Journal of Solid and Fluid Mechanics (JSFM), 13(3): 1-4, 2023

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/JSFM.2023.12245.3643

Manufacturing Engineering of Iran

Numerical simulation of heat transfer in a parabolic solar collector absorber tube using two-phase method

Saman Khosravi[1], **Marzieh Rezazadeh** [2]

[1] MSc, Mechanical Engineering Group, Golpayegan College of Engineering, Golpayegan, Isfahan University of Technology, Iran
[2] Assist. Prof., Mechanical Engineering Group, Golpayegan College of Engineering, Isfahan University of Technology, Golpayegan, Iran
*Corresponding author: m.rezazade@iut.ac.ir

Received: 09/03/2022 Revised: 06/03/2023 Accepted: 07/31/2023

Abstract

A parabolic solar collector uses highly reflective materials to collect and concentrate the heat energy from solar radiation. The thermal efficiency of the solar collectors increases by using nanofluid. It is necessary to consider some thermal properties of nanofluid and operating parameters to achieve maximum efficiency. This article presents the heat transfer of a nanofluid in the absorber tube of a parabolic collector under non-uniform radial heat flux. Two types of nanofluids were utilized and prepared TiO2/Syltherm 800 and Al2O3/water with 1.0%, 2.0%, 3.0%, and 4.0% volume fractions are used as working fluids for Reynolds number 10,000, 20000, and 30,000. The results represented that the maximum increase in Nusselt number of TiO2/Syltherm 800 and Al2O3/water compared to their base fluid is 66% and 57%, respectively. The maximum increase in Nusselt number corresponds to TiO_2/Siltherm 800 nanofluid at Reynolds 10000 and concentration of 4%. In this case, the Performance evaluation criterion, PEC, is 2.93. For both nanofluids, PEC increases with increasing concentration. With increasing Reynolds number, PEC decreases for TiO2-Siltherm 800 and increases for Al2O3-water nanofluid.

Keywords: Parabolic collector; Heat transfer; Nanofluid; Two-phase, Non-uniform heat flux

1. Introduction

The solar collector is a heat exchanger that takes the solar radiant energy and converts it to useful thermal energy in the heat transfer fluid that circulates through the solar field. The solar collector must have a high thermal conductivity coefficient, high absorption coefficient, and low emission coefficient and be stable at high temperatures. By using nanofluids in solar collectors, the thermal efficiency of the collector can be increased. A nanofluid is a suspension of nanoscale particles in a base fluid. It is observed that the amount of heat transfer increased by using nanofluid. Thermal properties of nanofluids such as thermal conductivity, specific heat capacity, and viscosity play an essential role in the thermal performance of nanofluids. The thermal performance of collectors depends on the temperature, environmental conditions, working fluid, particle size, and volume concentration of particles. Computational fluid dynamics can be used for the heat transfer characteristics including thermal and flow attributes of nanofluids flow in a parabolic solar collector tube. Several studies were carried out to investigate the effect of nanofluids on the thermal efficiency of the parabolic collector.

Belus and Tzivandis [1], optimize and evaluate a solar-driven trigeneration system that operates with nanofluid-based parabolic trough collectors (PTC). They used Al_2O_3 and TiO_2 nanoparticles in Siltherm-800 and concluded that nanofluids lead to higher thermal efficiency. They also found that the maximum increase in thermal efficiency for aluminum Al_2O_3 and TiO_2 nanoparticles is 1.91 and 1.17, respectively. Ghasemi and Ranjbar [2] simulated forced convection heat transfer of nanofluid flow inside the absorber tube of a solar parabolic trough collector. They considered steady turbulent flow using the SIMPLE algorithm. The results showed that using nanofluid leads to enhanced heat transfer performance. Furthermore, the results reveal that by increasing the nanoparticle volume fraction, the average Nusselt number increases.

