Ain Shams Engineering Journal (2015) xxx, xxx–xxx

Ain Shams University

Ain Shams Engineering Journal

www.elsevier.com/locate/asej
www.sciencedirect.com

MECHANICAL ENGINEERING

Non-similar solutions of mixed convection flow from an exponentially stretching surface

P.M. Patil [a,*], D.N. Latha [a], S. Roy [b], Ebrahim Momoniat [c]

[a] *Department of Mathematics, Karnatak University, Pavate Nagar, Dharwad 580 003, India*
[b] *Department of Mathematics, I. I. T. Madras, Chennai 600 036, India*
[c] *School of Computational and Applied Mathematics, University of Witwatersrand, Private Bag-3, Wits-2050, Johannesburg, South Africa*

Received 25 May 2015; revised 7 September 2015; accepted 18 October 2015

KEYWORDS

Double diffusive convection;
Non-similar solution;
Exponentially stretching sheet;
Chemical reaction;
Newton's linearization and finite difference scheme

Abstract In this paper we focus on to obtaining non-similar solutions for steady two dimensional double diffusive mixed convection boundary layer flows over an impermeable exponentially stretching sheet in an exponentially moving free stream under the influence of chemically reactive species. The nonlinear partial differential equations governing the flow, temperature and species concentration fields are presented in non-dimensional form with the help of suitable non-similar transformations. The resulting final non-dimensional set of coupled nonlinear partial differential equations is solved by using an implicit finite difference scheme in combination with the Newton's linearization technique. The effects of various non-dimensional physical parameters on velocity, temperature and species concentration fields are discussed. The results reveal that the streamwise coordinate ξ remarkably influences the flow, thermal and solutal concentration fields which display the existence of non-similar solutions.

1. Introduction

Self-similar solutions for the coupled momentum, thermal and species concentration boundary layers over flat surfaces are presented comprehensively in the convective heat and mass transfer text books by Incropera et al. [1] and Bejan [2]. Bejan [2] has suggested a similarity temperature variable which reduces the energy equation to an ordinary differential equation. Soundalgekar and Murty [3] have examined the effects of power law surface temperature variation on the heat transfer from a continuous moving surface with constant surface velocity. Similarity solutions were reported by Ali [4] for the case of a power-law surface velocity and three different thermal boundary conditions. Moutsoglou and Chen [5] have considered buoyancy effects on the flow and heat transfer from an inclined continuous sheet with either uniform wall temperature or uniform surface heat flux.

* Corresponding author.
E-mail addresses: pmpmath@gmail.com, pmpatil@kud.ac.in (P.M. Patil), sjroy@iitm.ac.in (S. Roy), Ebrahim.Momoniat@wits.ac.za (E. Momoniat).

Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.asej.2015.10.012
2090-4479 © 2015 Faculty of Engineering, Ain Shams University. Production and hosting by Elsevier B.V.

Nomenclature

C	species concentration
C_f	local skin-friction coefficient
C_p	specific heat at constant pressure
C_w	concentration at the wall
C_∞	ambient species concentration
D	mass diffusivity
f	dimensionless stream function
F	dimensionless velocity
g	acceleration due to gravity
G	dimensionless temperature
Gr, Gr^*	Grashof numbers due to temperature and species concentration, respectively
H	dimensionless species concentration
L	characteristic length (m)
N	ratio of buoyancy forces
Nu	Nusselt number
Pr	Prandtl number (ν/α)
Re_L	Reynolds number
Ri	Richardson number
$R(x)$	variable chemical reaction rate
Sc	Schmidt number (ν/D)
Sh	Sherwood number
T	temperature (K)
T_w	temperature at the wall (K)
T_∞	ambient temperature of the fluid (K)
u	velocity component in the x direction (m s^{-1})
v	velocity component in the y direction (m s^{-1})
x, y	Cartesian coordinates (m)

