Powder Technology 315 (2017) 194–204

Contents lists available at ScienceDirect

Powder Technology

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

Heat and mass transfer analysis of nanofluid over linear and non-linear stretching surfaces with thermal radiation and chemical reaction

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ARTICLE INFO

Article history:
Received 28 January 2017
Received in revised form 22 March 2017
Accepted 26 March 2017
Available online 4 April 2017

Keywords:
MHD
Nanofluid
Linear and non-linear stretching sheets
Thermophoresis
Brownian motion

ABSTRACT

This article presents MHD heat and mass transfer flow of nanofluid over linear and non-linear stretching sheets embedded in porous media under the influence of Brownian motion, thermophoresis, thermal radiation and chemical reaction. Appropriate transformations reduce the non-linear partial differential systems into ordinary differential equations. Galerkin Finite element method is employed to solve these momentum, temperature and concentration equations numerically subject to the boundary conditions. The influence of various pertinent parameters on velocity, temperature and concentration profiles of the fluid is discussed and the results are plotted through graphs. Furthermore, skin-friction coefficient, Nusselt number and Sherwood number are investigated in detail and results are shown in tabular form. It is concluded that the velocity and temperature profiles escalate, whereas concentration profile depreciates when Brownian motion parameter rises.

1. Introduction

Nanofluid is visualized to elaborate a fluid in which the nanometer-sized particles are suspended in the conventional heat transfer base fluids like oil, water and ethylene glycol, etc. These conventional heat transfer fluids have poor heat transfer abilities due to their low thermal conductivity. To enhance the thermal conductivity of such types of fluids, the nanoscale solid particles are suspended in base fluids which change the thermophysical properties of these fluids and enhanced the heat transfer rate remarkably. Choi [1] first used the word nanoparticles to enhance the thermal conductivity of base fluids. He described many experimental and numerical studies in literature to know how the thermal conductivity is enhanced. Eastman et al. [2] has revealed that the thermal conductivity-enhanced ethylene glycol based nanofluid has increased up to 60% when CuO nanoparticles of volume fraction 5% are added to base particle. Buongiorno [3] developed a mathematical model for convective transport of nanofluid. He concluded that the thermophoresis and Brownian motion mechanism are most important mechanism to analyze the convective heat and mass transfer characteristics. Tiwari and Das [4] have analyzed heat transfer augmentation of nanofluids in a two-sided lid-driven heated square cavity. Abu-Nada et al. [5] have deliberated the effects of inclination angle on natural convection in enclosures filled with Cu-water nanofluid. Kuznetsov and Nield [6] studied the influence of Brownian motion and thermophoresis on natural convection boundary layer flow of a nanofluid past a vertical plate. Magnetic nanoparticles are especially useful in biomedicine, sink float separation, cancer therapy, etc. Specific biomedical applications involving nanofluids include hyperthermia, magnetic cell separation, drug delivery and contrast enhancement in magnetic resonance imaging. Thermal radiation plays a very significant role in the surface heat transfer when convection heat transfer is very small. It has applications in manufacturing industries for the design of reliable equipment's, nuclear plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles. Also, the effects of thermal radiation on forced and free convection flow are important in the content of space technology and process involving high temperature. In addition, in many chemical engineering processes, chemical reactions take place between a foreign mass and the working fluid which moves due to the stretching of the surface. The order of the chemical reaction depends on many factors. First order chemical reaction is one of the simplest reaction in which the rate of reaction is directly proportional to the species concentration. Rana et al. [7] presented numerical solution to the boundary layer flow and heat transfer analysis of nanofluid over a non-linear stretching sheet with Brownian motion and thermophoresis and found increment in rates of heat transfer as the values of Brownian motion rises. Noghrehabadi et al. [8] perceived the impact of slip effect and volume fraction of nanoparticle on flow and heat transfer characteristics of nanofluid over stretching sheet and found that the thickness of the thermal boundary layer is boosted as the values of velocity slip parameter upsurges. Rahman et al. [9] studied MHD radiative flow and heat transfer analysis of nanofluid over a non-linear stretching sheet by taking convective boundary condition into the account. Chamkha