Abed et al. [3] investigated numerically the effect of non-metallic nanoparticles on heat transfer inside the collector tube with non-uniform heat flux in the range of Reynolds number between 10^4 and 10^5 and with volume fraction of 2%, 4%, and 6%. Numerical simulations were performed for a solar collector to test the effectiveness of six non-metallic nanoparticles, namely aluminum oxide (Al_2O_3), cerium oxide (CeO_2), copper oxide (CuO), iron oxide (Fe_2O_3), titanium dioxide (TiO_2) and silicon dioxide (SiO_2) in three basic fluids, therminol VP-1, water, and molten salt. The results showed that SiO_2, however, is the most efficient nanoparticle regardless of the choice of the base working fluid for all the tested volume fractions. Furthermore, for typical operating conditions for SiO2 with a volume fraction of 6% in the water base fluid, the average Nusselt number, thermal efficiency, and PEC increase, respectively, by 32.4%, 5.11%, and 1.313.

Hong et.al [4] numerically studied the thermal and flow characteristics of a parabolic solar collector. The turbulent flow inside the absorber tube was modeled via the finite volume method, while a non-uniform concentrated heat flux was imposed on the absorber tube. The results represented that increasing the Cu nanoparticle concentration causes an increase in the Nusselt number. Furthermore, the effect of Cu nanoparticles on the heat transfer enhancement became more significant as the Reynolds number decreased. Farooq et.al [5] used CFD analysis to analyze the effect of multiple working fluids on the efficiency of PTC. Two different types of nanofluids used for analyzing the thermal efficiency of PTC through numerical simulations, are Alumina and Copper-oxide nanofluids with a concentration of 1%. Two different mass flow rates i.e., 0.0112 Kg/s and 0.0224 Kg/s considered. The highest efficiency is 13.01 and 13.1% using Al_2O_3 as nanofluids at 0.0112 Kg/s and 0.0224 Kg/s flow rates, while CuO has an efficiency of 13.92% and 14.79% for these flow rates. Changing the material from steel to copper and aluminum increased the fluid outlet temperature. The maximum output temperature corresponds to copper with 311 K. Steel and aluminum showed lower outlet temperatures of 307 K and 308 K, respectively.

In this research, the heat transfer characteristics of a nanofluid in an absorber tube of a parabolic solar collector in shiraz city is investigated using Ansys-fluent software. The condition of the circumferentially non-uniform wall heat flux is considered in this study. The two-phase mixture model is employed to analyze the thermal and fluid dynamic behavior of the nanofluid. The effect of nanofluid on the heat transfer rate, the pressure drops, and as a result, the required power of the pump is investigated

2. Geometry and simulation parameters

The solar collector selected for this study is the LS-2 model. [6]. Figure 1 shows the geometry of the absorber tube of LS-2 parabolic solar collector. The absorber tube is considered single-layer for simplification. The geometric characteristics of the collector tube are presented in Table 1.

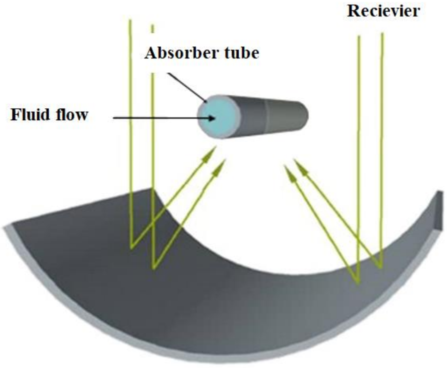

Figure 1. Parabolic solar collector [6].

Table 1. Solar collector characteristics of LS-2 model [6].

Definition	symbol	unit	value
Collector length	L	m	7.8
Collector width	W	m	5
Absorber radius	Rb	m	0.033
Glass cover radius	Rg	m	0.0575

The introduction should show the background of the subject and main contributions. It is necessary to explain clearly the novelty and contribution of present work in the last paragraph of introduction.

3. Grid independence

The grid independence is performed by employing various mesh sizes as shown in Table 2. According to Table 2, it is observed that grid independence is achieved with 1593355 elements beyond which there is no significant change in the outlet temperature.