Greek symbols

α	thermal diffusivity (m^2 s^{-1})
β, β^*	volumetric coefficients of the thermal and concentration expansions, respectively
Δ	chemical reaction parameter
ε	velocity ratio parameter
ξ, η	transformed variables
μ	dynamic viscosity (kg m^{-1} s^{-1})
ν	kinematic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})
ψ	stream function (m^2 s^{-1})

Subscripts

e	free stream condition
w	conditions at the wall
ξ, η	denote the partial derivatives with respect to these variables, respectively

Magyari and Keller [6] have examined the heat and mass transfer characteristics on boundary layer flow due to an exponentially continuous stretching sheet. An effect of suction on the heat transfer phenomena over an exponentially stretching continuous surface was examined by Elbashbeshy [7]. Partha et al. [8] have investigated the effects of viscous dissipation on the mixed convection heat transfer from an exponentially stretching surface. Al-Odat et al. [9] have studied the effects of magnetic field on the thermal boundary layer flow over an exponentially stretching continuous surface. Sajid and Hayat [10] have studied the influence of thermal radiation on the boundary layer flow due to an exponentially stretching sheet. Bidin and Nazar [11] obtained the numerical solutions of the boundary layer flow over an exponentially stretching sheet with thermal radiation. Dulal Pal [12] discussed the mixed convection heat transfer in the boundary layers on an exponentially stretching sheet with magnetic field. The effect of radiation on the MHD boundary layer flow due to an exponentially stretching sheet was investigated by Ishak [13]. Mukhopadhyay and Gorla [14] have examined the effects of partial slip on boundary layer flow past a permeable exponentially stretching sheet in the presence of thermal radiation. In all these studies, self-similar or locally similar solutions have been presented. Rehman et al. [15] have studied the boundary layer stagnation point flow of third grade fluid over an exponentially stretching sheet. Stagnation flow of couple stress nanofluid over an exponentially stretching sheet through porous medium was examined by Rehman et al. [16]. Rahman and Nadeem [17] have analyzed the heat transfer characteristics over a vertical exponentially stretching cylinder. Rehman et al. [18] have discussed the nanoparticle effect over the boundary layer flow from an exponentially stretching cylinder. Hayat et al. [19–21] have examined the effects of three dimensional flows for MHD, viscoelastic and Eyring-Powel fluids over an exponentially stretching sheet. Flow of Casson nanofluid with viscous dissipation and convective conditions were studied by Hussain et al. [22].

Further, the phenomenon of chemically reactive species has special significance in chemical and hydrometallurgical industries. The formation of smog represents a first order homogeneous chemical reaction. For instance, one can take into account the emission of NO_2 from automobiles and other smokestacks. Thus, NO_2 reacts chemically in the atmosphere with unburned hydrocarbons (aided by sunlight) and produces peroxyacetylnitrate, which forms a layer of photo-chemical smog. Chemical reactions can be treated as either homogeneous or heterogeneous processes. It depends on whether they occur at an interface or as a single-phase volume reaction [23]. Patil and Kulkarni [24] have examined the effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation. Patil and Pop [25] have studied the effects of surface transfer on unsteady mixed convection flow over a vertical cone with chemical reaction. Effects of chemical reaction on mixed convection flow of a polar fluid through a porous medium in the presence of internal heat generation were examined by Patil et al. [26]. Hayat et al. [27] have analyzed the effects of temperature and concentration stratification of mixed convection flow of an Oldroyd-B fluid with thermal radiation and chemical reaction. Shehzad et al. [28] have discussed the stagnation point flow of thixotropic fluid with mass transfer and chemical reaction. Hayat et al. [29] have examined the effects of Soret and Dufour on three-dimensional flow over an exponentially stretching surface through a porous medium in the presence of chemical reaction and heat source/sink. Hsiao [30,31] analyzed the heat and mass transfer characteristics on mixed

Please cite this article in press as: Patil PM et al., Non-similar solutions of mixed convection flow from an exponentially stretching surface, Ain Shams Eng J (2015), http://dx.doi.org/10.1016/j.asej.2015.10.012