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Entropy generation in a porous annulus due to micropolar fluid flow with slip and convective boundary conditions

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ABSTRACT

A numerical work has been performed to study the entropy generation of micropolar fluid flow and heat transfer in an annulus with porous walls under the transverse magnetic field associated with slip and convective boundary conditions. Assume that the injection velocity at one wall is same as the suction velocity at the other wall. The governing equations of the fluid flow are linearized using quasilinearisation method and further, solved by the Chebyshev spectral collocation method. The numerical data for velocity, microrotation and temperature fields are used to evaluate entropy generation and Bejan number. It has been found that the maximum entropy generation is observed at the inner cylinder and minimum entropy generation is observed at the outer cylinder. Also entropy generation increases with increase in coupling number, Hartman number, cross flow Reynolds number, Biot number and Brinkman number. Whereas it reduces with increase in slip parameter.

1. Introduction

Nowadays, entropy generation has been the topic of great interest in many fields such as electronic cooling, heat exchangers, porous media, turbo machinery, and combustions. The optimization of thermal systems has been received a unique attention. Thermal systems have been analyzed and optimized using the second law of thermodynamics. The second law of thermodynamics states that the Exergy (available energy) is always destroyed partially or totally and destroyed amount of energy is proportional to the entropy generation. The performance of thermal devices is always affected by irreversible losses that lead to an increase of entropy and reduction of thermal efficiency. Thus, our ability to reduce the entropy generation or minimize the destruction of energy is related to the best efficient energy system design. There are various sources for entropy generation in engineering systems. In thermal systems, the main sources of entropy generation are heat transfer, viscous dissipation, electrical conduction and chemical reaction. The different effective factors behind the entropy generation in applied thermal engineering, where destruction of available work of a system occurs during the generation of entropy, was investigated by Bejan [1,2]. Numerous researches [3–8] have analyzed the irreversibility profiles and entropy generation for different geometric configurations with porous inserts.

The flow between concentric cylinders, where inner or outer cylinders rotate has many applications such as swirl nozzles, rotating electrical machines, commercial viscometers, journal bearings, and chemical and mechanical mixing devices. In practical situations, many factors affect the flow and heat transfer through annular space. Considerable research studies were carried out to investigate the fluid flow through concentric cylinders. Kahraman and Yurusoy [9] investigated the entropy generation due to non-Newtonian fluid flow in an annular pipe with relative rotation. Mirzazadeh et al. [10] studied the characteristics of heat transfer and entropy generation for the viscoelastic fluid flow through an annulus of the concentric rotating cylinders with different angular velocities. Yari [11] analyzed the entropy generation and fluid flow through micro annulus by considering the slip velocity, viscous dissipation effect and temperature jump. It is noticed that the entropy generation decreases with an increase in the Knudsen number. Chen et al. [12] presented the effects of Prandtl number, Rayleigh number and curvature of annulus on flow pattern, temperature distribution and entropy generation inside a vertically concentric annular space due to natural convection. Tshehla and Makinde [13] studied the entropy generation in the flow of a variable viscosity fluid through two concentric pipes with convective cooling. Mahian et al. [14–16] presented the entropy generation of

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Nomenclature

Be	Bejan number
Bi_1,Bi_2	Biot numbers
B_0	magnetic induction
Br	Brinkman number
C_f	skin friction coefficient
f	dimensionless velocity
g	dimensionless microrotation
Ha	Hartman number
h_1,h_2	the convective heat transfer coefficients
j^*	microinertia parameter
K_f	thermal conductivity
m^2	micropolar parameter
N	coupling number
N_h	entropy generation due to heat transfer
N_ϑ	entropy generation due to viscous dissipation
N_m	entropy generation due to magnetic field
N_s	dimensionless entropy generation number
Nu	Nusselt number
P	fluid pressure
P_r	Prandtl number
R	cross flow Reynolds number
r_1,r_2	radius of the inner and outer cylinders
T	temperature
T_1	ambient temperature
T_2	temperature of the hot fluid
T_p	dimensionless temperature difference

Greek symbols

α	slip parameter
β,γ	gyration viscosity coefficients
κ	vortex viscosity
ρ	density of the fluid
σ	dimensional microrotational component
σ_e	fluid electrical conductivity
θ	dimensionless temperature
Ω_1,Ω_2	angular velocities of the inner and outer cylinders
μ	viscosity of the fluid

