Energy 109 (2016) 49–61

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Two phase simulation and sensitivity analysis of effective parameters on turbulent combined heat transfer and pressure drop in a solar heat exchanger filled with nanofluid by Response Surface Methodology

Mojtaba Mamourian*, Kamel Milani Shirvan, Soroush Mirzakhanlari

Department of Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

ARTICLE INFO

Article history:
Received 30 January 2016
Received in revised form
18 March 2016
Accepted 17 April 2016

Keywords:
Response Surface Methodology
Sensitivity analysis
Solar heat exchanger
Two phase simulation
Turbulent heat transfer
Pressure drop

ABSTRACT

In this paper, a 2-D numerical investigation and a sensitivity analysis of combined turbulent mixed convection and radiation heat transfer have been done using two phase mixture model in a solar heat exchanger. Numerical simulations are carried out to study the effects of the four parameters, the Richardson number ($10^{-2} \leq Ri \leq 10^2$), volume fraction of nanoparticles ($0.00 \leq \phi \leq 0.04$), nanoparticles diameter (40 nm $\leq d_p \leq$ 60 nm) and the wall surface emissivity ($0 \leq \varepsilon \leq 1$). The effective parameters analysis is processed utilizing the RSM (Response Surface Methodology). It is found that decreasing the Ri number and ϕ and also increasing in ε and d_p increases the mean total Nusselt number. Due to a decrease in Ri number and increase in ϕ, ε and d_p the pressure drop ratio enhances. The sensitivity of the mean total Nusselt number and pressure drop ratio to Ri number is negative. The sensitivity of the mean total Nusselt number to d_p and ε is positive but to ϕ is negative. Moreover, the sensitivity of the mean Nusselt number to Ri number, ϕ, d_p and ε is more than the sensitivity of the pressure drop ratio to these parameters.

1. Introduction

The mixed convection heat transfer in channels has important applications and usage in various cases of thermal engineering such as compact heat exchangers, thermal-energy conversion devices, solar collectors, solar heat exchangers and cooling of electronic equipment. Flat plates are also involved in many practical applications of convective heat transfer, such as heat transfer components like flat plate solar collectors, condensation process, and solar heat exchangers. Hence, one of basic essentials in investigating the heat transfer in channels is to predict the heat transfer from a flat plate. In addition, new energy fields, specifically solar energy, has been investigated in several fields due to the energy crisis; among them, thermal systems that are a type of heat exchangers, are widely used. For instance, a solar-liquid heating collector as a type of heat exchanger converts the solar energy to the transport medium internal energy [1].

A heat exchanger makes the efficient heat transfer or exchange between two substances possible. Since the common fluids of the commercial applications in heat exchangers (Including water, ethylene glycol and oil) usually have low thermal conductivity, different methods have been used to improve the heat transfer rate of these fluids. For instance, adding of nanoparticles such as Cu, Al_2O_3 and TiO_2 which creates a mixture called nanofluid and improves heat transfer coefficient [1]. In fluids heat transfer and especially solar energy systems such as solar heat exchangers, nanofluids have various applications. Many numerical and experimental studies have investigated the mixed and turbulent convection heat transfers in heat exchangers and solar heat exchangers, for example, a numerical investigation on the fully developed mixed turbulent flow and heat transfer in a receiver tube heated by non-uniform heat flux has been done by Li et al. [2]. They found that it is not possible to perform the heat transfer design and predict it for parabolic trough solar collectors based on the experimental correlations for forced or traditional mixed convention. Mohseni and Bazargan [3] have studied an investigation on entropy generation in turbulent mixed convection heat transfer flow of supercritical fluids by a two dimensional Computational Fluid Dynamics (CFD) code. The results showed that in vicinity of wall region and in the region away from the wall, the mechanisms of entropy generation act differently within the viscous sub-layer. In another paper, Huang et al. [4] have conducted a numerical study

* Corresponding author. P.O.B. 91775–1111, Mashhad, Iran.
E-mail address: mamourian@um.ac.ir (M. Mamourian).

http://dx.doi.org/10.1016/j.energy.2016.04.079
0360-5442/

Nomenclature

C_p	specific heat (J kg^{-1} K^{-1})
d_p	nanoparticle diameter (nm)
F_{ij}	view factor between surfaces i and j
g	gravitational acceleration (m s^{-2})
Gr	Grashof number ($Gr = \frac{g\beta_{eff} q'' H^4}{K_{eff} \nu_{eff}^2}$)
$G_{k,m}$	The generation of the turbulence kinetic energy
h	Average convective heat transfer coefficient
H	The height and width of the cavity (m)
K	thermal conductivity (W m^{-1} K^{-1})
L	Heat exchanger length (m)
Nu	Local Nusselt number
p	pressure (N m^{-2})
P	dimensionless pressure
Pr	Prandtl number
Q_r	The net dimensionless radiative heat flux
q''_0	heat flux (W m^{-2})
Re	Reynolds number
Ri	Richardson number
T	temperature (K)
u, v	velocity components along x-axis and y-axis, respectively (m s^{-1})
U, V	dimensionless of velocity component
x, y	x- and y-axis coordinates, respectively
X, Y	dimensionless Cartesian coordinates

