Available online at www.sciencedirect.com
ScienceDirect
Comput. Methods Appl. Mech. Engrg. 329 (2018) 40–54
Computer methods in applied mechanics and engineering
www.elsevier.com/locate/cma

Three-dimensional convective flow of CNTs nanofluids with heat generation/absorption effect: A numerical study

Zakir Hussain[a,*], T. Hayat[a,b], A. Alsaedi[b], B. Ahmad[b]

[a] *Department of Mathematics, Quaid-I-Azam University 45320, Islamabad 44000, Pakistan*
[b] *Nonlinear Analysis and Applied Mathematics (NAAM) Research Group, Department of Mathematics, Faculty of Science, King Abdulaziz University, P.O. Box 80257, Jeddah 21589, Saudi Arabia*

Received 23 February 2017; received in revised form 22 May 2017; accepted 19 September 2017
Available online 2 October 2017

Highlights

- Three dimensional convective flow of CNTs nanofluids is investigated.
- Single and multiple walls carbon nanotubes are accounted as nanoparticles.
- The porous space with nonlinear stretching sheet saturates the base fluid.
- Heat and mass transfer are studied with nonuniform heat generation/absorption.
- Impact of homogeneous–heterogeneous reactions is considered.

Abstract

Three-dimensional flow of carbon water nanofluid by nonlinear stretched sheet is studied. Nanofluid saturates the porous space. Heat transfer mechanism is examined via more suitable convective type condition and nonuniform heat generation/absorption. The solutal concentration is regulated by a simple isothermal model of homogeneous–heterogeneous reactions. The numerical solutions are obtained through shooting technique by Runge–Kutta method of order five. Both single and multiple walled carbon nanotubes as nanoparticles in the base fluid are considered. Graphical illustrations and tabulated values point out the impact of sundry variables. Both components of velocity show reverse effect for stretching rate ratio. The simulations predict that wall heat flux is inversely proportional to heat generation variable. However value of heat flux is predicted more in case of larger convecting heating strength and volume fraction of carbon nanotubes. Heat transfer coefficient is more in single walled carbon nanotubes (SWCNTs) than in multi walled carbon nanotubes (MWCNTs). Heterogeneous–homogeneous variables and Schmidt number have opposite behaviors on nanoparticle concentration distribution. Excellent agreement is shown through comparison of past and present results.

Keywords: Three-dimensional flow; CNTs (SWCNT and MWCNTs); Homogeneous–heterogeneous processes; Nonlinear stretching sheet; Convective condition; Nonuniform heat generation/absorption

* Corresponding author.
E-mail addresses: zakir.qamar@yahoo.com, zhqamar@math.qau.edu.pk (Z. Hussain).

https://doi.org/10.1016/j.cma.2017.09.026
0045-7825/

1. Introduction

Carbon nanotubes were discovered in 1991 by Lijima. He investigated first time the multi walled carbon nanotubes (CNTs) through Krastschmer and Huffman method. In addition single walled carbon nanotubes were reported by Donald Bethune in 1993. Carbon nanotubes have wide applications in many areas like energy, health care, environment, electronics, etc. [1–7]. It is well known that nanofluids can reduce the difficulties related with the materials of low thermal conductivity such as kerosene oil, water, gasolene, etc. Nanofluids contain suspension of nanoscale materials of length 1–100 nm in liquid carrier. Nanofluids have fascinating utilizations in vehicle engine cooling, heat exchanger, solar water heating, bio-medicine, cooling of electronic chips, advancement in diesel engine efficiency, etc. Choi [8] first addressed the terminology of nanofluids during an anomalous rise thermal conductivity by filling water with copper nanoparticles. Solar energy is globally known as free accessible and pollution free agent of renewable energy. Solar collector changes solar radiation into heat energy. It is observed that nanofluid instead of water enhances thermal performance of these collectors [9]. The modified cooling efficiency of nanofluids can cover the emerging challenges of heat transfer in utilization such as hybrid-powered engines, refrigeration/air-conditioning, etc. Three-dimensional nanofluid flow with natural convection is explored by Sheikholeslami et al. [10]. Ellahi et al. [11] presented nanofluid flow over a sheet with mixed convection. Sheikholeslami et al. [12] investigated three-dimensional flow of nanofluid in rational system. Hayat et al. [13] reported Maxwell nanofluid in three dimension. Three dimensional MHD flow of nanofluid with slip effect is discussed by Babu et al. [14]. Mahanthesh et al. [15] addressed three-dimensional flow of MHD nanofluid with nonlinear radiation. Further literature reviews are found in these studies [16–20].

Temperature variation and heat flux at the sheet are considered in numerous studies. Convective condition has been given little attention in the past in spite of its wide utilization in processes related to nuclear plants, material drying, thermal energy storage and others. Sheikholeslami et al. [21] studied three-dimensional heat transfer of nanofluid with convective condition. Hayat et al. [22] discussed convective flow of Sisko nanofluid in three dimension. Zhou et al. [23] investigated mixed convection nanofluid in 3D with magnetic field. Rauf et al. [24] addressed Cassion nanofluid with three-dimensional convective flow. Junaid et al. [25] analyzed three-dimensional convective flow over a deforming surface. Ahmed et al. [26] reported MHD convective flow past a stretching sheet. Flow of Maxwell nanofluid with mixed convection is explored by Abbasi et al. [27]. Effects of thermal radiation, heat generation and magnetic field in three-dimensional flow of Jeffrey nanofluid are addressed by Shehzad et al. [28]. Further studies on heat transfer analysis can be reviewed in the attempts [29–40].

Reactions are categorized as homogeneous and heterogeneous. The catalyst is in same phase (homogeneous) or in opposite phase (heterogeneous) where the reaction occurs. Homogeneous catalyst occurs normally in gaseous state while heterogeneous catalyst happens in solid state. These reactions have wide range of applications in biochemical procedures, catalysis and burning, etc. Merkin et al. [41] analyzed homogeneous–heterogeneous reactions in boundary-layer flow governed by a simple isothermal model. Modeling of three-dimensional flow with homogeneous–heterogeneous reactions can be found in these studies [42–46].

Our main interest here is to deal three-dimensional nanofluid flow under the influences of homogeneous–heterogeneous reactions, nonuniform heat generation/absorption and convective boundary condition. The problems are modeled firstly and then used Runge–Kutta of order fifth for numerical solutions. The obtained results are properly discussed.

Note that Xue and renovated Hamilton–Crosser models [47,48] are considered to study thermal conductivity of CNTs nanofluid. Xue model stresses the particle size, volume fraction, thermal conductivity and temperature to enhance the thermal behavior of nanofluids. Obviously Brownian motion and thermophoresis also play main role in heat transfer advancement. Xue model has no involvement for such aspects.

2. Formulation

We investigate water carbon nanofluid flow through a porous medium. The three dimensional flow is by nonlinear stretching sheet (see Fig. 1). Nonlinear sheet velocities in x- and y-directions are $u_w = a^*(x+y)^n$ and $v_w = b^*(x+y)^n$ with $a^*, b^*, n \succ 0$ the constants. The nonuniform heat generation/absorption is also investigated. Surface temperature is adjusted by convection process through the hotted fluid with temperature T_f. Single and multi walls carbon nanotubes have been adopted as nanoparticles. The homogeneous reaction in cubic auto catalysis form is given by

$$\mathbf{A}^* + 2\mathbf{B}^* \to 3\mathbf{B}^*, rate = k_r a^{**} b^{**2}. \quad (1)$$