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Original Research Paper

Entropy generation analysis of eccentric cylinders pair sources on nanofluid natural convection with non-Boussinesq state

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ABSTRACT

In this study, the natural convection heat transfer and entropy generation in horizontal eccentric cylinders with different arrangements of two constant temperature sources are investigated numerically. The distance between eccentric cylinders was filled with pure fluid and Cu_ water nanofluid. The sources with constant temperature T_h and T_c were located on the inner and outer cylinders and the other walls were assumed to be insulated. Governing equations were formulated by using Boussinesq approximation and non-Boussinesq state (density inversion) and were solved on a non-uniform mesh in eccentric cylinders by using the finite volume method. The numerical calculation was carried out for Rayleigh number ($10^4 \leqslant Ra \leqslant 5 \times 10^5$), volume fraction of nanoparticles ($0 \leqslant \Phi \leqslant 0.08$) and different arrangements of heat sources with different angles in $Pr = 13.31$ and constant eccentricity ($e_v = 0.7$). The results were compared with concentric cylinders and presented from streamlines and isotherms flow field, local and average Nusselt number, local and total entropy generation. The results showed that eccentricity, different arrangements, discrete constant temperature sources and non-Boussinesq state affected the best state of heat transfer. In addition, increasing Rayleigh number and volume fractions of nanoparticles caused an increase in the rate of heat transfer and total entropy generation. It was concluded that Boussinesq approximation and eccentric cylinders had higher rate of heat transfer and entropy generation than non-Boussinesq state and concentric cylinders, respectively. The results indicated which arrangements and kinds of cylinders were optimum and applicable to use in industry and heat exchanger.

1. Introduction

Natural convection is the main mechanism of heat transfer in enclosures. Eccentric cylinders have a wide range of applications in heat exchangers-receivers, solar collectors, insulation and flooding protection for buried pipes used for district heating and cooling, cooling systems in nuclear reactors, cooling of electronic devices and thermal systems in comparison to other kinds of enclosures. In eccentric cylinders, optimization geometry model or changing some characteristics of fluid causes to enhance the rate of heat transfer in comparison to other enclosures. Using an optimal model or nanofluid is one of the important ways to enhance the rate of heat transfer [1]. Many researchers have studied eccentric cylinders, discrete sources, nanofluid and entropy generation that are explained and discussed as follows:

Eccentric cylinders geometry is a new kind of geometry used in the industry that some studies on eccentric cylinders are explained as follows:

Projahn et al. [2] studied a numerical simulation on heat transfer between concentric and eccentric horizontal cylinders in different Ra numbers to compare them. Density was assumed to be linear in their research. Effects of non-Boussinesq state on natural convection in eccentric cylinders were investigated experimentally by Seki et al. [3]. Their results showed that the effect of non-Boussinesq state was unpredictable, and its average Nu number was different from Boussinesq approximation. Raghavarao and Sanyasiraju [4] investigated steady state natural convection in eccentric cylinder filled with water and showed that the flow was symmetrical to the vertical axis; they also showed that the rate of heat transfer depends on the density at non-Boussinesq state. They found that the maximum rate of heat transfer occurs on the inner cylinder for positive vertical eccentricity and on the outer cylinder for negative vertical eccentricity.

Heating all surface of geometry always is not possible or/and it has a high cost, so discrete sources to heat special parts are useful. Some studies about discrete sources are explained as follows:

Nanofluid was first studied by Chu et al. [5] into rectangular enclosure with a hot source located on a vertical wall. Many researchers studied on natural convection in enclosures with dis-

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Nomenclature

Be	Bejan number
C_p	specific heat at constant pressure (J/kg K)
C	constant
D	diameter of inner cylinder (m)
e_v	vertical distance from the center eV = $d/(r_o - r_i)$
d_p	nanoparticles diameter (m)
g	gravitational acceleration components (m/s^2)
k	fluid thermal conductivity (W/m K)
l	cavity length (m)
L	gap between inner and outer cylinder, i.e., $L = r_o - r_i$ (m)
Nu	local Nusselt number
$\overline{Nu}$	average Nusselt number
P	pressure ($kg/m\ s^2$)
Pr	Prandtl number
r	Radial coordinate (m)
Ra	Rayleigh number
$\dot{S}_l$	entropy generation (W/m^3 K)
$\dot{S}_{l,N}$	non-dimensional local entropy generation
$\dot{S}_{T,N}$	non-dimensional total entropy generation
T	temperature (K)
u, *v*	velocity components (m/s)
U, *V*	non-dimensional velocities
x, *y*	Cartesian coordinates (m)
X, *Y*	non-dimensional Cartesian coordinates

