

HOSTED BY



Contents lists available at ScienceDirect

# Engineering Science and Technology, an International Journal

journal homepage: <http://www.elsevier.com/locate/jestch>

## Full Length Article

# Melting heat transfer in boundary layer stagnation-point flow of nanofluid toward a stretching sheet with induced magnetic field

B.J. Gireesha<sup>a,b,\*</sup>, B. Mahanthesh<sup>b,c</sup>, I.S. Shivakumara<sup>d</sup>, K.M. Eshwarappa<sup>e</sup><sup>a</sup> Department of Mechanical Engineering, Cleveland State University, Cleveland, OH 44114, USA<sup>b</sup> Department of Studies and Research in Mathematics, Kuvempu University, Shankaraghatta, Shimoga 577 451, Karnataka, India<sup>c</sup> Department of Mathematics, AIMS Institutes, Peenya, Bangalore 560058, Karnataka, India<sup>d</sup> Department of Mathematics, Bangalore University, Karnataka, India<sup>e</sup> Department of Mathematics, Government Science College, Hassan, Karnataka, India

## ARTICLE INFO

### Article history:

Received 20 June 2015

Received in revised form

23 July 2015

Accepted 30 July 2015

Available online 9 September 2015

### Keywords:

Induced magnetic field

Melting heat transfer

Stagnation-point

Nanofluid

Heat generation/absorption

## ABSTRACT

A steady two-dimensional hydromagnetic stagnation-point flow of an electrically conducting nanofluid past a stretching surface with induced magnetic field, melting effect and heat generation/absorption has been analyzed numerically. The model used for the nanofluid incorporates the effects of Brownian motion and thermophoresis. The nonlinear partial differential equations are transformed into ordinary differential equations using suitable similarity transformations, before being solved numerically. Effect of pertinent parameters on different flow fields are determined and discussed in detail through several plots and a table. Obtained numerical results are compared and found to be in good agreement with previously published results in a limiting sense. Further, in the absence of melting and magnetic field effect, the skin friction co-efficient results are compared with exact solutions, which are reported earlier.

Copyright © 2015, The Authors. Production and hosting by Elsevier B.V. on behalf of Karabuk University. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## 1. Introduction

Boundary layer flow and heat transfer characteristics over stretching surfaces have been the topics of extensive research due to their wide range of applications, such as manufacturing of food and paper, polymer extrusion, wire drawing, glass fiber production, stretching of plastic films and many others. Sakiadis [1] was the first among others to consider the steady boundary layer flow of a viscous incompressible fluid on a continuous flat surface. Crane [2] extended this work [1] over a stretching surface. The results obtained in the present study have similar physical agreement with the work of Crane [2] and Hsiao [3,4] who have studied the heat and mass mixed convection for magnetohydro-dynamic viscoelastic fluid past a stretching sheet with Ohmic dissipation. An analysis has been made by Liancun et al. [5] to study the solution of an unsteady flow and heat transfer on a permeable stretching sheet with non uniform heat source/sink. Recently, Gireesha et al. [6] reported the numerical solution for boundary layer flow past a non-isothermal stretching surface with Hall effect. On the other hand, stagnation regions exist on all blunt bodies moving in a viscous fluid. The stagnation-point flow is described as the fluid flow near the stagnation region of a

circular body, which exists for both the cases of a fixed or moving body in a fluid. The study of boundary layer stagnation-point flow of an incompressible viscous fluid on a stretching sheet has attracted the attention of researchers due to its wide applications in industry and practical applications. Some of the applications are cooling of electronic devices by fans, cooling of nuclear reactors during emergency shutdown, solar central receivers exposed to wind currents, in the design of thrust bearings and radial diffusers, drag reduction, thermal oil recovery and many hydrodynamic processes. In view of these applications, Hiemenz [7] investigated the two-dimensional stagnation point flow over a plate. Later on, Gorla [8] studied the stagnation point flow of a non-Newtonian fluid in the presence of a transverse magnetic field. Mahapatra and Gupta [9] analyzed heat transfer characteristics in stagnation-point flow toward stretching sheet. Representative studies dealing with the stagnation-point flow have been reported by Nazar et al. [10], Ishak et al. [11], Takhar et al. [12] and Ramesh et al. [13].

