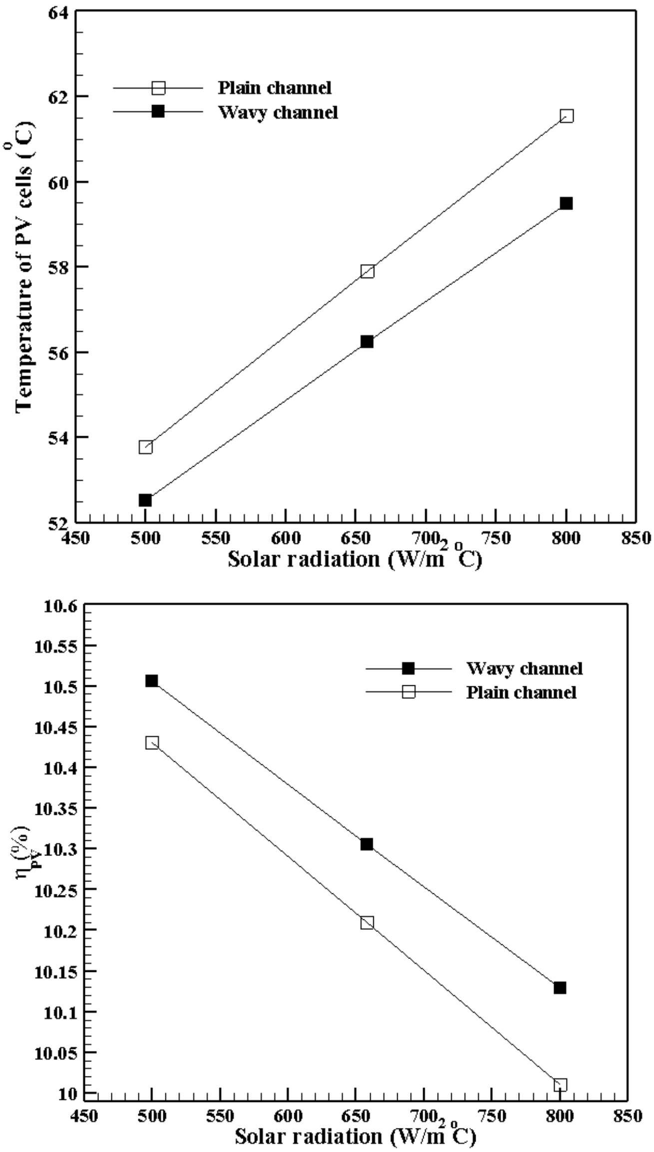


Figure 5. The variation of the overall efficiency of the PVT system with the ambient temperature.

3.2. Solar Irradiation Intensity's Impact

The higher intensity of solar radiation results in a higher temperature of PV cells; consequently, decreasing the power production capability of the system, but more heat could be collected from the panel.



(a)

(b)

Figure 6. (a) PV cell's temperature and (b) PVT system's power production efficiency variations versus solar irradiation intensity.

The PVT system's total (heat+power) efficiency when using wavy channels will go up by about 2.5% when the solar irradiation intensity picked up from 500 to 800 W/m2.ºC.

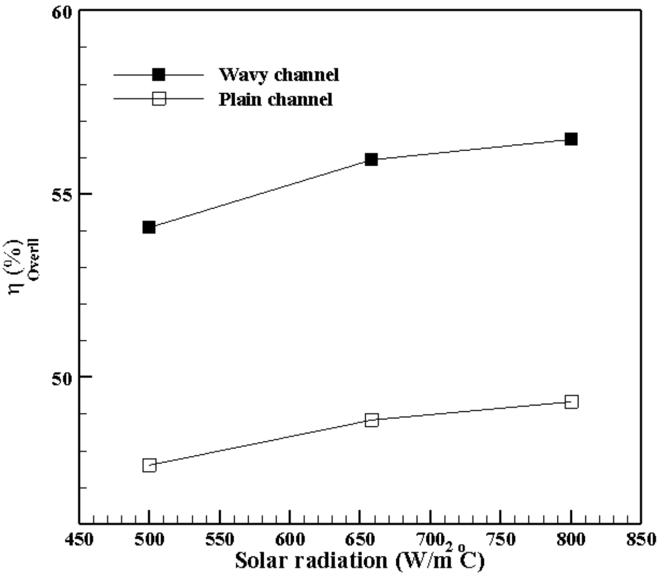


Figure 7. The variation of the overall efficiency of the PVT system with the solar radiation.

4. Conclusions

Wavy surfaces are widely used to increase heat transfer in the industry. In this research, the impacts of wavy channels as well as surrounding temperature and solar irradiation intensity on the power generation efficiency and total (power+heat) efficiency of a wavy channel-equipped PVT system using were numerically analyzed ANSYS CFX. The results depict that the variation of surrounding temperature has a stronger effect on the increase of the PVT system's performance, while solar irradiation intensity is more impactful on the electrical efficiency of the setup. The total (heat+power) efficiency of the PVT system using a wavy channel has an increase of about 2.5% and 14.8% when the solar irradiation is intensified from 500 to 800 W/m2.oC and the surrounding air get hotter from 28 oC to 38 oC, respectively. The electricity production efficiency of the system, however, as the more important parameter, has an opposite dependence on these parameters, decreasing by 3.6%% and 1.9%, under the abovementioned growth of solar energy and surrounding temperature. Therefore, for wavy channeled PVT panels, the colder the air is and the lower the solar irradiation intensity is, the better the performance will be.

Acknowledgment

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