Greek symbols

α	thermal diffusivity (m^2/s)
β	thermal expansion coefficient (K^{-1})
θ	angle of the rotation about vertical axis (different arrangement)
Θ	angular coordinate in the cylindrical system
ψ	non-dimensional temperature
μ	dynamic viscosity (m^2/s)
ν	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
ϕ	particle volume fraction
φ	irreversibility distribution ratio
ζ	dimensionless time $\zeta = \alpha t/l^2$

Subscripts

c	cold
d	destroyed
f	fluid
eff	effective
h	hot
i	inner
nf	nanofluid
o	outer
s	solid
0	reference value at cold condition

Superscript

$*$	non-dimensional

crete heat sources following their work. An investigation on natural convection in high rectangular enclosure with eleven heat sources was done by Keyhani et al. [6]. They found that discrete non-uniform heat sources raised the rate of heat transfer. Numerical and experimental work was presented by Ho and Chang [7] for four constant temperature sources with different aspect ratios. Temperature field obtained from numerical study matched very well with the measurements of the experimental model. Muftuoglu and Bilgen [8] investigated numerical simulation about the optimal location of constant temperature in square enclosure and determined the rate of heat transfer and volumetric flow. Heat transfer in a rectangular channel with a single heat source and an in-line, four-row array of 12 heat sources which are flush mounted to one wall of a horizontal one was investigated by Incopera et al. [9] experimentally so as to determine the average convection coefficient. Sankar et al. [10] studied the effects of radius ratio, Ra number and Darcy number on natural convection flows in a vertical concentric cylinders with discrete heating on the inner. Gersey and Mudawar [11] studied the orientation effects on critical heat flux from discrete, in-line heat sources in a flow channel due to gravity.

Nanofluid is the fluid with different amounts of nanoparticles in base pure fluid. Some studies on Nanofluid are explained as follows:

Sheikholeslami et al. [12] found out that natural convection heat transfer in a semi-annulus enclosure filled with Cu–water nanofluid with different angles of turn affected the streamlines, isotherms and maximum or minimum values of local Nusselt number. Effects of thermal conductivity and viscosity of Alumina-Water Nanofluid on the rate of heat transfer were investigated by Ho et al. [13]. They showed that nanofluid different equations affected the rate of heat transfer. Nanoparticles materials comparison was investigated by Abu-Nada et al. [14] for various volume fractions in concentric cylinders with entire sources in inner and outer. Qi-Hong [15] studied the effects of the number of heat sources and divided them on the side by using Copper–water nanofluid in square enclosure, then showed that the number of discrete sources increased due to the increase in the rate of heat transfer.

Some of the useful energy was destroyed during each energy process because the irreversibility of the results in a significant decrease in the maximum achievable efficiency of the thermal process was expressed as entropy generation. Some studies on entropy generation are explained as follows:

Bejan [16,17] attempted to determine the gap between thermodynamics, heat transfer and fluid mechanics. He employed the second law of thermodynamics to examine and reduce the entropy generation due to heat and flow transport. Following the Bejan work, numerous studies were done to investigate the entropy generation in free and force convection [18–22]. This method is also known as the second law analysis and thermodynamic optimization which was employed by many researchers to calculate or analyze energy or entropy generation in many kinds of flows, such as single/two-phase and wet steam flows [23–30]. Shit et al. [31] were studied about variation of entropy generation on the unsteady boundary layer flow by using nanofluid and its effects in magneto hydrodynamic flow and convective heat transfer of an exponentially stretching surface in the presence of thermal radiation. The effect of relative rotational motion between the inner and outer cylinders of a cylindrical annulus on entropy generation was studied by Mahmud and Fraser [32]. They found that the entropy generation rate showed asymptotic behavior near the outer cylinder and provided that the rotation of the inner cylinder was higher than the outer. Allouache and Chikh [33] reported that the performance of an annular heat exchanger with a porous medium attached over the inner pipe is based on second-law analysis.

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