Nanofluid is a fluid containing nanometer sized particles, called nanoparticles. It is well known that the nanofluids can tremendously enhance the heat transfer characteristics of the base fluid. Heat transfer is an important process in physics and engineering, and therefore improvements in heat transfer characteristics will improve the efficiency of many processes. Thus, nanofluids have many applications in industry such as heat exchangers, coolants, micro-channel heat sinks and lubricants. Based on these real world applications, Choi [14] has introduced the concept of nanofluid in

\* Corresponding author. Tel.: +91 9741 148002, fax: +91 08282 256255.

E-mail address: [g.bijjanaljayanna@csuohio.edu](mailto:g.bijjanaljayanna@csuohio.edu) (B.J. Gireesha).

Peer review under responsibility of Karabuk University.

order to develop advanced heat transfer fluids with substantially higher conductivities. Later on, the boundary layer flow of nanofluid past a stretching surface under the effect of Brownian motion and thermophoresis was investigated by Khan and Pop [15]. Kuznetsov and Nield [16] investigated the natural convective boundary-layer flow of a nanofluid past a vertical plate by incorporating Brownian motion and thermophoresis effects. Recently, Chamkha et al. [17] analyzed the natural convection past a sphere embedded in a porous medium saturated by a nanofluid. Gorla et al. [18] have reported the numerical solutions for a steady boundary layer flow of nanofluid on a stretching circular cylinder in a stagnant free stream. Unsteady boundary layer stagnation-point flow in a nanofluid was examined by Bachok et al. [19]. Makinde and Aziz [20] obtained the numerical solution for boundary layer flow and heat transfer of nanofluid over a stretching surface with convective boundary conditions. Alsaedi et al. [21] analyzed the stagnation point flow of nanofluid near a permeable stretched surface with convective boundary. A numerical study has been carried out by Gireesha et al. [22] to study the nanoparticle effects on three-dimensional boundary layer flow and heat transfer of an Eyring–Powell fluid over a stretching sheet. They also considered the Brownian motion and thermophoresis effects and solved the problem using Shooting method. Hsiao [23] investigated the heat and mass transfer mixed convection nanofluid flow. Chaoli et al. [24] studied the MHD flow and radiation heat transfer of nanofluids in porous media with variable surface heat flux and chemical reaction. The velocity slip and temperature jump effects on nanofluid over a stretching sheet was carried out by Liancun et al. [25]. Recently, Gireesha et al. [26] have studied the effect of dust particles on boundary layer flow and heat transfer of nanofluid over a porous stretching surface.

Melting heat transfer in steady laminar flow over a stationary flat plate has been studied by Epstein and Cho [27]. Then after, Kazmierczak et al. [28] studied the steady convection flow over a flat plate embedded in a porous medium with melting heat transfer effect. Gorla et al. [29] have studied the melting heat transfer in mixed convection flow over vertical plate. Recently, an analysis has been carried out by Bachok et al. [30] to analyze a steady two-dimensional stagnation point flow and heat transfer over a melting stretching sheet. On the other hand, the effect of an induced magnetic field in an electrically conducting fluid has wide range of applications in real world problems. Such studies are pertinent in astronautical re-entry, thermo-magneto-aerodynamics, nuclear reactors, MHD energy generator systems and magnetohydrodynamic boundary layer control technologies [31]. To date, very little attention has been shown to consider the effect of induced magnetic field on boundary layer flow and heat transfer over surfaces. Kumari et al. [32] considered the boundary layer flow and heat transfer on stretching surface with induced magnetic field. An unsteady laminar boundary layer flow of an electrically conducting fluid past a semi-infinite flat plate with an aligned magnetic field has been studied by Takhar et al. [33]. Beg et al. [34] studied the hydromagnetic convection flow of a Newtonian, electrically-conducting liquid metal past a translating, non-conducting plate with aligned magnetic field. Ghosh et al. [35] presented an exact solution for hydromagnetic natural convection boundary layer flow past an infinite vertical flat plate under the influence of a transverse magnetic field with magnetic induction effects. Liancun et al. [36] have addressed the MHD effects on the flow and heat transfer over a porous shrinking surface with velocity slip and temperature jump. Recently, Ali et al. [37,38] investigated the influence of an induced magnetic field on boundary layer stagnation-point flow over a stretching surface.

