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Technical Note

Numerical investigation of natural convection in an inclined enclosure filled with porous medium under magnetic field

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Abstract

In the present study, natural convection of fluid in an inclined enclosure filled with porous medium is numerically investigated in a strong magnetic field. The physical model is heated from left-hand side vertical wall and cooled from opposing wall. Above this enclosure an electric coil is set to generate a magnetic field. The Brinkman–Forchheimer extended Darcy model is used to solve the momentum equations, and the energy equations for fluid and solid are solved with the local thermal non-equilibrium (LTNE) models. Computations are performed for a range of the Darcy number from 10^{-5} to 10^{-1}, the inclination angle from 0 to $\pi/2$, and magnetic force parameter γ from 0 to 100. The results show that both the magnetic force and the inclination angle have significant effect on the flow field and heat transfer in porous medium.

Keywords: Natural convection; Porous medium; Magnetic force; Local thermal non-equilibrium (LTNE)

1. Introduction

The research of natural convection in porous medium has been conducted widely in recent years, which involves post-accidental heat removal in nuclear reactors, cooling of radioactive waste containers, the migration of moisture through the air contained in fibrous insulations, the dispersion of chemical pollutants through water-saturated materials, heat exchangers, solar power collectors, grain storage, food processing, energy efficient drying process, to name of a few. Nield and Bejan [1] and Ingham and Pop [2] contributed to a wide overview of this important area in heat transfer of porous medium. There are many open literature related to natural convection in rectangular porous enclosures [3–7]. The study of thermal convection in inclined enclosures is motivated by a desire to find out any effects of the slope on thermally driven flows which are found in many engineering applications. Caltagirone and Bories [8] studied the stability criteria of free convective flow in an inclined porous layer. Vasseur et al. [9] investigated the natural convection in a thin inclined porous layer exposed to a constant heat flux and in other contributions by Sen et al. [10] and Baytas [11]. The aforementioned natural convection is only related to buoyancy-driven flows. As is known recently, the magnetic force is another driving force, which is proportional to the magnetic susceptibility of the fluid and approximately proportional to the gradient of the square of magnetic induction. Natural convection under magnetic force has been examined quite recently by some investigators [12–15]. However, almost no attentions are paid on the combined effects of both magnetic and gravitational forces on the natural convection in porous medium. Furthermore, magnetic force has received more attention in the field of metallic materials, and less in the field of non-metallic materials. It is acceptable only when the magnetic force is small. With the increase of magnetic field intensity, the magnetic force has more effects on the non-metallic materials. The application of strong magnetic field for porous medium may be found in the field of medical

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Nomenclature

a_{sf}	specific surface area of the porous medium (m^{-1})
$\underline{b}_0$	uniform magnetic induction (T)
$\underline{b}$	magnetic induction (T)
B	dimensionless magnetic flux
c_p	specific heat at constant pressure ($J\,kg^{-1}\,K^{-1}$)
d_p	sphere particle diameter (m)
Da	Darcy number (K/H^2)
F	geometric function
g	gravitational acceleration ($m\,s^{-2}$)
h	distance between coil and the center of the enclosure (m)
h_{sf}	solid-to-fluid heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
H	side length of the enclosure (m)
i	electric current in a coil (A)
k	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
K	permeability (m^2)
Nu	Nusselt number, Eq. (6)
p	pressure (Pa)
P	dimensionless pressure
Pr	Prandtl number, $Pr = \nu_f/\alpha_m$
r	distance from coil segment to a point (m)
R	coil radius (m) in Fig. 1, dimensionless distance in Eq. (3)
Ra	Rayleigh number, $Ra = gH^3\beta(T_h - T_c)/(\nu\alpha_m)$
$\vec{s}$	tangential vector of a coil
T	temperature (K)
u, v, w	velocity components ($m\,s^{-1}$)
U, V, W	dimensionless velocity components
x, y, z	x-, y-, z-coordinates
X, Y, Z	dimensionless coordinates

Greek symbols

α	inclination angle, radian
α_m	thermal diffusivity ($m^2\,s^{-1}$)
β	thermal expansion coefficient (K^{-1})
γ	dimensionless magnetic strength parameter
δ	mass fraction of oxygen
θ	dimensionless temperature
μ	viscosity of gas ($kg\,m^{-1}\,s^{-1}$)
μ_m	magnetic permeability ($m\,kg\,(s\,A)^{-2}$)
ν	kinematic viscosity ($m^2\,s^{-1}$)
ρ	density ($kg\,m^{-3}$)
χ	mass magnetic susceptibility of fluid ($m^3\,kg^{-1}$)
Λ	dimensionless thermal conductivity
ϕ	porosity
ξ	dimensionless solid-to-fluid heat transfer coefficient

Subscripts

f	fluid
ef	effective properties for fluid
s	solid
es	effective properties for solid

treatment such as magnetic resonance imaging and/or attachment of small magnets on the tissue surface to reduce the muscle ache. The details of these effects on the metabolism have not been clarified yet. However, there may be plenty of applications in the near future in the field of engineering operations. Thus, as a first trial we intend to study the effects of magnetic force on the natural convection in porous enclosure. The heat and flow characteristics are studied on the effect of the inclination angle (α), Darcy number (Da), and magnetic force parameter (γ). The porous medium is supposed to consist of air (paramagnetic fluid $\gamma > 0$) and soda lime, and the corresponding thermal and magnetic properties can be found in Refs. [7,13].

2. System considered

The schematic view of the problem is shown in Fig. 1. The cubic enclosure is filled with saturated porous medium. One of a vertical wall is isothermally heated and an opposite wall is cooled and the other walls are thermally insulated. A coil is set above and coaxially with the enclosure to produce magnetic field. The hot and cold walls are kept vertically while the magnetic force field is inclined at an angle of α from a gravitational direction. Fig. 1b shows schematics of the gravity force separated in the Y- and Z-coordinate with the X-axis kept horizontal and the magnetic force is mostly in the Z-coordinate. The inclination angle (α) varies from 0 to $\pi/2$. In the present study, the size of the cubic enclosure H is 0.064 m, the radius R of coil is 0.05 m and the distance h between coil and the center of the cubic is 0.032 m (see Fig. 1). However, the qualitative results are not limited for these combinations of parameters.

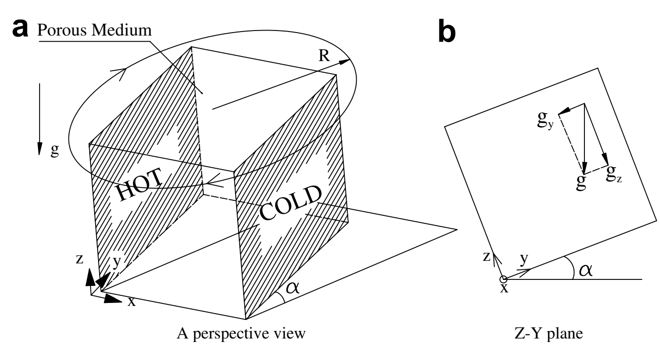

Fig. 1. Schematic diagram of the physical system.