Investigation of using hybrid nanofluid-phase change material spectral splitter in photovoltaic/thermal system

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ABSTRACT

The photovoltaic/thermal system is capable of generating both heat and electricity simultaneously. The purpose of using spectral filters is to make full use of the solar radiation spectrum and thermal separation of photovoltaic and thermal units. The purpose of this paper was to investigate a new hybrid spectral filter consisting of phase change material and nanofluid to achieve a filter close to the ideal spectral filter. In this regard, the photovoltaic/thermal system with a combined nanofluid-phase change material spectral filter was simulated using energy balance equations in MATLAB software and its performance was compared with two conventional and nanofluid-based spectral splitting photovoltaic/thermal systems from energy and exergy viewpoints. Also, the optical properties of nanofluid and phase change material were simulated and the models were validated with the experimental data available in the literature. The results showed that by using a combined filter the photovoltaic temperature can be reduced by up to 50% and the output fluid temperature can be increased by twice. The exergy efficiency of the system with the combined filter was about 14% and 22% higher than conventional and nanofluid-based spectral splitting photovoltaic/thermal systems, respectively. The system also achieved the highest exergy efficiency at concentration ratios greater than 15.

KEYWORDS

Phase Change Material, Nanofluid, Photovoltaic/Thermal System, Energy, Exergy.

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1. Introduction

Photovoltaic/thermal systems are a combination of solar collectors and photovoltaic technology which convert solar energy into both electricity and heat. One way to improve the performance of photovoltaic/thermal systems is to use spectral splitters. Spectral splitters divide the solar radiation spectrum into different bands and direct each spectral band to its appropriate receiver. Therefore, they thermally decouple the PV and thermal components, to enable them to operate separately at significantly different temperatures. Liquid absorption filters are a type of spectral splitters that can be used as both the spectral filter and heat transfer fluid [1]. The feasibility of using nanofluids as liquid absorptive filters is demonstrated in previous works [2].

Besides, there are studies in the literature that evidenced the capability of phase change materials to serve as spectral absorption filters. Manz et al. [3] measured the transmittance of Calcium Chloride Hexahydrate as a part of an external building wall. They found that their investigated phase change material transmits a significant portion of radiation in the visible and near-infrared spectrum at liquid state. Goia et al. [4] studied the optical properties of a paraffin-filled double glazed window. They showed that paraffin has a nearly constant transmittance in the visible band and selective behavior in the near-infrared spectrum. However, the use of phase change materials as spectral filters in photovoltaic/thermal systems has not been investigated so far.

In the present study, a numerical model is proposed for a concentrated photovoltaic/thermal with spectral splitting photovoltaic/thermal system with a novel optical filter composed of phase change material and nanofluid. The performance of the system is investigated from an energy and exergy viewpoints. In the proposed spectral filter, the nanofluid is used to absorb UV and visible radiation and the phase change material is used to absorb some part of the infrared spectrum.

2. Methodology

In the present work, three different configurations of concentrated photovoltaic/thermal system including conventional (A), nanofluid based spectral splitting (B) and nanofluid/phase change material based spectral splitting (C) photovoltaic/thermal systems, which are shown in Figure 1, are modeled through conducting the energy equation for components of the system and one-dimensional heat diffusion equation for phase change material. The explicit scheme of finite difference method is used to solve differential equations of system components and the simulation is done using MATLAB software.