Superscripts

$'$	differentiation with respect to η

nanofluid flow through an annulus of rotating concentric cylinders. Assad and Oztop [17] examined the effect of internal heat generation on entropy generation between two rotating cylinders. They proved that the decreasing internal heat generation results in a decrease in entropy generation. Chauhan and Kumar [18] studied Entropy analysis in an annulus partly saturated with a porous medium due to third grade fluid flow. Mahian et al. [19–21] determined the influence of MHD flow on the entropy generation for Newtonian and non-Newtonian fluid flow through a vertical annulus. Mazgar et al. [22] presented entropy generation due to interaction between thermal radiation and mixed convection in a semi-transparent and non-gray gas, bounded by two vertical coaxial cylinders. Eegunjobi and Makinde [23] investigated the entropy generation rate numerically for a transient variable viscosity Couette flow between two concentric pipes.

The study of heat transfer has much importance in high temperature processes like nuclear plants, gas turbines, thermal energy storage etc. Different kinds of boundary conditions are applied in heat transfer processes. Thermal boundary conditions, heat flux boundary conditions and convective boundary conditions are commonly encountered in heat transfer processes. Further, the study of slip velocity has much importance in both macro and micro scales in technology such as polishing of surfaces and in micro devices. The effects of these boundary conditions on entropy generation for any fluid flow of different geometries have been studied by several authors. Mahmud and Fraser [24] applied the second law of thermodynamics to analyze the heat transfer and fluid motion in rotating concentric cylinders using heat flux boundary conditions. Iman [25] investigated the importance of thermal boundary conditions of the heated/cooled walls in the development of flow, heat transfer, and observed the characteristics of entropy generation in a porous enclosure. Antar and El-Shaarawi [26] investigated the effects of uniform heat flux boundary conditions on entropy generation over a rotating solid sphere with forced convection. Butt et al. [27] presented the effects of hydrodynamic slip on entropy generation in a viscous flow over a vertical plate with convective boundary conditions. Anandalakshmi and Basak [28] studied the effect of various heating patterns (different heating and Rayleigh-Benard convection) on entropy generation in a porous rhombic enclosure for different Pr and inclination angles. Anand [29] discussed the velocity slip effect on heat transfer and entropy generation of fully developed power law fluid flow in a micro channel. Mostafa and Ali [30] presented the effect of slip boundary condition on entropy generation for Newtonian and non-Newtonian fluid flows through a parallel plate channel. Ibanez [31] studied the combined effects of magnetic field, suction/injection Reynolds number and hydrodynamic slip on the entropy generation subjected to convective boundary conditions. Adesanya and Makinde [32] examined the entropy generation in couple stress fluid flow steadily through a porous channel with slip velocity. Adesanya and Makinde [33] investigated the thermodynamic analysis in forced convective flow of a third grade fluid through a vertical channel.

Studies on micropolar fluids have recently received considerable attention due to their application in a number of processes that occur in industry. Such applications include the extrusion of polymer fluids and real fluids with suspensions, solidification of liquid crystals, cooling of a metallic plate in a bath, animal bloods, porous media, turbulent shear flows, flow in capillaries and micro channels, and colloidal and suspension solutions. In Micropolar fluids rigid particles contained in a small fluid volume element are limited to rotation about the center of the volume element described by the micro-rotation vector. Physically micropolar fluids may be described as the non-Newtonian fluids consisting of dumb-bell molecules or short rigid cylindrical elements. The theory of micropolar fluids is first proposed by Eringen [34]. Weng et al. [35] applied the micropolar fluid to study the stability problem of flow between two concentric rotating cylinders. Nadeem et al. [36] studied the peristaltic flow of a micropolar fluid with heat transfer in an annulus. Imtiaz and Mahfouz [37] investigated numerically the conjugate heat transfer in an annulus between two concentric cylinders. Devi et al. [38] studied the mixed convection micro polar flow through a porous medium in a cylindrical annulus using finite element analysis. Srinivasacharya and Himabindu [39] considered the entropy generation in a micropolar fluid flow through an inclined channel with slip and convective boundary conditions.

The aim of the present work is to examine the effects of Biot number, slip parameter and Hartman number on entropy generation between porous concentric rotating cylinders due to micropolar fluid flow. The governing equations in cylindrical coordinates