International Communications in Heat and Mass Transfer 38 (2011) 917–922

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Dual solutions in boundary layer stagnation-point flow and mass transfer with chemical reaction past a stretching/shrinking sheet☆

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ARTICLE INFO

Available online 1 May 2011

Keywords:
Dual solutions
Boundary layer
Stagnation-point flow
Mass transfer
Chemical reaction
Stretching/shrinking sheet

ABSTRACT

In this paper, an analysis is presented to study dual nature of solution of mass transfer with first order chemical reaction in boundary layer stagnation-point flow over a stretching/shrinking sheet. The governing equations are transformed into a set of self-similar ordinary differential equations by similarity transformations. The transformed equations are solved numerically using very efficient shooting method. The study reveals that the dual solutions of velocity and concentration exist for certain values of velocity ratio parameter (the ratio of stretching/shrinking rate and straining rate). The concentration boundary layer thickness decreases with increasing values of Schmidt number and reaction-rate parameter for both solutions.

1. Introduction

The viscous flow in the boundary layer region due to a stretching sheet has immense theoretical and technical applications in manufacturing processes in industries such as the aerodynamic extrusion of plastic sheets, glass fiber production, the cooling and drying of paper and textiles. Crane [1] was first who considered steady boundary layer flow of a viscous incompressible fluid over a linearly stretching plate and found closed form analytical solution for the self-similar equations. The pioneering work of Crane [1] was extended by many researchers such as Pavlov [2], Gupta and Gupta [3], Rajagopal et al. [4], Sankara and Watson [5], Chen and Char [6], Vajravelu and Rollins [7] and Chamkha [8] by considering different types of fluid and various physical conditions. On the other hand, Hiemenz [9] first investigated the two-dimensional stagnation flow over a plate and developed an exact solution to the Navier Stokes equations. Chiam [10] studied the combine problem of Hiemenz [9] and Crane [1] i.e. the stagnation-point flow over a stretching sheet where he considered identical stretching velocity and straining velocity and found no boundary layer structure near the sheet. After few years, Mahapatra and Gupta [11] re-investigated the stagnation-point flow towards a stretching sheet taking different stretching and straining velocities and ultimately they found two different kinds of boundary layer structure near the sheet depending on the ratio of the stretching and straining velocity rates. However, some other important investigations concerning the stagnation-point flow over stretching sheet were made by Mahapatra and Gupta [12], Nazar et al. [13], Ishak et al. [14], Layek et al. [15], Ishak et al. [16] and Nadeem et al. [17]. Recently, Ishak et al. [18–20] reported dual solutions for mixed convection stagnation-point flow on a vertical surface.

Literature survey indicates that the flow induced by a shrinking sheet recently gains attention of modern researchers for its interesting characteristics. In the best of author's knowledge, Wang [21] first brought in the concept of the flow developed due to shrinking sheet while studying the behavior of liquid film on an unsteady stretching sheet. The existence and uniqueness of the similarity solution of the equation for the flow due to a shrinking sheet with suction were established by Miklavčič and Wang [22]. Hayat et al. [23] gave an analytic solution of magnetohydrodynamic (MHD) flow of a second grade fluid over a shrinking sheet. Later, Hayat et al. [24] also obtained an analytical solution of the MHD rotating flow of a second grade fluid past a porous shrinking sheet by homotopy analysis method (HAM). Fang and Zhang [25] found a closed-form exact solution for two-dimensional MHD flow over a porous shrinking sheet subjected to wall mass transfer. Noor et al. [26] reported a series solution of MHD viscous flow due to a shrinking sheet using Adomian decomposition method (ADM). Recently, Fang et al. [27] solved analytically the viscous flow over a porous shrinking sheet with a second order slip flow model. Further, Fang and his co-authors [28–33] discussed some other important aspects of shrinking flow. On the other hand, Wang [34] first investigated the stagnation-point flow towards a shrinking sheet for both two-dimensional and axisymmetric cases. He obtained dual solutions and unique solution for specific values of the ratio of shrinking and straining rates. Wang's [34] problem extended by Ishak et al. [35], Bhattacharyya and Layek [36], Bhattacharyya et al. [37] and Lok et al. [38] with different physical conditions.

The diffusion of spices with chemical reaction in the boundary layer flow has huge applications in water and air pollutions, fibrous insulation, atmospheric flows and many other chemical engineering problems. Chambre and Young [39] considered the diffusion of a

☆ Communicated by A.R. Balakrishnan and T. Basak.

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0735-1933/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2011.04.020