ARTICLE IN PRESS

Propulsion and Power Research ■■■■;■(■):■■■–■■■

HOSTED BY

ELSEVIER

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com

ORIGINAL ARTICLE

Micropolar fluid flow and heat transfer over an exponentially permeable shrinking sheet

Aurangzaib[a], Md. Sharif Uddin[b], Krishnendu Bhattacharyya[c,d,*], Sharidan Shafie[e]

[a]Department of Mathematical Sciences, Federal Urdu University of Arts, Science & Technology, Gulshan-e-Iqbal, Karachi, Pakistan
[b]Mathematics Discipline, Khulna University, Khulna 9208, Bangladesh
[c]Department of Mathematics, Institute of Science, Banaras Hindu University, Varanasi 221005, Uttar Pradesh, India[1]
[d]Department of Mathematics, The University of Burdwan, Burdwan 713104, West Bengal, India
[e]Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, Skudai, Johor Bahru 81310, Johor, Malaysia

Received 10 June 2015; accepted 29 August 2016

KEYWORDS

Micropolar fluid flow;
Heat transfer;
Dual solutions;
Shrinking sheet;
Exponential velocity

Abstract The importance of boundary layer flow of micropolar fluid and heat transfer over an exponentially permeable shrinking sheet is analysed. The similarity approach is adopted and self-similar ordinary differential equations are obtained and then those are solved numerically using very efficient shooting method. Similar to that of Newtonian fluid flow case, here also dual similarity solutions for velocity, microrotation and temperature are obtained when certain amount of mass suction is applied through the porous sheet. For steady flow of micropolar fluid over exponentially shrinking porous sheet the mass suction need to be stronger compared to the Newtonian fluid flow. From dual velocity, microrotation, and temperature profiles it is found that the velocity decreases with material parameter (related to micropolar fluid) for first solution and it increases for second, whereas the effects are opposite for fluid temperature. On the other hand, for larger material parameter microrotation profile reduces for both types of solutions. But it significant that the skin friction coefficient, the couple stress coefficient and the heat transfer coefficient show similar variation with increasing material parameter, all those physical quantities decrease for first solution and increase for second solution.

*Corresponding author. Tel.: +91 9474634200.

E-mail addresses: krish.math@yahoo.com, krishmath@bhu.ac.in, krishnendu.math@gmail.com (Krishnendu Bhattacharyya).

[1]Previous affiliation of K. Bhattacharyya.

Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

http://dx.doi.org/10.1016/j.jppr.2016.11.005

1. Introduction

The boundary layer flow and heat transfer due to a stretching/shrinking sheet is very important and has attracted considerable interest of various researchers because of its huge number of applications in industry and engineering. Some of such applications are in aerodynamic extrusion of plastic sheets, hot rolling, metal spinning, artificial fibers, glass-fiber production, paper production, and drawing of plastic films. The pioneering work was made by Crane [1], he examined the steady flow over a linearly stretching plate. The effect of suction or injection with heat and mass transfer over a stretching sheet was discussed by Gupta and Gupta [2]. Dutta et al. [3] investigated the temperature distribution in the flow on a stretching sheet in the presence of heat flux. Since then Crane's work was extended by many researcher [4–9] by considering different aspect. However, very limited attention has been given to study the flow over an exponentially stretching sheet though it is very significant in many engineering processes. The flow with heat transfer over an exponentially stretching sheet was first considered by Magyari and Keller [10]. The boundary layer flow and heat transfer over an exponentially stretching sheet in the presence of wall mass suction was studied by Elbashbeshy [11]. Al-Odat et al. [12] reported the magnetic effect on thermal boundary layer on an exponentially stretching surface with an exponential temperature distribution. Later, Sajid and Hayat [13] examined the effect of thermal radiation on the boundary layer flow over an exponentially stretching sheet using homotopy analysis method (HAM) and reported series solutions for velocity and temperature. Bidin and Nazar [14] and Ishak [15] investigated numerically the radiation effect on the flow and heat transfer over an exponentially stretching sheet. Bhattacharyya [16] demonstrated the characteristics of steady flow and reactive mass transfer past an exponentially stretching sheet in presence of an exponentially moving free stream. Liu et al. [17] analyzed the boundary-layer three-dimensional flow and heat transfer of a viscous fluid due to an exponentially stretching surface. Nadeem et al. [18] and Bhattacharyya and Layek [19] studied different aspects of the flow of nanofluid past an exponentially stretching sheet with various conditions. Recently, important articles on boundary layer flow for exponential stretching of flat sheet were reported by Mukhopadhyay et al. [20], Ene and Marinca [21] and Raju et al. [22].

