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MHD flow and heat transfer in a backward-facing step☆

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Abstract

The laminar flow of a viscous incompressible electrically conducting fluid in a backward-facing step is investigated under the usual magnetohydrodynamic (MHD) hypothesis. Numerical simulations are performed for Reynolds numbers less then $Re=380$ in the range of $0 \leq N \leq 0.2$, where N is the Stuart number or interaction parameter which is the ratio of electromagnetic force to inertia force. Heat transfer is investigated for Prandtl number ranging from $Pr=0.02$ corresponding to liquid metal, to $Pr=7$ corresponding to water. It is found through the calculation of the reattachment length that external magnetic field acts to decrease the size of the recirculation zone. Velocity profiles show that, out of the recirculation zone, the basic flow is damped by the magnetic induced force, whereas flow near the walls channel is accelerated. Heat transfer is significantly enhanced by the magnetic field in the case of fluids of high Prandtl numbers.

Keywords: Backward-facing step; Magnetohydrodynamic; Heat transfer; Magnetic field

1. Introduction

Magnetohydrodynamics (MHD) flows of an electrically conducting fluid are encountered in many industrial applications such as purification of molten metals from non-metallic inclusions, liquid metal, plasma, metal working process, geothermal energy extractions and in many other applications. Amaouche et al. [1] examine the effect of a constant magnetic field on the thermal instability of a two dimensional stagnation point. It is found through the calculation of neutral stability curves that magnetic field acts to increase the stability of the basic flow. Wang and Chen [2] studied the effect of magnetic field on mixed convection boundary layer flow on inclined wavy plates. They showed that the action of the magnetic field tends to accelerate the flow near the leading edge and decelerate it far downstream of the leading edge. The control of vortex shedding and heat transfer by magnetic field is achieved by Lee et al. [3] in the case of confined jet flow. As the intensity of applied magnetic field increases, the vortex shedding formed in the channel becomes weaker and the oscillating amplitude of impinging

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Nomenclature

$\vec{B}$	external magnetic field
C_P	specific heat at constant pressure
$\vec{F}$	Lorentz force
$\vec{J}$	current density
H	channel width downstream of the step
h	step height
k	thermal conductivity of the fluid
N	Stuart number $(\sigma HB^2/\rho u_{av})$
Nu	local Nusselt number $(-\partial\theta/\partial y)_w]$
$\overline{Nu}$	space averaged Nusselt number
Pe	Peclet number $(Re \cdot Pr]$
Pr	Prandtl number $(\mu C_P/k)$
Re	Reynolds number $(u_{av}\ H/v)$
u_{av}	averaged velocity at the channel inlet
$\vec{u}$	velocity vector
u, v	velocity components nondimensionalized by u_{av}
x, y	Cartesian coordinates nondimensionalized by H
Xr	reattachment length

Greek symbols

θ	dimensionless temperature $(T-T_c)/(T_h-T_c)]$
μ	dynamic viscosity of the fluid
v	kinematic viscosity of the fluid
ρ	density of the fluid
ϕ	electrical potential
σ	electrical conductivity

Subscripts

av	average
c	cold
h	hot
w	wall

jet decrease. The flow and thermal fields become the steady state if the magnetic Reynolds number is greater than a critical value.

2. Problem statement

Two-dimensional forced convection flow of electrically conducting fluid in a backward-facing step submitted to a uniform magnetic field is simulated. The computational domain and the coordinate system are presented in Fig. 1. Channel expansion ratio is fixed at $H/h=2$ in all the study. The applied magnetic field is normal to the plane (x, y). At the channel inlet, a fully developed parabolic profile for the axial velocity is deployed. No-slip boundary conditions for velocities on all solid walls are used. At the exit, convective boundary condition (CBC) is used for all variables. Thermal boundary conditions are those of Chen et al. [4], the inlet flow is assumed to be at high temperature while the walls downstream of the step are at low temperature.