Motivated by the aforementioned works, the aim of the present study is to investigate the influence of magnetohydrodynamic effects on melting heat transfer in boundary layer stagnation-point flow of an electrically conducting nanofluid toward a stretching surface

with heat source/sink and induced magnetic field. The novelty of this study is to analyze the effect of an induced magnetic field on melting heat transfer in electrically conducting nanofluids. After applying similarity transformations, the resulting governing equations have been solved numerically using standard method called Runge–Kutta–Fehlberg fourth-fifth order scheme for velocity, temperature and concentration profiles.

## 2. Problem formulation

The physical configuration of the present problem is as shown in Fig. 1. We have considered a steady two-dimensional hydromagnetic boundary layer flow of an electrically conducting nanofluid near a stagnation point toward a stretching surface in its own plane with velocity proportional to the distance from stagnation point. The influence of an induced magnetic field is taken into account.

It is assumed that the velocity of an external flow is  $U_e(x) = ax$  and the velocity of stretching sheet is  $U_w(x) = cx$ , where  $a$  and  $c$  are positive constants. The temperature of melting surface is  $T_m$ , while ambient values of temperature and nanoparticle volume fraction are  $T_\infty$  and  $C_\infty$  respectively, where  $T_\infty > T_m$  and  $C_w$  is the value of nanoparticle volume fraction at the surface.

The basic equations for the steady flow of an electrically conducting nanofluid by neglecting the effect of Hall current, viscous dissipation and Ohmic heating can be written as follows ([34] and [35]):

Continuity equation for velocity:

$$\nabla \cdot \mathbf{V} = 0, \quad (2.1a)$$

Continuity equation for induced magnetic field:

$$\nabla \cdot \mathbf{H} = 0, \quad (2.1b)$$

Conservation of momentum equation:

$$\rho_f (\mathbf{V} \cdot \nabla) \mathbf{V} - \frac{\mu_e}{4\pi} (\mathbf{H} \cdot \nabla) \mathbf{H} = -\nabla P + \mu \nabla^2 \mathbf{V}, \quad (2.2)$$

Conservation of induced magnetic field equation:

$$\nabla \times (\mathbf{V} \times \mathbf{H}) + \eta_0 \nabla^2 \mathbf{H} = 0, \quad (2.3)$$

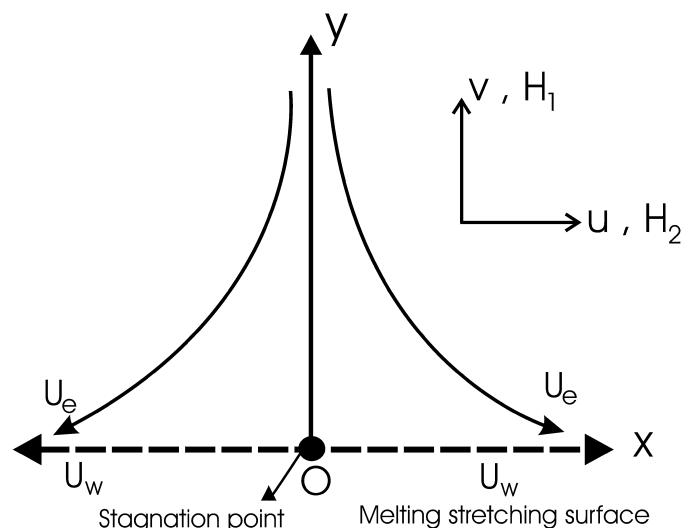


Fig. 1. Physical model and geometry of the problem.

Download English Version:

<https://daneshyari.com/en/article/477556>

Download Persian Version:

<https://daneshyari.com/article/477556>

[Daneshyari.com](https://daneshyari.com)