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Effect of dust particles on thermal convection in ferromagnetic fluid saturating a porous medium

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Abstract

This paper deals with the theoretical investigation of the effect of dust particles on the thermal convection in ferromagnetic fluid saturating a porous medium subjected to a transverse uniform magnetic field. For a flat ferromagnetic fluid layer contained between two free boundaries, the exact solution is obtained using a linear stability analysis. For the case of stationary convection, medium permeability, dust particles and magnetization have always a destabilizing effect on the onset of instability. The critical wave number and critical magnetic thermal Rayleigh number for the onset of instability are also determined numerically for sufficiently large values of buoyancy magnetization parameter M_1. Graphs have been plotted by giving numerical values to the parameters to depict the stability characteristics. It is observed that the critical magnetic thermal Rayleigh number is reduced solely because the heat capacity of clean fluid is supplemented by that of the dust particles. The principle of exchange of stabilities is found to hold true for the ferromagnetic fluid saturating a porous medium heated from below in the absence of dust particles. The oscillatory modes are introduced due to the presence of the dust particles, which were non-existent in their absence. A sufficient condition for the non-existence of overstability is also obtained.

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Keywords: Ferromagnetic fluid; Thermal convection; Porous medium; Dust particles

1. Introduction

In the last millennium, the investigation on ferrofluids attracted researchers because of the increase of applications in areas such as instrumentation, lubrication, vacuum technology, vibration damping, metals recovery, acoustics; its commercial usage includes vacuum feed-throughs for semiconductor manufacturing and related uses, pressure seals for compressors and blowers, engineering, medicine, chemical reactor and high-speed silent

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Nomenclature

b	subscript; basic state
$\mathbf{B}$	magnetic induction (T)
B	magnitude of $\mathbf{B}$ (T)
$C_{V,H}$	specific heat at constant volume and magnetic field (kJ/m^3 K)
C_s	specific heat of solid (porous matrix) material (kJ/m^3 K)
C_{pt}	specific heat of dust particles (kJ/m^3 K)
d	thickness of the ferromagnetic fluid layer (m)
D/Dt	the convective derivative (s^{-1})
$\mathbf{g}$	acceleration due to gravity $\mathbf{g} = (0, 0, -g)$ (m/s^2)
$\mathbf{H}$	magnetic field intensity (amp/m)
$\mathbf{H}^{ext}$	external magnetic field intensity (amp/m)
$\mathbf{H}'$	the perturbation in magnetic field intensity (amp/m)
H	magnitude of $\mathbf{H}$ (amp/m)
H_0	uniform magnetic field intensity (amp/m)
K	Stokes drag coefficient (kg/s)
$\hat{\mathbf{k}}$	unit vector in the z-direction
k_x	the wave number along the x-direction (m^{-1})
k_y	the wave number along the y-direction (m^{-1})
k	the resultant wave number, $k = \sqrt{(k_x^2 + k_y^2)}$ (m^{-1})
k_1	medium permeability (m^2)
K_1	thermal conductivity (W/m K)
K_2	$[= -(\partial M/\partial T)_{H_0,T_a}]$ the pyromagnetic coefficient (amp/m K)
$\mathbf{M}$	magnetization (amp/m)
$\mathbf{M}'$	the perturbation in the magnetization (amp/m)
M	magnitude of $\mathbf{M}$ (amp/m)
M_0	the magnetization when magnetic field is H_0 and temperature T_a (amp/m)
p	the fluid pressure (psi)
p'	the perturbation in fluid pressure (psi)
$\mathbf{q}$	Darcian (filter) velocity of the ferromagnetic fluid (m/s)
$\mathbf{q}' = (u, v, w)$	the perturbation in velocity (0, 0, 0) (m/s)
$\mathbf{q}_d$	filter velocity of the dust particles (m/s)
$\mathbf{q}_1'$	$= (\ell, r, s)$ the perturbation in velocity (0, 0, 0) (m/s)
t	time (s)
T	temperature (K)
T_0	constant average temperature at the bottom surface $z = -d/2$ (K)
T_1	constant average temperature at the upper surface $z = +d/2$ (K)
T_a	average temperature (K)

Greek letters

α	coefficient of thermal expansion (K^{-1})
β	a uniform temperature gradient $\beta(= \lvert dT/dz \rvert)$ (K/m)
ν	kinematic viscosity (m^2/s)
μ	dynamic viscosity (constant) (kg/m s^2)
μ_0	magnetic permeability of free space (H/m)
η	the particle radius (m)
ρ	fluid density (kg/m^3)
ρ_0	density at the ambient temperature (kg/m^3)
ρ_s	density of solid (porous matrix) material (kg/m^3)
χ	$= (\partial M/\partial H)_{H_0,T_a}$ the magnetic susceptibility
θ	the perturbation in temperature T(K)
ρ'	the perturbation in density ρ (kg/m^3)
∇	del operator (m^{-1})
ε	medium porosity (m^3/m^3)
σ	the growth rate (s^{-1})
Φ'	the perturbed magnetic potential (amp)

printers, etc. The major perspectives are connected with a massive shocks and oscillation damping (earthquake, airbags), but the contemporary application concerned mostly seals and cooling of loudspeakers. Strong efforts have been undertaken to synthesize stable suspensions of magnetic