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Control of natural convection via inclined plate of CNT-water nanofluid in an open sided cubical enclosure under magnetic field

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ABSTRACT

A computational analysis has been performed in this work to solve three-dimensional magnetohydrodynamic natural convection in an open cubical enclosure filled with CNT-water nanofluid. The cavity is heated from left vertical wall and an inclined plate is attached inside the cavity with finite length. The study is solved for different governing parameters as Rayleigh number ($10^3 \leq Ra \leq 10^5$), nanoparticle volume fraction ($0\% \leq \varphi \leq 5\%$), Hartmann number ($0 \leq Ha \leq 100$) and inclination angle of the fin ($0° \leq \theta \leq 360°$). It is observed that all of these parameters can be used as passive control element for heat and fluid flow and the maximum heat transfer is formed when $\theta = 180°$ but minimal value of average Nusselt number is changed according to nanoparticle addition into base fluid.

1. Introduction

Control of heat and fluid flow in an open or closed cavity is important to save energy in engineering systems filled with nanofluid or pure fluid. It is important for electronic cooling equipment, heat exchangers or some cooling devices. Nanotechnology is becoming popular with increasing of technology due to its wide range of applications. Coupling MHD and nanotechnology in heat and fluid flow area such as fusion, cooling of fission reactors, and molten steel flow can be used as control element for convective heat transfer. Nanoparticles of Carbon nanotube (CNT) can be added to a base fluid due to their excellent thermophysical and electrical properties.

Wen and Ding [1] investigated the effective thermal Conductivity of aqueous suspensions of carbon nanotubes (Carbon Nanotube Nanofluids), It was found that effective thermal conductivity increased with increasing concentration of carbon nanotubes and the dependence is nonlinear even at very low concentrations. This differs from the results for metal/metal oxide nanofluids. Wang et al. [2] studied the removal of lead ions from aqueous solution by using magnetic hydroxypropyl chitosan/oxidized multiwalled carbon nanotubes composites. Ji et al. [3] studied the improvement of the thermal conductivity of a phase change material by the functionalized carbon nanotubes. The results show when the MWNTs with more oxygen-containing groups can have more hydrogen bonding interactions with the PA molecules, and the nanotubes are better dispersed in the PA/ethanol solution. Kakade and Pillai [4] studied the efficient route towards the covalent functionalization of single walled carbon nanotubes. The obtained results are believed to be important for the processing and engineering of pure carbon nanotubes and polymer-CNT composites for many promising applications, including electrocatalysis, chemical/biosensing and developing electronic devices such as FETs and SETs. Meibodi et al. [5] investigated the role of different parameters on the stability and thermal conductivity of carbon nanotube/water nanofluids. Talaei et al. [6] studied the effect of functionalized group concentration on the stability and thermal conductivity of carbon nanotube fluid as heat transfer media. The results show that increasing the functionalized group causes better stability and higher thermal conductivity if the surface of MWNT does not damage in functionalize process. Estellé et al. [7] investigated the lignin as dispersant for water-based carbon nanotubes nanofluids: Impact on viscosity and thermal conductivity. It was found that the thermal conductivity of base fluid decrease with the amount of surfactant, thermal conductivity of nanofluid well increased with nanoparticle content. Li et al. [8] studied the experimental investigation of β-cyclodextrin modified carbon nanotubes nanofluids for

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Nomenclature

$\vec{B}$	magnetic field ($=\vec{B}'/B_0$)
Be	Bejan number
C_p	specific heat at constant pressure (J/kg K)
$\vec{E}$	dimensionless electric field
$\vec{e}_B$	direction of magnetic field
$\vec{g}$	gravitational acceleration (m/s^2)
$\vec{J}$	dimensionless density of electrical current
k	thermal conductivity (W/m K)
l	enclosure width
n	unit vector normal to the wall
N_s	dimensionless local generated entropy
Nu	local Nusselt number
Pr	Prandtl number
Ra	Rayleigh number
S'_{gen}	generated entropy (kJ/kg K)
t	dimensionless time ($t'.\alpha/l^2$)
T	dimensionless temperature $[(T'-T'_c)/(T'_h-T'_c)]$
T'_c	cold temperature (K)
T'_h	hot temperature (K)
T_o	bulk temperature $[T_o=(T'_c+T'_h)/2]$ (K)
$\vec{V}$	dimensionless velocity vector ($\vec{V}'.l/\alpha$)
x, y, z	dimensionless Cartesian coordinates (x'/l, y'/l, z'/l)

