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Nanoparticle Shape Effect on a Nanofluid-Based Parabolic Trough Concentrating Photovoltaic/Thermal System

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1- Introduction

The limited resources of fossil fuels and their pollutant emissions reveal the necessity of renewable energies. Solar energy is the most important renewable energy source, which shows the greatest potential for energy production among other renewable energies in Iran. Among solar technologies, photovoltaic/thermal (PV/T) systems are capable of producing electrical and thermal energy, simultaneously. In addition, concentrating photovoltaic/thermal (CPV/T) systems are a category of PV/T systems which are used to concentrate sunlight using Fresnel lenses, parabolic, compound parabolic and hyperbolic concentrators. The CPV/T systems are able to generate more electricity and higher quality of the thermal energy.

Recently, nanofluids have been introduced as one of the innovative ways to improve the efficiency of solar energy systems. The nanofluid is defined as the suspension of nanosized particles (less than 100 nm) in conventional fluids, which exhibits better heat transfer properties compared to the base fluids. However, there are few studies on the use of the nanofluid as a coolant in CPV/T systems.

Among the works that have been done so far, effects of using nanofluids with different nanoparticles' shapes on the performance of linear parabolic trough concentrating CPV/T system has not been evaluated, yet. Accordingly, the purpose of the current study is to investigate and compare the effect of using nanofluids with four nanoparticle shapes including platelet, cylindrical, blade and brick on the performance of this system from the first and second law of thermodynamics standpoint in both laminar and turbulent flow regimes. Furthermore, the study of the present base fluid in the CPV/T system has been done for the first time.

2- Mathematical modeling

The studied linear parabolic trough concentrating photovoltaic/thermal system to provide a mathematical model is shown in Fig. 1. In order to drive the energy equations for different components of this system, a differential element of length of dx and width of w was considered. The assumptions used to write the energy equations were steady and one-dimensional heat transfer, constant thermo-physical properties of all components of the system, and the neglecting the specific heat capacity of all components except the nanofluid inside the pipe.

In this research, the 4th-order Runge–Kutta method was used to solve energy balance equations. The base fluid was an ethylene glycol-water mixture with a ratio of 50:50, where aluminum oxide was employed as nanoparticles material.

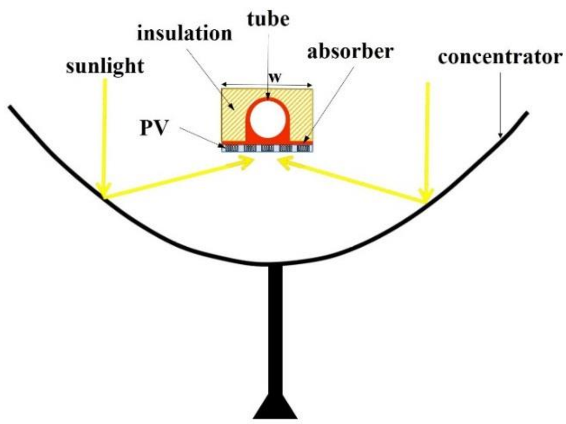

Fig. 1. Concentrating photovoltaic/thermal system.

3- Validation

The numerical model was validated using the available experimental data for a CPV/T system with an effective linear parabolic mirror aperture area of 1.95m^2, a concentration ratio of 16.92, photovoltaic/thermal receiver with 1.5m×0.12m×0.09m dimensions and pipe diameter of 0.03m. According to the comparison, there is a very good agreement between the results of the proposed model of the present study with the measured temperature reported by Ji et al.

4- Results and discussion

The results indicated that, due to increasing the volume fraction of nanoparticles, viscosity and thermal conductivity increase, but the thermal capacity decreases. The variations of viscosity and thermal conductivity with volume fraction lead to a reduction of the Nusselt number in both flow regimes. On the other hand, the heat transfer coefficient is proportional to the Nusselt number and the thermal conductivity. In the laminar flow, the superior effect of increasing thermal conductivity leads to heat transfer coefficient increase. While in the turbulent regime, a sharp decrease in the Nusselt number with a volume fraction reduces the heat transfer coefficient. Finally, the increase in the heat transfer coefficient in a laminar flow reduces the photovoltaic temperature, but the reduction of the heat transfer coefficient in the turbulent flow increases the photovoltaic temperature. The cylindrical nanoparticles and brick nanoparticle cause lower photovoltaic

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temperature in laminar and turbulent flow regimes, respectively.