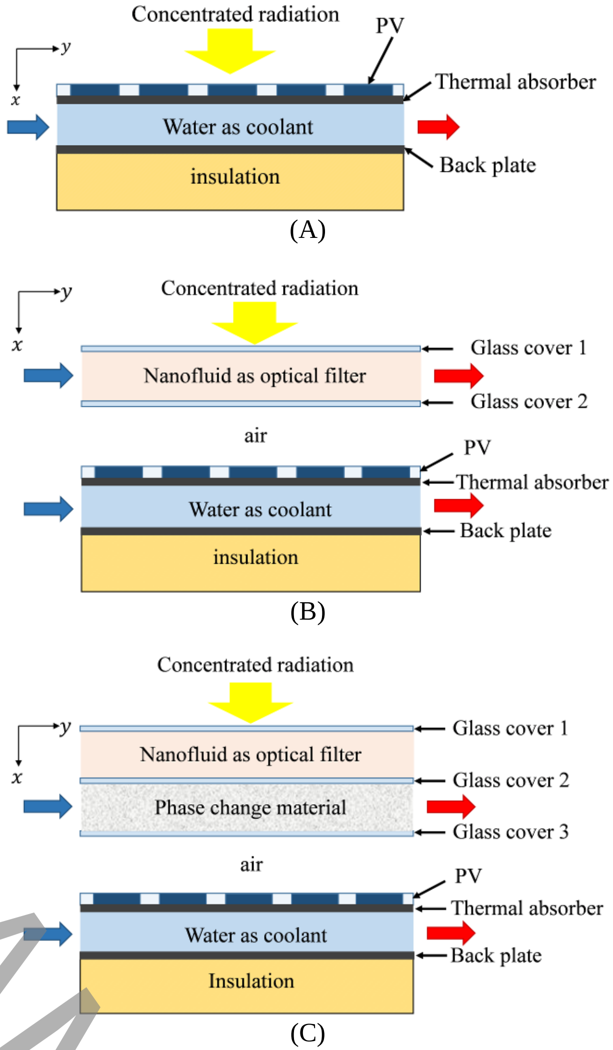

Figure 1. Concentrated photovoltaic/thermal system configurations.

In configuration (B), Ag/water nanofluid is used as a spectral filter, while a combination of Ag/water nanofluid and Calcium Chloride Hexahydrate ($CaCl_2.6H_2O$ or S27) phase change material is used as a spectral splitting unit in configuration (C). A concentration of 0.05 wt. % and nanoparticles diameter of 10 nm is considered for nanofluid. For simulating configurations (B) and (C), it is necessary to determine the optical properties of nanofluid and phase change material. Rayleigh scattering method has been used to calculate the transmittance of nanofluid. This method can be used when the particles are very small. Also, the absorptance and transmittance of the phase change material in solid and liquid states can be evaluated by using the refractive and extinction indices of the phase change material at different wavelengths.

3. Validation

The mathematical model was validated by comparing PV temperature, electrical efficiency and thermal efficiency of nanofluid based spectral splitting photovoltaic/thermal system has been compared with experimental data of Cui and Zhu [5]. Cui and Zhu [5] used a MgO/water nanofluid with 10 nm nanoparticle diameter, 0.02 wt. % concentration, 6 lit/h flow rate and 1 cm thickness as a spectral filter. During their experiment, the radiation, ambient temperature and wind velocity were 870 W/m^2, 15.5 °C and 0.5 m/s, respectively. Table 1 represents the comparison results which shows the accuracy of the present simulation.

Table 1. Comparison between numerical results of present study and the experimental results of Cui and Zhu [5].

Parameter	Present study	Cui and Zhu [5]	Difference (%)
PV temperature (°C)	27	27.3	1.1%
Temperature increase of nanofluid (%)	7.2	7.5	4
Electrical efficiency (%)	14.5	14.7	1.4
Thermal efficiency (%)	46.5	47.2	1.5

4. Results and Discussion

Figure 2 displays the transmittance of the nanofluid/phase change material spectral splitting unit. When the phase change material is liquid, the filter transmittance in the spectral window of photovoltaic cells is greater than 0.8 and outside this range, the transmittance is much lower. However, when the phase change material becomes solid, the transmittance decreases in the whole radiation spectrum.

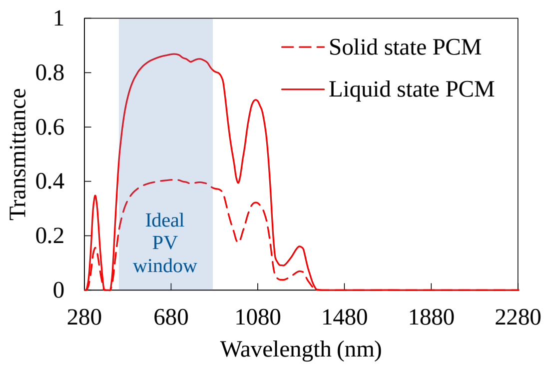

Figure 2. The transmittance of nanofluid/phase change material spectral splitting unit.