Greek symbols

α	thermal diffusivity, k/(ρcp) (m^2 s^{-1})
β	thermal expansion coefficient, (K^{-1})
ε	dissipation of turbulent kinetic energy (m^2 s^{-1})
θ_s	dimensionless temperature
δ	The distance between the particles
μ	dynamic viscosity (Pa s)
V	kinematics viscosity (m^2 s^{-1})
$\overline{\nu_t}$	The mean turbulent viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})
τ	shear stress (Pa)
σ_ε	The turbulent Prandtl numbers for ε

Subscripts

c	convective
dr	drift
eff	effective
f	Primary phase
i,j	ith and jth subdivisions
k	kth phase
m	mixture
n	The number of the phases
p	particle, secondary phase
r	radiation
s	solid
t	turbulent

on the fully developed combined natural and forced turbulent heat transfer and flow in a receiver tube heated by non-uniform heat flux. The results showed some differences between mixed fluid flow and heat transfer under non-uniform and uniform heat fluxes. An experimental study on pressure drop and friction factor for the laminar and transition opposing mixed convection in the entrance region through a rectangular duct has also been performed by Chong et al. [5]. Their results showed that the pressure drops increase with the mean air velocity, and when the Reynolds numbers were larger or smaller than 1500, different characteristics was observed by the friction factors. For instance, in Reynolds numbers smaller than 1500 the friction factors enhanced with the Grashof and reduced with Reynolds numbers. However, in larger Reynolds numbers, the friction factors were almost independent of the Reynolds and Grashof numbers. Chen and Du [6] have investigated a numerical study on the turbulent double-diffusive natural convection in a rectangle cavity. In this paper, they have studied the effects of the ratio of the buoyancy forces, Rayleigh number and the aspect ratio on entropy generation. An experimental and numerical study on enclosure pressure effects on radiation and convection heat losses from two finite concentric cylinders using two radiation shields has been studied by Saedodin and Motaghedi -Barforoush [7]. They found that the reduction of the total heat loss from the inner cylinder is caused by both radiation shield emissivity and enclosure pressure Habibi Matin and Ahmed Khan [8] have done an investigation on the entropy generation analysis of the heat and mass transfer through a slit micro-channel. Another experimental investigation on the turbulent forced convection in a vertical eccentric annulus with several heat fluxes and different inlet air velocities has been done by Hosseini et al. [9]. An experimental correlation was also obtained in this paper for the Nusselt number as a function of the Reynolds number and eccentricity. Farhad Ismail et al. [10] have investigated a numerical study on the turbulent convection heat transfer in a rectangular plate mounted over a flat surface. They have compared their numerical results with the results of previously published experimental data and obtained results were in good agreement. Wang et al. [11] have performed an experimental study on a solar powered self-cooled cooling system based on solid desiccant coated heat exchanger. The results obtained revealed that the self-cooled solid desiccant coated heat exchanger system has a higher thermal coefficient of performance COP_{th} and better moisture removal capacity than the ordinary solid desiccant coated heat exchanger system. In another study, the heat transfer enhancement in a new type heat exchanger using solar parabolic trough systems has been done by Şahin et al. [12]. They found that the heat transfer enhancements utilizing tabulators were 2.28, 2.07 and 1.95 times better compared with the smooth tube for pitch p = 15, 30 and 45 mm, respectively. Templeton et al. [13] have performed a study on effective solar energy storage utilizing a double pipe geothermal heat exchanger. In this paper, the effects of heat extraction and injection rate on the techno-economic performance of geothermal energy production have been studied.

However, some researchers have taken the effects of the adding nanoparticles to account to increase the heat transfer rate. These researches are mostly done by considering a single phase and some of them two phases. Rejeb et al. [14] have investigated a numerical and experimental study to consider the performance of a nanofluid in photovoltaic thermal collector. The results revealed a higher performance for the mixture with pure water as base fluid in comparison with ethylene glycol. Another numerical investigation on the turbulent convection heat transfer of Al_2O_3-water nanofluid in a circular tube subjected to constant wall temperature has been done by Bianco et al. [15]. The results showed that increasing the nanofluid concentration increases the Nusselt number. A numerical study on flow characteristics, heat transfer and entropy generation of nanofluid flow inside an annular pipe which was partially or completely filled with porous media using two-phase mixture model has been investigated by Siavashi et al. [16]. They found that