Greek symbols

α	thermal diffusivity (m^2/s)
β	thermal expansion coefficient (1/K)
ρ	density (kg/m^3)
μ	dynamic viscosity (kg/m s)
ν	kinematic viscosity (m^2/s)
Φ	dimensionless electrical potential
φ	nanoparticle volume fraction
φ_s	irreversibility coefficient
θ	plate inclination
σ	electrical conductivity
$\vec{\psi}$	dimensionless vector potential ($\vec{\psi}'/\alpha$)
$\vec{\omega}$	dimensionless vorticity ($\vec{\omega}'.\alpha/l^2$)
ΔT	dimensionless temperature difference

Subscripts

av	average
c	cold
h	hot
fr	friction
f	fluid
n	normal
nf	nanofluid
s	solid (nanoparticle)
x, y, z	Cartesian coordinates

Superscript

′	dimensional variable

solar energy systems: Stability, optical properties and thermal conductivity. Su et al. [9] investigated the effect of carbon nanotubes on the physical properties of a binary nanofluid. The results show that the CNTs–ammonia binary nanofluid had remarkably higher effective thermal conductivities than the base fluid, but hardly higher surface tension and kinetic viscosity. Farbod et al. [10] studied the Stability and thermal conductivity of water-based carbon nanotube nanofluids. It was found that the thermal conductivity of nanofluids increases with decreasing the length of the CNTs, and with increasing the temperature up to 50 °C (the maximum temperature tested). Gu et al. [11] investigated the Control growth of carbon nanofibers on Ni/activated carbon in a fluidized bed reactor. Li et al. [12] studied the removal of lead ion and oil droplet from aqueous solution by lignin-grafted carbon nanotubes. The results demonstrate the as-obtained nanocomposite with a natural polymer layer has advanced adsorption capability, low in cost and eco-friendliness, and accordingly is an ideal candidate for water cleanup. Yang et al. [13] investigated the reinforcement of norbornene-based nanocomposites with norbornene functionalized multi-walled carbon nanotubes. Halelfadl et al. [14] studied the analytical optimization of a rectangular microchannel heat sink using aqueous carbon nanotubes based nanofluid as coolant. The optimized results showed that use of the nanofluid as a working fluid reduce the total thermal resistance and can enhance significantly the thermal performances of the working fluid at high temperatures. Jiang et al. [15] investigated the measurement and model on thermal conductivities of carbon nanotube nanorefrigerants. It was found that the thermal conductivities of CNT nanorefrigerants increase significantly with the increase of the CNT volume fraction. Zhang et al. [16] studied the effect of morphology of carbon nanomaterials on thermo-physical characteristics, optical properties and photo-thermal conversion performance of nanofluids. Zhao et al. [17] investigated the Bioelectrochemistry of hemoglobin immobilized on a sodium alginate-multiwall carbon nanotubes composite film. Mesgari et al. [18] investigated the thermal stability of carbon nanofluids for solar thermal applications. Neumayer and Haubner [19] investigated the formation of carbon-nano-fibres and carbon-nanotubes with a vertical flow-reactor. the results show when increasing the temperature, and reducing the gas pressure, the nanotubes were grown together and high amounts of low-quality carbon-nanotube powder were collected from the exhausted gas. Li et al. [20] studied the effect of polyether amine canopy structure on carbon dioxide uptake of solvent-free nanofluids based on multiwalled carbon nanotubes. Other related studies can be seen in literature [21–32].

The main aim of this work is to study the effects of inclined plate on heat and fluid flow in a CNT nanofluid filled open enclosure for different parameters under magnetic field. Based on above literature survey there is no work on three dimensional open sided cavities in the presence of inclined fin.

2. Definition of physical model

The physical model is defined in Figs. 1a and 1b. It is mainly three-dimensional cubical cavity with one side opened and an inclined plate insertion to control flow like a valve. Left vertical side of the cavity is hotter than that of outside and plate. Fig. 1b defines the boundary condition for z = 0.5 plan. Magnetic field is applied from left side and right side of the cavity is under open wall condition. Top, bottom, back and front sides of the cavity is insulated (see Table 1).

3. Governing equations

Governing equations for the studied configuration were written using the 3D vorticity-vector potential formalism. This formalism allows the elimination of the pressure which is delicate to treat. Vorticity and vector potential are defined respectively by the following two relations:

$$\vec{\omega}' = \vec{\nabla} \times \vec{V}' \tag{1}$$