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Effect of slip on entropy generation in a single rotating disk in MHD flow

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ABSTRACT

In the present study, the effect of slip on entropy generation in magnetohydrodynamic (MHD) flow over a rotating disk is investigated by semi-numerical analytical solution technique. The nonlinear governing equations of flow and thermal fields are reduced to ordinary differential equations by the Von Karman approach, then solved via differential transform method (DTM), a recently-developed, powerful analytical method. Related entropy generation equations are derived and nondimensionalized using geometrical and physical flow field-dependent parameters. For a rotating surface the form of slip introduced into the governing equations is rarefaction. For comparison, slip and no-slip regimes in the range $0.1 > Kn > 0$ and their interaction with magnetic effects are investigated by minimum entropy generation. While minimizing entropy generation, equipartitioning is encountered between fluid friction irreversibility and Joule dissipation.

1. Introduction

In the last three decades, an increasing awareness of the limits of world energy resources has caused countries to reexamine their energy policies. Governments have taken drastic measures to eliminate wasted energy. The scientific community has started taking a closer look at energy conversion devices and developing new techniques and analysis methods to better utilize existing resources. All energy producing, converting and consuming systems must be reexamined carefully and all possible available-work destruction mechanisms removed. On the theoretical side, this can only be done by utilizing the second law of thermodynamics which is related to entropy generation.

The first traceable interest in magnetohydrodynamics (MHD) flow was in 1907, when Northrup built an MHD pump prototype [1,2]. Since then, analysis of the effects of both rotation and magnetic fields on fluid flows has been an active area of research. While technology expanded in many directions, the subject of MHD has developed in the use of magnetic fields and the range of fluid and thermal processes [3]. In many practical applications, such as MHD power generator and boundary layer flow control are required to know the effect of magnetic fields on flow fields. Many mechanical systems employ integrated microelectronic and chip elements. As a result, increasingly small electronic parts are produced and the heat produced by these components must be removed for a reliable and long life. During the production and working life of microelectronic heat transfer devices, an electrically conducting fluid is subject to a magnetic field [4–6]. In such cases the fluid experiences a Lorentz force which changes the flow velocities. This in turn affects the rate of heat and mass transfer. By knowing these compound and complicated effects, new or improved designs in the manufacturing process can be devel-

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Nomenclature

B	magnetic induction vector
Be	Bejan number
B_o	constant magnetic flux density
Br	rotational Brinkman number
c_p	constant temperature specific heat
E	electric field
F	dimensionless radial velocities
G	dimensionless circumferential velocities
H	dimensionless axial velocities
J	electric current
k	thermal conductivity
Kn	Knudsen number
N_f	entropy generation due to fluid friction
N_G	entropy generation number
N_H	entropy generation due to heat transfer
N_m	entropy generation due to joule dissipation effect
$N_{S,av}$	dimensionless volumetric entropy generation rate
p	pressure
P	dimensionless pressure
r	radial coordinate
Pr	Prandtl number
Q	electric charge density
R	radius
$\bar{r}$	dimensionless radial coordinate
Re	rotational Reynolds number
Re_m	magnetic Reynolds number
$\dot{S}_G'''$	rate of entropy generation
T	temperature
T_∞	temperature at infinity
u	radial velocity
V	velocity vector
v	circumferential velocity
w	axial velocity
z	axial coordinate

Greek letters

α	dimensionless temperature difference
β	magnetic interaction number
γ	slip factor
ζ	dimensionless axial coordinate
η	tangential momentum accommodation coefficient
θ	circumferential coordinate
ϑ	dimensionless temperature
λ	mean free path
λ_m	magnetic diffusivity
μ	dynamic viscosity
ρ	density
σ	fluid's electrical conductivity
Φ	viscous dissipation function
ϕ	irreversibility distribution ratio
Ω	angular velocity of the rotating disk
$\forall$	volume

Subscripts

av	average
0	reference value
∞	ambient condition

oped [7]. Therefore the problem considered is related to rotary-type MHD flow with slip. Flow fields of rotating disks in a magnetic field is chosen since these types of flow fields are of great interest in many practical and engineering tasks.