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Forced convection of ferrofluids in a vented cavity with a rotating cylinder

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In this study, numerical investigation of the forced convection of ferrofluid in a square cavity with ventilation ports in the presence of an adiabatic rotating cylinder is carried out. The governing equations are solved with a finite element based solver. The effects of Reynolds number ($20 \le Re \le 400$), angular rotational speed of the cylinder ($-500 \le \Omega \le 500$), strength and location of the magnetic dipole ($0 \le \gamma \le 250$), ($0.2 \le a \le 0.8$, $-0.8 \le b \le -0.2$) on the flow and thermal fields are numerically studied. It is observed that the length and size of the recirculation zones can be condtrolled with magnetic dipole strength and angular rotational speed of the cylinder. When the magnetic dipole is closer to the bottom wall of the cavity, flow is accelerated towards the bottom wall with larger influence area. The increasing values of the angular rotational speed of the cylinder in the clockwise direction enhance the heat transfer.

1. Introduction

Fluid flow around a rotating cylinder has a lot of practical applications such as rotating tube-heat exchangers, nuclear reactor fuel rods and drilling of oil wells. Several studies have been conducted to investigate the mixed or natural convection in enclosures with rotating or stationary cylinders [1–6]. Hussain and Hussein [7] have numerically investigated the mixed convection in an enclosure with a rotating cylinder using a finite volume method. The numerical experiment is carried out for a range of Reynolds number and Grashof numbers. Their results showed that rotating cylinder locations have an important effect in enhancing convection heat transfer in the square enclosure. Costa and Raimundo [8] have numerically studied the mixed convection in a differentially heated square enclosure with an active rotating circular cylinder. They observed that depending on the rotation, the free and forced convection can be combined or opposite. The effects of the radius, rotation velocity and thermal conductivity and thermal capacity of the cylinder on the mixed convection problem is studied.

Magnetic field effects on the fluid flow and heat transfer have received much attention during the recent years due to its importance in many technological applications such as coolers of nuclear reactors, micro-electronic devices and purification of molten metals. A review of heat transfer enhancement using ferrofluids is given in Ref. [9]. Due to the effect of the magnetic field, the fluid flow experiences a Lorentz force. Employing an external magnetic field can be used as a control method since magnetic field can suppress the convective flow field [10–13]. Finlayson [14] has studied the stability of ferromagnetic fluid for a fluid layer heated from below and subjected to a uniform vertical magnetic field. A temperature gradient was established across the fluid layer which causes a spatial variation in magnetization and hence convection. Strek and Jopek [15] have simulated the channel flow under the influence of magnetic dipole using a finite element code. They reported that inhomogeneous magnetic body force due to temperature gradient a convection similar to buoyancy force. Oztop et al. [16] have studied the mixed convection with a magnetic field in a top sided lid-driven cavity heated by a corner heater. They showed that heat transfer decreases with increasing the Hartmann number and magnetic field plays an important role to control heat transfer and fluid flow. Rahman et al. [17] have studied the conjugate effect of Joule heating and magnetic force, acting normal to the left vertical wall of an obstructed lid-driven cavity saturated with an

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Nomenclature

a, *b*	location of the magnetic dipole
B	magnetic induction
h	local heat transfer coefficient, (W/m^2 K)
H	magnetic field
k	thermal conductivity, (W/m K)
L	length of the enclosure, (m)
Mn	Magnetic number, $\mu_0 H_r^2/\rho_0 \nu_r^2$
n	unit normal vector
Nu	local Nusselt number, hL/k
p	pressure, (Pa)
Pr	Prandtl number, ν/α
Re	Reynolds number, u_0L/ν
T	temperature, (K)
u, *v*	x-y velocity components, (m/s)
x, *y*	Cartesian coordinates, (m)

Greek characters

α	thermal diffusivity, (m^2/s)
γ	strength of the dipole
θ	non-dimensional temperature, $T-T_c/T_h-T_c$
ν	kinematic viscosity, (m^2/s)
ρ	density of the fluid, (kg/m^3)
Φ	viscous dissipation
χ	magnetic susceptibility
Ω	nondimensional rotation velocity of cylinder, $\omega L/2u_0$

Subscripts

c	cold wall
max	maximum
mean	average
h	hot wall

electrically conducting fluid numerically using finite element method. They showed that the Joule heating parameter and the Hartmann number have notable effect on fluid flow and heat transfer. Jafari et al. [18] have studied the heat transfer and fluid flow characteristics for a kerosene based ferrofluid in two cylinders with different dimensions using computational fluid dynamics. They studied the effects of temperature gradients and uniform magnetic fields on the heat transfer and observed that magnetic field enhances the transport processes. They also showed that heat transfer increases when the magnetic field is perpendicular to the temperature gradient. Ishak et al. [19] have investigated the steady magnetohydrodynamic mixed convection flow adjacent to a vertical surface with prescribed heat flux. They found that magnetic parameter plays an important role in controlling the boundary layer separation.