The outlet temperature increases in both laminar and turbulent regimes owing to reduction of thermal capacity with increasing volume fraction. In a laminar flow, different nanoparticle shapes have an approximately equal outlet temperature. In the turbulent flow, blade and brick nanoparticles have a slightly higher outlet temperature because of their higher heat transfer coefficients.

Due to the reduction of photovoltaic temperature with increasing volume fraction in laminar flow, the electrical energy and exergy efficiency increase, but they decrease in the turbulent flow as the photovoltaic temperature increases in this flow regime. In the laminar flow, the thermal energy efficiency rises because of increasing the output temperature. But in a turbulent flow, reducing the thermal capacity reduces the thermal energy efficiency when the volume fraction increases. The thermal exergy efficiency is more affected by the outlet temperature and increases with increasing volume fraction in both flow regimes.

Increasing the electrical and thermal energy efficiency in laminar flow leads to an increase in total energy efficiency with volume fraction, while in turbulent regime the total energy efficiency decreases due to decrement of electrical and thermal energy efficiencies. The cylindrical nanoparticles in laminar flow and brick nanoparticles in turbulent flow have the highest energy efficiency.

The total exergy efficiency increases in the laminar flow as electrical and thermal exergy efficiencies increase. In the turbulent flow, total exergy efficiency of platelet, cylindrical, and blade shaped nanoparticles decrease because of decreasing the electrical exergy efficiency. But for the brick nanoparticles which has the highest electrical and thermal exergy output in the turbulent flow, the contrast between the effects of decreasing the electrical exergy efficiency and increasing the thermal exergy efficiency leads to exergy efficiency increases first and then decreases, as shown in Fig. 2.

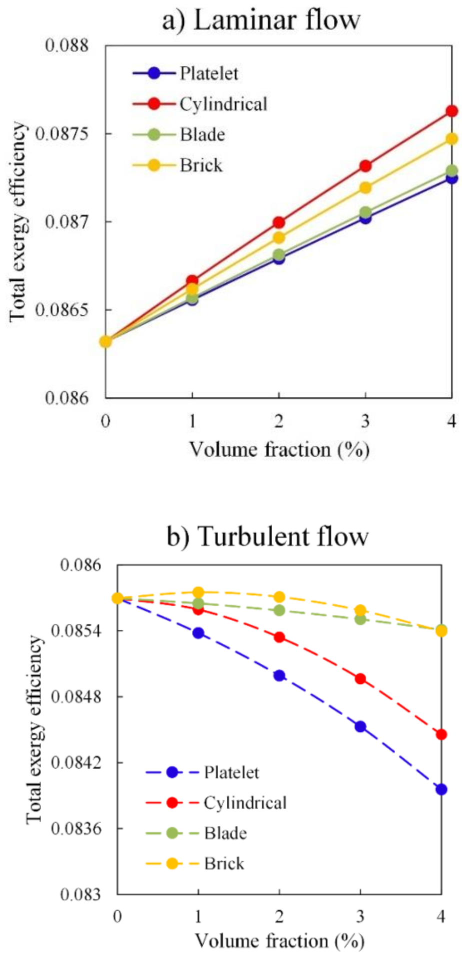

Fig.2. Variation of total exergy efficiency with volume fraction for different nanoparticle shapes in laminar and turbulent regimes.

5- Conclusion

In this research, a linear parabolic trough concentrating photovoltaic/thermal system was modeled. The effect of using Al_2O_3/ethylene glycol-water 50:50 on photovoltaic temperature, outlet temperature and energy and exergy efficiencies of the system were evaluated. Also, the effect of nanoparticle concentration was studied for various nanoparticles' shape of platelet, cylindrical, blade and brick. The summary of the results is as follows:

- As the volume fraction of nanoparticles increases, the photovoltaic temperature decreases in the laminar flow and increases in the turbulent flow, but the outlet temperature increases in both flow regimes.
- The lowest photovoltaic temperature in the laminar and turbulent flow regime was associated with the cylindrical nanoparticle and the brick-shaped nanoparticle, respectively.
- In the laminar flow, the shape of the aluminum oxide nanoparticles does not affect the outlet temperature. But in the turbulent flow, nanofluids containing blade and brick nanoparticles result in higher outlet temperature.
- The total energy efficiency increases in laminar flow and decreases in turbulent flow.
- The total exergy efficiency increases in the laminar flow, while in the turbulent flow, total exergy efficiency of platelet, cylindrical and blade nanoparticles decreases.
- The use of cylindrical nanoparticles in laminar flow and brick-shaped nanoparticles in turbulent flow lead to highest total energy and exergy efficiencies.