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http://dx.doi.org/10.1016/j.powtec.2017.03.059
0032-5910/

et al. [10] have reported non-Darcy free convection nanofluid flow over a vertical plate saturated by porous medium with Brownian motion, thermophoresis and internal heat generation. They found that velocity, temperature and nanoparticle concentration profiles elevate in the fluid regime with higher values of Brownian motion parameter. Ghalambaz et al. [11] presented numerical solution to investigate the effect of Brownian motion and thermophoresis on flow, heat and mass transfer analysis of nanofluid over a convectively heated vertical plate and found significant enhancement in fluid velocity, temperature and concentration as the values of thermophoresis parameter rises. Ghalambaz et al. [12] analyzed theoretically the impact of variable viscosity and thermal conductivity boundary layer flow, heat and mass transfer characteristics of Al_2O_3 – water based nanofluid over vertical cone by taking enhanced boundary condition into the account. They found that the rate of heat transfer deteriorates with rising values of nanoparticle diameter and concentration when the surface of the cone is hot, however, it upsurges when the surface of the cone is cold. Rashidi et al. [13] analyzed the heat and mass transfer analysis of nanofluid over a stretching sheet under the influence of magnetic field and thermal radiation. Zargartalebi et al. [14] deliberated variable thermophysical properties of nanofluid over horizontal plate by taking zero mass flux of nanoparticle on the surface. The results reveal that the thickness of hydrodynamic and thermal boundary layers elevates with rising values of Brownian motion parameter. Sheremet et al. [15] discussed the natural convection heat transfer enhancement of three – dimensional Buongiorno's model nanofluid over porous enclosure. Chamkha et al. [16] deliberated the heat and mass transfer analysis of non–Newtonian nanoflud over vertical cone saturated by non–Darcy porous medium with uniform heat and volume fraction fluxes. Zakari et al. [17] perceived the influence various aspects like, size, shape and type of nanofluid, type and temperature of the base fluid on heat transfer enhancement of nanofluid. The results reveal that the rate of heat transfer is more when the size of the nanoparticle is less.

All the above studies are focused on boundary layer flow, heat and mass transfer analysis over a surface stretched with a linear velocity. However, in the production of plastic sheet taking a surface with a linear velocity is not more realistic, because it involves a nonlinear stretching sheet velocity. In the production of plastic sheets and in metallurgical process the stretching sheet velocity is always nonlinear, so it is more accurate to consider sheet with nonlinear velocity than the linear velocity. Keeping above applications, Mabood et al. [18] presented a numerical solution to examine the boundary layer flow and heat transfer analysis of nanofluid over a nonlinear stretching sheet with viscous dissipation and reported that the temperature of the remarkably enhances with higher values of Brownian motion and thermophoresis. Mustafa et al. [19] analyzed the impact of Brownian motion and thermophoresis on axisymmetric nanofluid flow over a nonlinear stretching sheet with zero mass flux of nanoparticles boundary condition on the surface of the sheet. Sheikholeslami et al. [20] perceived two – phase model nanofluid flow and heat transfer over nonlinear stretching sheet by taking magnetic field and thermal radiation into the account. Hayat et al. [21] studied the MHD second grade nanofluid flow over nonlinear stretching sheet by taking zero mass flux of nanoparticles at the boundary of the surface, they found that the temperature profiles of the fluid enhances with rising values of magnetic parameter. Hayat et al. [22–23] studied MHD boundary layer flow and heat transfer characteristics of nanofluid over nonlinear stretching sheet. Sheremet et al. [24] perceived the entropy generation and natural convection over differentially heated square cavity filled with Cu – water based nanofluid using the mathematical model proposed by Tiwari and Das. They reported that the values of Nusselt number boosted as the values of volume fraction of nanoparticles rises. Sudarsana Reddy et al. [25] presented MHD natural convection flow over vertical cone influenced by size, shape, type of nanofluid and type of base fluid, temperature of base fluid under variable thermophysical properties. Sudarsana Reddy et al. [26] analyzed the impact of heat generation/absorption on MHD steady state flow of Al_2O_3–water and TiO_2–water nanofluids over a stretching sheet embedded in porous media with Soret and Dufour effects. Makinde et al. [27] studied the influence of radiation, Brownian motion, thermophoresis and variable viscosity on MHD boundary layer flow, heat and mass transfer analysis of nanofluid over radially stretching convective surface. Ahmed et al. [28] deliberated unsteady axisymmetric power low fluid flow and heat transfer over stretching sheet. Sudarsana Reddy et al. [29] presented the boundary layer flow, heat and mass characteristics analysis of Cu-water and Ag-water nanofluid over a rotating disk through porous medium in the presence of magnetic field and chemical reaction. Rashad et al. [30] perceived the heat and mass transfer characteristics of Cu – water based nanofluid over rectangular cavity saturated by porous medium with magnetic field and heat generation. Rashad et al. [31] have presented mixed convection of localized heat source/sink in a nanofluid-filled lid-driven square cavity with partial slip and magnetic field. Imtiaz et al. [32] have discussed MHD flow of ferrofluid over a curved stretching surface by taking magnetic – Fe_3O_4 as the nanoparticle and water as the base fluid. They found that velocity of the fluid enhances as the values of curvature parameter upsurges.