Figure 4 shows the effect of the concentration ratio on photovoltaic temperature, nanofluid outlet temperature, total energy efficiency and total exergy efficiency. By increasing the concentration ratio, the temperatures rise due to the increase in received radiation. The photovoltaic temperature of configuration (A) and nanofluid outlet temperature of configuration (C) are higher because the radiation directly hits the photovoltaic cells in configuration (A) while in configuration (C) it first passes through the spectral filter. According to Figure 4, configuration (C) can achieve up to 50% lower photovoltaic temperature and nanofluid outlet temperature can increased by twice compared to the configuration (A). The total energy efficiency of a configuration (A) is higher than configurations (B) and (C). While the exergy efficiency of configuration (C) is greater than configurations (A) and (B). As a result, it can be concluded that the photovoltaic/thermal system with a nanofluid/phase change material filter is a good option from an exergy viewpoint for concentration ratios greater than 15. At a concentration ratio of 30, photovoltaic temperatures of configuration (C) is reduced by about 47% compared to a conventional photovoltaic/thermal system and about 25% compared to a photovoltaic/thermal system with a nanofluid filter. The output temperature of the nanofluid in configuration (C) is about 75% higher than the configuration (B). The total energy efficiency of the configuration (C) is about 7 and 2% lower than configurations (A) and (B), respectively, whereas its total exergy efficiency is about 14 and 22% higher than configurations (A) and (B), respectively.

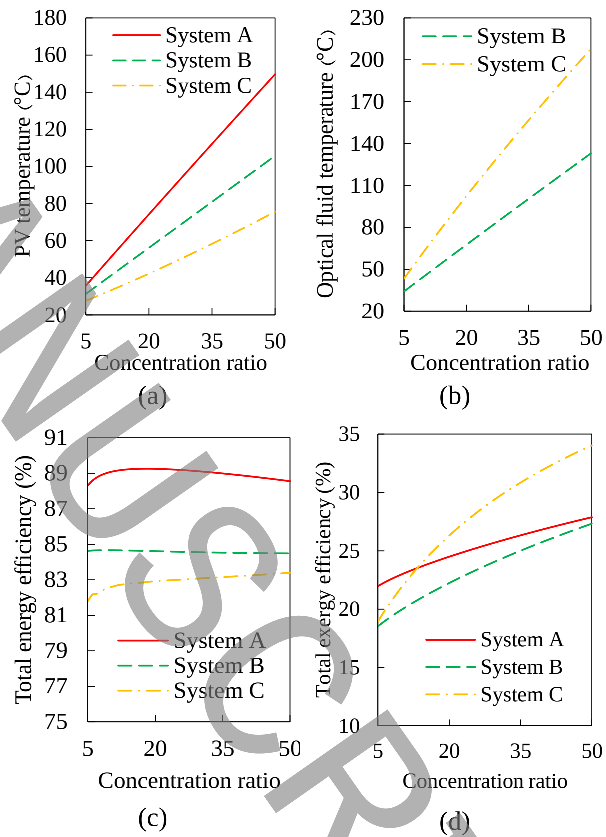

Figure 3. Variation of (a) photovoltaic temperature, (b) optical fluid temperature, (c) total energy efficiency and (d) total exergy efficiency for A, B and C configurations.

5. Conclusions

In this paper, a photovoltaic/thermal system with nanofluid/phase change material spectral unit along with conventional and nanofluid based spectral splitting photovoltaic/thermal systems were modeled and compared in terms of energy and exergy. Also, the optical properties of nanofluid and phase change material were simulated. According to the results of the present study, the following remarks were drawn:

- Nanofluid/phase change material spectral filter can be considered as an effective step to approach the ideal spectral filter.
- Photovoltaic/thermal system with nanofluid/phase change material spectral filter showed the lowest photovoltaic temperature and the highest output fluid temperature.
- From the energy viewpoint, the conventional photovoltaic/thermal system had the best performance, while from the exergy viewpoint, the system with the nanofluid/phase change material spectral filter was the best.
- Using a nanofluid/phase change material spectral filter in concentration ratios greater than 15 is recommended.
- Using a hybrid spectral filter instead of a nanofluid filter at a concentration ratio of 30 reduces the photovoltaic temperature by about 25%, increases the spectral filter temperature by about 75%, and increases the exergy efficiency by about 22 %.

6. References

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