Table 2. Outlet temperature for different mesh size

Number of elements	Outlet temperature
409348	304.7898
810517	305.0209
1593355	305.3833
2049861	305.3554

4. Model validation

The present method is validated by studying the heat transfer of TiO_2/water nanofluid in the absorber tube. The diameter of nanoparticles is considered 21 nm, volume concentrations of 1% and an inlet temperature of 298 K. The simulation results are compared with the experimental results of Dansongost and Wang Weisz [7] and are shown in Figure 2. According to Figure 2, the results are in good agreement and the maximum error is 5.6%. The reason is that the error of the experimental method decreases with increasing Reynolds number.

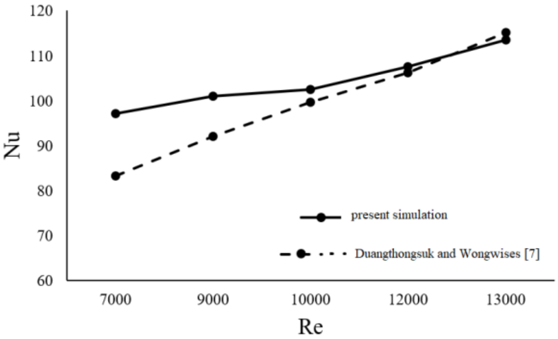

Figure 2. Nusselt number variation versus Reynolds number.

5. Results and Discussion

Figure 3 illustrates the Nusselt number increase for Syltherm 800/TiO_2 and Al_2O_3/water nanofluid versus different Reynolds numbers. According to Figure 3, the

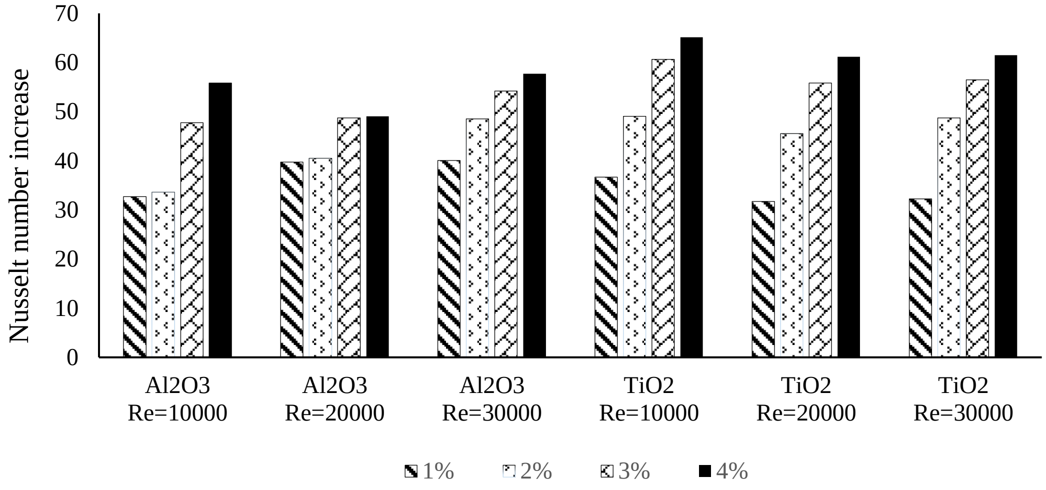

Figure 3. Nusselt number increase versus Reynolds number for Syltherm 800/TiO2 and Al2O3/water nanofluid.

maximum Nusselt number increase of Syltherm 800/TiO_2 occurs at Reynolds 10000 and a concentration of 4%. The maximum Nusselt number of Al_2O_3/water corresponds to Reynolds number 30000 and 4% concentration.

An increase in nanoparticles volume fraction causes a pressure drop in the flow. Adding nanoparticles in the base fluid is acceptable if the heat transfer factor overcomes the friction factor. Performance evaluation criterion (PEC) is a dimensionless number representing heat transfer and hydraulic performance of thermal applications [8]. Figures 4 and 5 show the PEC variation versus Reynolds number for Syltherm 800/TiO_2 and Al_2O_3/water nanofluid at different volume fractions. The dimensionless number of PEC is greater than one for all situations and the heat transfer factor overcomes the friction factor.