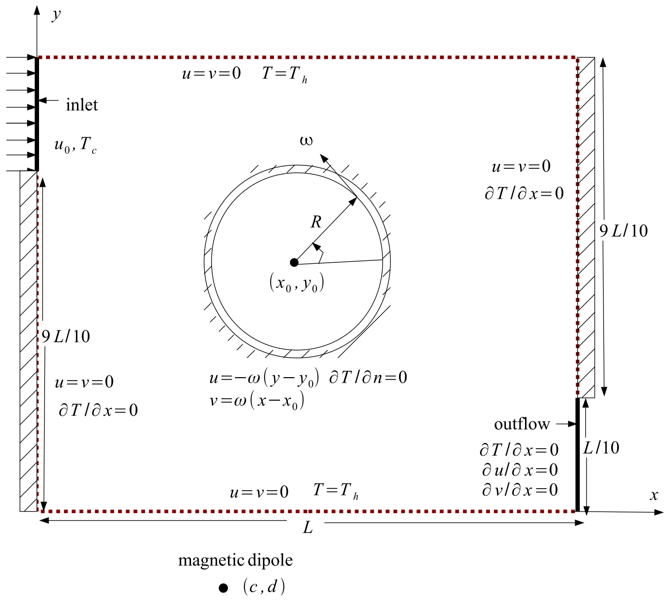
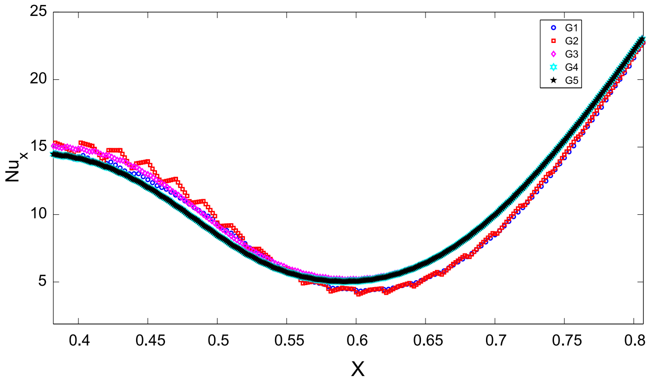
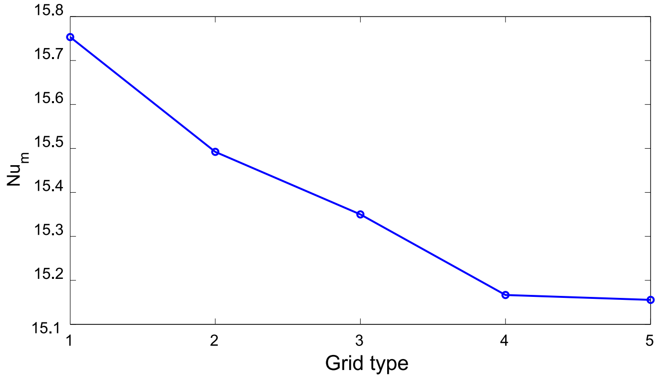


Fig. 1. Geometry and the boundary conditions for the ventilated cavity with an adiabatic rotating cylinder placed at the center of the cavity under the influence of magnetic dipole.

In the present study, the effects of a rotating cylinder under the influence of magnetic dipole on the heat transfer enhancement and fluid flow characteristics are numerically studied in a vented cavity. To the best of the authors' knowledge, a numerical investigation for such a configuration has never been reported in the literature. The preset numerical study aims at investigating the effects of magnetic field parameters (strength and location of the magnetic dipole source) and angular rotational speed of the cylinder on the fluid



(a) local Nusselt number



(b) averaged Nusselt number

Fig. 2. (a)- Local and (b)- averaged Nusselt number distribution along the bottom wall of the cavity at (Re = 400, Ω = 500, γ = 250, (a,b) = (0.5,–0.25) for various grid densities.