Alexandria Engineering Journal (2015) 54, 1029–1036

HOSTED BY

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Analysis of heat transfer due to stretching cylinder with partial slip and prescribed heat flux: A Chebyshev Spectral Newton Iterative Scheme

A. Majeed [a], T. Javed [a], A. Ghaffari [a,*], M.M. Rashidi [b,c]

[a] Department of Mathematics and Statistic, International Islamic University, Islamabad 44000, Pakistan
[b] Shanghai Key Lab of Vehicle Aerodynamics and Vehicle Thermal Management Systems, Tongji University, 4800 Cao An Rd., Jiading, Shanghai 201804, China
[c] ENN-Tongji Clean Energy Institute of Advanced Studies, Shanghai, China

Received 24 May 2015; revised 23 August 2015; accepted 29 September 2015
Available online 23 October 2015

KEYWORDS

Casson fluid;
Boundary layer flow;
Spectral method;
Stretching cylinder;
Partial slip

Abstract This study is dedicated to analyze the combined effects of partial slip and prescribed surface heat flux when the fluid is moving due to stretching cylinder. A very moderate and powerful technique Chebyshev Spectral Newton Iterative Scheme is used to determine the solution of the present mathematical model. Involved physical parameters, namely the slip parameter, Casson fluid parameter, curvature parameter and Prandtl number are utilized to control the fluid moments and temperature distribution. The results show that the fluid velocity and the skin friction coefficient on the stretching cylinder are strongly influenced by the slip parameter. It is further analyzed that hydrodynamic boundary layer decreases and thermal boundary layer increases with the slip parameter. Influence of Casson fluid parameter on temperature profile provides the opposite behavior as compared to the slip parameter. The comparison of numerical values of skin friction coefficient and the local Nusselt number is made with the results available in the literature. The accuracy and convergence of Chebyshev Spectral Newton Iterative Scheme is compared with finite difference scheme (Keller box method) through tables. The CPU time is calculated for both schemes. It is observed that CSNIS is efficient, less time consuming, stable and rapid convergent.

1. Introduction

It is extremely difficult to find the exact or series solutions of every industrial and engineering problems. In this situation, scientists and engineers are taking much interest in finding the numerical solution of the problem, especially for nonlinear coupled equations. In the past, many researchers used different techniques to solve many laminar and turbulent flow problems

* Corresponding author. Tel.: +92 51 9019511.
E-mail address: abuzar.iiui@gmail.com (A. Ghaffari).
Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2015.09.015

Nomenclature

a	radius of cylinder
C_f	skin friction coefficient
c_p	specific heat at constant pressure
f	dimensionless stream function
k	thermal conductivity
l	reference length
Nu	Nusselt number
p	pressure
Pr	Prandtl number
q_w	surface heat flux
Re_x	local Reynolds number
r	radial coordinate
T	fluid temperature
T_w	temperature of the cylinder surface
T_∞	ambient temperature
u	radial velocity component
U_w	velocity of the stretching cylinder
w	axial velocity component
z	axial coordinate

Greek symbols

β	Casson fluid parameter
γ	transverse curvature
η	similarity variable
θ	dimensionless temperature
ν	kinematic viscosity
μ	dynamic viscosity
τ_w	surface shear stress
ρ	density
ψ	stream function

Subscripts

w	conditions at the surface
∞	conditions at infinity

Superscript

$'$	differentiation with respect to η

in which Cortell [1] used shooting method with Runge–Kutta scheme to solve the Blasius flow problem. Keller and Cebeci [2] have introduced the implicit finite difference scheme known as Keller-box method for laminar and turbulent boundary layer flow. Sharma et al. [3] solved unsteady MHD convection heat and mass transfer past a semi-infinite vertical porous moving plate using element free Galerkin method. Keimanesh et al. [4] used Multi-Step Differential transform method to solve third grade non-Newtonian fluid flow between two parallel plates. Rashidi et al. [5,6] used Homotopy analysis method (HAM) to solve non-Newtonian fluid flow problem between circular plates and over non-isothermal wedge. Recently Motsa has developed some efficient numerical techniques namely Spectral Homotopy analysis method [7], Spectral Relaxation method and Spectral Quasi-linearization method [8] and Spectral local linearization method [9] to investigate boundary layer flow problems.

Flow over a stretching cylinder has fascinated many researchers due to its industrial and engineering applications. Crane [10] was the first who investigated the flow over a stretching sheet. Gupta and Gupta [11], Datta et al. [12], Chen and Char [13] extended the work of Crane [10] by including the heat and mass transfer analysis under different physical situations. Wang [14] was the pioneer, who investigated the flow over a stretching cylinder. Ishak et al. [15,16] have discussed uniform suction/blowing and MHD effects on flow and heat transfer due to stretching cylinder. Abbas et al. [17] dealt with the laminar MHD flow and heat transfer of an electrically conducting viscous fluid over a stretching cylinder in the presence of thermal radiation through a porous medium. Bachok and Ishak [18] investigated the steady laminar flow caused by a stretching cylinder immersed in an incompressible viscous fluid with prescribed surface heat flux.

In literature survey, it is discovered that the flow field obeys the no-slip condition. However, certain physical situations exist which do not cope with the said conditions that is why the replacement of no-slip boundary condition with slip boundary condition is highly essential. The role of the slip condition is vital in shear skin, hysteresis effects and spurts. Slips comes into existence when the fluid is a rarefied gas, [19], or in the case when it is particulate such as blood, foam, emulsion or suspension [20]. Slip also arises on hydrophobic surfaces, especially in micro and nano-fluidics [21]. Recently, Mukhopadhyay [22–24] studied the effects of partial slip with MHD and chemically reactive solute transfer over a stretching cylinder. Hayat et al. [25] have investigated the effect of heat and mass transfer in flow along a vertical stretching cylinder with slip condition. A rheological model of Casson fluid pronounces the properties of many polymers over a wide range of shear rates. Various experimental studies on blood flow with varying hematocrits, anticoagulants, temperature, etc. offer the behavior of blood as a Casson fluid. Recently in this connection some useful research achievements are made for Casson fluid flow over a stretching surfaces [26–29].

In this article, we studied the heat and fluid flow of non-Newtonian Casson fluid due to stretching cylinder with partial slip and prescribed heat flux using the Chebyshev Spectral Newton Iterative Scheme (CSNIS). The effects of the parameters on velocity and temperature profiles are discoursed with the assistance of graphs. The graphs of skin friction coefficient and the local Nusselt number are plotted against different values of parameters. Comparison of the numerical values of skin friction coefficient and the local Nusselt number is performed with the help of those results already found in the literature as well as the said comparison is done with finite difference method as shown in tables. It is found that the results are in excellent agreement.

2. Problem formulation

We considered the flow of non-Newtonian Casson fluid outside the stretching cylinder of radius r. The flow is assumed as steady and axi-symmetric subjected to laminar boundary