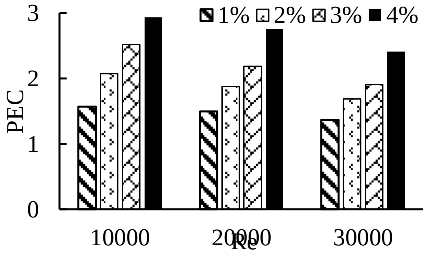

Figure 4. PEC variation versus Reynolds number for Syltherm 800/TiO_2 nanofluid.

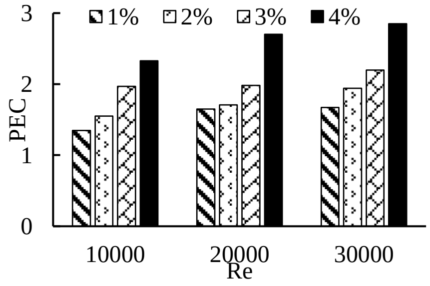

Figure 5. PEC variation versus Reynolds number for Al_2O_3/water nanofluid.

6. Conclusions

In this paper, the heat transfer of nanofluid in a parabolic solar collector absorber tube was investigated. Syltherm 800/TiO_2 and Al_2O_3/water nanofluid with concentrations of 1%, 2%, 3% and 4% were used in this simulation for 20000, 10000 and 30000 Reynolds number. The absorber tube considered under non-uniform heat flux and the inlet temperature was 300 K.

Nusselt number increase and PEC for nanofluids nanofluid were studied. In all cases, the PEC value is greater than one, which indicates that the thermal performance of collector increases for both nanofluids and overcomes the pressure drop.

The maximum increase in Nusselt number corresponds to Syltherm 800/TiO_2 with a concentration of 4% at Reynolds 10000. On the other hand, the amount of heat transfer increases with increasing concentration of both nanofluids, but PEC decreases for Syltherm 800/TiO_2 and increases for Al_2O_3/water.

7. References

[1] Bellos E, Tzivanidis C (2017) Optimization of a solar-driven trigeneration system with nanofluid-based parabolic trough collectors. *Energies* 10(7): 848.

[2] Ghasemi S E, Ranjbar A A (2017) Effect of using nanofluids on efficiency of parabolic trough collectors in solar thermal electric power plants. I*nternational Journal of Hydrogen Energy* 42(34): 21626-21634.

[3] Abed N, Afgan I, Cioncolini A, Iacovides H, Nasser A and Mekhail T (2020) Thermal performance evaluation of various nanofluids with non-uniform heating for parabolic trough collectors. *Case Studies in Thermal Engineering* 22: 100769.

[4] Hong K, Yang Y, Rashidi S, Guan Y, Xiong Q (2021) Numerical simulations of a Cu–water nanofluid-based

parabolic-trough solar collector. *Journal of Thermal Analysis and Calorimetry*. 143:4183-4195.

[5] Farooq M, Farhan M, Ahmad G, Usman M, Sultan M, Hanif M S, Imran M, Anwar S, El-Sherbeeny A M and Shakir M A (2022) Thermal performance enhancement of nanofluids based parabolic trough solar collector (NPTSC) for sustainable environment. *Alexandria Engineering Journal* 61(11):8943-8953.

[6] Sokhansefat T, Kasaeian A B, Kowsary F (2014) Heat transfer enhancement in parabolic trough collector tube using Al2O3/synthetic oil nanofluid. Renewable and Sustainable *Energy Reviews*. 33:636-644.

[7] Duangthongsuk W, and Wongwises S (2010) An experimental study on the heat transfer performance and pressure drop of TiO2-water nanofluids flowing under a turbulent flow regime. *International Journal of Heat and Mass Transfer*. 53(1-3):334-344.

[8] Ekiciler R, Arslan K, Turgut O and Kurşun B (2020) Effect of hybrid nanofluid on heat transfer performance of parabolic trough solar collector receiver. *Journal of Thermal Analysis and Calorimetry* 143: 1-18.