The main aim of this article is to examine the impact of thermal radiation and chemical reaction on MHD boundary layer flow, heat and mass transfer analysis over linear and nonlinear stretching sheets saturated by porous medium. The suitable similarity transformations are introduced to convert non-linear partial differential equations into system of ordinary differential equations and are solved numerically by using extremely validated Galerkin Finite element method and the results are plotted through graphs and tables. To our knowledge, the problem is new and no such articles reported yet in the literature.

2. Mathematical analysis

Consider the steady, two-dimensional boundary layer flow of nanofluid over both linear and non-linear stretching surfaces saturated by porous medium in the presence of chemical reaction and thermal radiation. This model is used for the nanofluid incorporates the effects of thermophoresis and Brownian motion. The co-ordinate system is such that x-axis is taken along the stretching surface in direction of the motion at the origin and the y-axis is perpendicular to the surface of the sheet as shown in Fig. 1. A uniform transverse magnetic field $B = B_0 x^{\frac{n-1}{2}}$ is applied along the y-axis. The stretching surface and fluid is maintained at uniform temperature and concentration T_w and C_w and these values are assumed to be greater than the ambient temperature and concentration T_∞ and C_∞, respectively. The sheet at $y = 0$ is stretched along the x-direction with velocity $u = ax^n$ where, $a, n > 0$. Under the above stated physical situations, the governing boundary-layer and

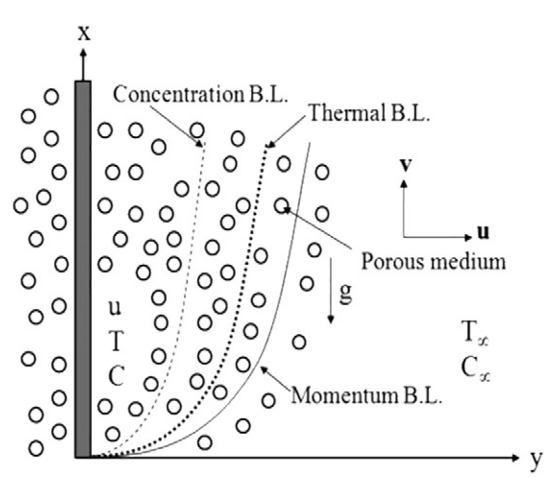

Fig. 1. Physical model and coordinate system.