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Entropy generation due to micropolar fluid flow between concentric cylinders with slip and convective boundary conditions

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Abstract In this study, the entropy generation of micropolar fluid flow through concentric cylindrical annulus associated with slip and convective boundary conditions is performed numerically. The fluid flow in an annulus is due to the rotation of the outer cylinder with constant velocity. The analysis of such kind of fluid flow is governed by nonlinear partial differential equations. In the present study these equations are solved using the spectral quasilinearization method. The resultant velocity, microrotation and temperature distributions from the spectral quasi linearization method are used to evaluate the entropy generation rate and the Bejan number. Further the impact of boundary conditions on the entropy generation is also presented.

1. Introduction

Fluid flow and heat transfer inside a cylindrical annular space through convection have many significant engineering applications. This type of fluid flow is observed in rotating electrical machines, swirl nozzles, rotating disks, standard commercial rheometers, and other chemical and mechanical mixing equipments. In practical situations, many factors affect the flow and heat transfer through annular space. Considerable research studies were carried out to investigate the Newtonian and non-Newtonian fluid flow through concentric cylinders. Taylor [1] studied theoretically and experimentally the flow of viscous incompressible fluid between two concentric cylinders. Hessami et al. [2] analyzed laminar mixed convection flow pattern and heat transfer for air inside a vertical cylindrical annular space. Borjini et al. [3] studied the effect of radiation on unsteady numerical convection between two horizontal concentric and vertically eccentric cylinders. Atayilmaz [4] carried out both numerical and experimental analysis on natural convection of heat transfer from horizontal concentric cylinders. Deka and Paul [5] studied the viscous flow between two porous concentric circular cylinders with radial flow and a constant heat flux at the inner cylinder.

Most of the industrial and engineering flow processes and thermal systems are unable to perform optimally due to entropy generation. It is important to establish the factors that

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Nomenclature

a	radius of the inner cylinder	Re	Reynolds number
b	radius of the outer cylinder	T_p	dimensionless temperature difference
Be	Bejan number		
Bi	Biot number	*Greek symbols*	
Br	Brinkman number	α	slip parameter
g^*	acceleration due to gravity	β, γ	gyration viscosity coefficients
g_s	buoyancy parameter	κ	vortex viscosity
Gr	Grashof number	ρ	density of the fluid
K_f	thermal conductivity	Γ	dimensionless microrotational component
m^2	micropolar parameter	θ	dimensionless temperature
N	coupling number	μ	viscosity of the fluid
N_v	entropy generation due to viscous dissipation		
N_h	entropy generation due to heat transfer	*Superscript*	
N_s	dimensionless entropy generation	$'$	differentiation with respect to λ

contribute to entropy generation. The established factors are to be minimized, thus optimizing the energy resources and flow system efficiency. Entropy analysis is a technique to quantify the thermodynamic irreversibility in any fluid flow and heat transfer processes, which is an outcome of second law of thermodynamics. Entropy generation is a measure of the amount of irreversibility associated with the real processes. Different factors that affect the entropy generation are heat transfer across finite temperature gradient, characteristic of convective heat transfer, viscous effects, etc. Entropy generation destroys the available energy of a system and as a result, imposes considerable extra costs to any thermal system.

The concept of entropy generation minimization is developed by Bejan [6]. Several researchers investigated the entropy generation on fluid flows through concentric cylinders. Sahin [7] investigated the entropy generation for a viscous fluid flow in a duct subjected to constant surface temperature. Tasnim and Mahmud [8] studied the entropy generation in a vertical concentric channel with isothermal boundary conditions. Haddad et al. [9] presented the entropy generation due to laminar forced convection in the entrance region of a concentric cylindrical annulus. It was found that the thermal entropy generation is relatively dominant over viscous entropy generation. Yari [10] studied the second-law analysis and entropy generation for heat transfer and fluid flow through microannulus by considering the viscous dissipation effect, slip velocity and temperature jump. Chen et al. [11] analyzed the natural convection and entropy generation in a vertically concentric annular space. Assad and Oztop [12] presented the effect of internal heat generation on entropy generation between two rotating cylinders. Mazgar et al. [13] studied the entropy generation through combined non-gray gas radiation and mixed convection within a concentric cylindrical annulus. Eegunjobi and Makinde [14] investigated the entropy generation rate in transient Couette flow of variable viscosity fluid between two concentric pipes where inner pipe is moving and outer pipe is fixed. Rashidi et al. [15] studied the effects of magnetic interaction number, slip factor and relative temperature difference on velocity and temperature profiles as well as entropy generation in magnetohydrodynamic (MHD) flow of a fluid with variable properties over a rotating disk. Das et al. [16] analyzed the entropy generation in a Couette flow caused due to the movement of the upper channel wall with suction/injection in rotating frame of reference.

Few studies on entropy generation are related to non-Newtonian fluids. Yilbas et al. [17] studied the entropy analysis for non-Newtonian fluid flow in annular Pipe. They found that the rate of entropy generation can be reduced by reducing both non-Newtonian parameter and Brinkman number. Kahraman and Yurusoy [18] examined the entropy generation due to non-Newtonian fluid flow in an annular pipe with relative rotation using a third-grade fluid model. Mirzazadeh et al. [19] have focused on the entropy generation induced by the flow of a non-linear viscoelastic fluid between concentric rotating cylinders. Their results showed that the entropy generation number increases with increase in Brinkman number. Mahian et al. [20] studied the entropy generation due to flow and heat transfer of nanofluids between corotating cylinders with constant heat flux on the walls. Kim et al. [21] investigated numerically the entropy generation in a U-shaped Pulsating Heat Pipe. Chen et al. [22] studied numerically the heat transfer and entropy generation within a fully developed mixed convection flow of Al_2O_3–water nanofluid in a vertical channel. Mkwizu and Makinde [23] investigated Brownian motion, thermophoresis and variable viscosity on entropy generation of nanofluid flow through a parallel channel with convective cooling. Das et al. [24] examined the entropy generation on pseudo-plastic nanofluid flow through a porous channel under the MHD effect with convective heating.

The non-Newtonian fluids, which include colloidal fluids, heterogeneous mixtures, exotic lubricants, animal blood, most slurries, and some liquids with polymer additives have microstructure and therefore do not follow the Newtonian fluid flow theory. In order to explore and understand the behavior of such fluids there were many non-Newtonian fluid theories established. Among these, micropolar fluid theory introduced by Eringen [25] has distinct features, such as microscopic effects arising from the local structure, micro motion of fluid elements, presence of couple stresses, body couples and non-symmetric stress tensor. Thus, it can be used to study the behavior of exotic lubricants, colloidal suspensions or polymeric additives, blood flow, liquid crystals and dirty oils.

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