In last few decades, the study of micropolar fluids has been considered by many researchers because of numerous industrial and engineering applications like colloids and polymeric suspensions, cervical flows, contaminated and clean engine lubricants, radial diffusion paint rheology, and thrust bearing technologies. A micropolar fluid was first introduced by Eringen [23]. The micropolar fluids are non-Newtonian fluids consisting of a suspension of small body fluids and colloidal fluid elements such as large dumbbell molecules. In the theory of micropolar fluids, the local effect arising from the microstructure and the intrinsic motion of fluid elements are taken into account. Peddieson and McNitt [24] extended the pioneer work of Erigen [23] in boundary layer theory. Ahmadi [25] obtained the self-similar solution of two-dimensional flow of a micropolar fluid on a semi-infinite plate. The steady boundary layer flow of a micropolar fluid was investigated numerically by Kümmerer [26]. A significant contribution in the theory of micropolar fluid was made by Sankara and Watson [27], when they investigated the boundary layer flow of micropolar fluids over a stretching surface. Later, Heruska et al. [28] extended the work of Sankara and Watson [27] to consider the effect of suction or injection through the porous sheet. The heat transfer in a micropolar flow over a non-isothermal stretching sheet with suction and blowing was examined by Hassanien and Gorla [29]. Na and Pop [30] considered the flow of micropolar fluid due to continuously stretching boundary. Das [31] investigated the combined effects of thermophoresis and chemical reaction with heat and mass transfer of a micropolar fluid over an inclined plate in the presence of variable fluid properties.

Recently, the flow of incompressible fluid near a shrinking sheet has attracted many researchers due to its numerous engineering applications. This kind of flow was first analyzed analytically by Wang [32]. Later, the existence and uniqueness of the flow over a shrinking sheet was proved by Miklavčič and Wang [33]. Fang [34] considered the power law surface velocity and mass transfer near a continuously shrinking sheet. Fang and Zhang [35] discussed MHD viscous flow over a shrinking sheet in the presence of suction through the porous sheet and obtained a closed-form analytical solution. Later, Ishak et al. [36] extended the problem of shrinking sheet to micropolar fluid by considering the stagnation point flow. Turkyilmazoglu [37] obtained multiple solutions for the hydromagnetic flow electrically conducting viscoelastic fluid over a shrinking sheet. The boundary layer flow and heat transfer over a shrinking sheet filled with micropolar fluid was discussed by Yacob and Ishak [38]. Bhattacharyya et al. [39] examined the boundary layer flow and heat transfer of a micropolar fluid past a porous shrinking sheet in the presence of thermal radiation and Turkyilmazoglu [40] determined the bounds for existence multiple solutions mathematically of same flow dynamics. Bhattacharyya et al. [41] illustrated the effects of magnetic field and chemical reaction on boundary layer stagnation-point flow and mass transfer over shrinking sheet with suction/blowing. Turkyilmazoglu [42,43] considered the MHD slip flow of non-Newtonian fluid over a shrinking surface. Bhattacharyya [44] investigated the boundary layer flow due to exponentially porous shrinking sheet and Bhattacharyya and Pop [45] studied the external magnetic field effect on that flow. Jain and Choudhary [46] showed the MHD effect on boundary layer flow in porous medium over an exponentially shrinking porous sheet with slip.

Motivated by the importance of micropolar fluid flow and the flow due to shrinking sheet, in this paper the flow of

Please cite this article as: Aurangzaib, et al., Micropolar fluid flow and heat transfer over an exponentially permeable shrinking sheet, Propulsion and Power Research (2016), http://dx.doi.org/10.1016/j.jppr.2016.11.005