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ORIGINAL ARTICLE

Numerical study on mixed convection cooling of solar cells with nanofluid

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Abstract In the present study, the mixed convection heat transfer for a nanofluid flow inside solar cell cooling system was numerically investigated. To this end, an inclined two-dimensional channel with insulated walls was taken under study. The solar cells were assumed to locate on one side of channel where the nanofluid enters at constant temperature. The study has been carried out for the Richardson numbers in the range $0.01 \leqslant Ri \leqslant 20$, with solid volume fraction $0 \leqslant \varphi \leqslant 0.04$, Reynolds number 100 and for Prandtl number 7.02. The effects of solid volume fraction and solar cells location in terms of Richardson number on the flow and temperature fields and also the heat transfer rate were studied. The results showed that the presence of nanoparticles led to an increase in temperature gradient and heat transfer near the solar cells. It was also observed that the maximum heat transfer in solar cells occurs in minimum inclination angle of channel at a certain relative distance between the cells.

1. Introduction

In recent years, many works including experimental, numerical, and analytical studies concerning the mixed convection heat transfer have been carried out due to the various applications of this phenomenon in different engineering systems (i.e. cooling systems).

In analytical method, the heat transfer mechanism is supported by mathematical equations to investigate the impacts of effective parameters on heat transfer process [1,2].

Kurtbas and Celik [3] have experimentally investigated the heat transfer characteristics of the mixed convection flow through a horizontal rectangular channel in the presence of open-cell metal foams of different pore densities. They could measure the temperature profile on the entire surfaces of the walls and presented average and local Nusselt numbers as function of Reynolds and Richardson numbers. Finally, a new correlation was established between the Nusselt number and the parameters under study (i.e. aspect ratio of the channel and Reynolds number).

Chong et al. [4] have studied the mixed convection heat transfer of thermal entrance region in an inclined rectangular duct for laminar and transition air flow. The experiments were designed to determine the effects of inclination angles on the heat transfer coefficients and friction factors. A detailed dis-

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Nomenclature

c	experimental constant, Eq. (9)
C_P	specific heat (J kg^{-1} K^{-1})
D	dimensionless distance between the solar cells
g	gravitational acceleration (m/s^2)
h	channel height (m)
k	thermal conductivity (W m^{-1} K^{-1})
l	channel length (m)
L	dimensionless channel length ($L = l/h$)
L_1	dimensionless distance between the channel edges from the first and last cell ($L_1 = l_1/h$)
Nu	local Nusselt number
Nu_m	average Nusselt number
p	fluid pressure (Pa)
P	dimensionless pressure, $p/\rho_{nf} U_0^2$
Pr	Prandtl number, v_f/α_f
Re	Reynolds number, $\rho U_0 h/\mu$
Ri	Richardson number, Gr/Re^2
T_C	inlet flow temperature (K)
T_H	temperature of solar cells (K)
u_s	Brownian motion velocity (m s^{-1})
U, V	dimensionless velocity components
w	solar cell length (m)
x, y	cartesian coordinates (m)

Greek symbols

α	thermal diffusivity (m^2/s)
β	thermal expansion coefficient (K^{-1})
φ	solid volume fraction
k_b	Boltzman constant (J K^{-1})
θ	dimensionless temperature of fluid $(T - T_C)/(T_H - T_C)$
λ	angle of channel
μ	dynamic viscosity (N s m^{-2})
v	kinematic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})

Subscripts

f	pure fluid
nf	nanofluid
s	nanoparticle

cussion on the dependence of heat coefficient on the duct inclination angle and Reynolds number was given in this literature.

The experimental data on flow visualization and heat transfer measurement for airflow in a horizontal channel were published in Ref. [5]. The measurements were performed over a wide range of conditions to determine regions of forced and mixed convection.

On the other hand, in some numerical-based researches, the effects of main parameters such as wall thickness-to-channel length ratios, Reynolds number, Grashof number and other parameters on the buoyant force and heat transfer for different geometries were studied [6,7].

The results of such basic studies were used to optimize the design procedure of heat exchangers, particularly in electronic boards cooling systems. The main objective of these papers was to identify the most efficient way to remove the dissipated heat from electronic components with special geometries.

Butina and Bessaïh [8] have simulated the mixed convection air-cooling of two identical electronic devices using finite volume method. The results showed that the Reynolds number, the inclination angle of the channel, the size of heat sources and the distance between them have noticeable impacts on the heat transfer rate through the channel.

A numerical analysis of laminar mixed convection heat transfer from two identical heat sources, which simulate electronic components, was presented by Hamouche and Bessaïh [9]. The results demonstrated that the separation distance, the height and the width of the components play a crucial role in heat transfer augmentation and cooling efficiency.

Oztop [10] has numerically investigated the laminar mixed convection heat transfer in a channel with volumetric heat source with different exit opening ratios. A two-dimensional model based on the finite volume method was developed for solving the equations of mass, momentum and energy. The simulations were made under different physical conditions (i.e. three different aspect ratios and three locations of output channels) and the results were reported in terms of streamlines, isotherms, Nusselt number, and temperature profiles. It was revealed that the Richardson number and the location of exit openings are the most important parameters involved.

Sun et al. [11] have studied the mixed convection heat transfer between the isothermal vertical plates to find optimal distance in which the transferred heat flux from an array of isothermal would be maximum. The results showed that the optimal distance for the mixed convection is smaller than either for pure natural convection or for pure forced convection. This distance was estimated based on pressure drop.

Guimaraes et al. [12] have studied the mixed convection in a rectangular channel with three discrete heat sources which were located on the bottom wall. The Effects of Reynolds number, Grashof number and channel slope on heat transfer have been numerically investigated and it was concluded that the inclination angle is of more relative importance at low Reynolds number. In general, the cases with inclination angle of 45 degrees and 90 degrees showed the lowest temperature average.

Low thermal conductivity of fluids such as water and air is the main limitation in convective heat transfer. Nowadays, in order to overcome this shortcoming, nanoparticle was added to the working media (i.e. pure fluid) to make a high thermal conductivity suspension.

Pishkar and Ghasemi [13] have numerically investigated the mixed convection heat transfer of horizontal finned channel with and without nanofluids. The results showed that the rate of heat transfer in fins is significantly affected by the distance between the blades. The effect of the solid volume fraction on heat transfer performance in high Reynolds numbers was found to be significant. In addition, the influence of the solid volume fraction on the heat transfer enhancement is more noticeable at higher values of the Reynolds number.

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