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Original Research Paper

Carbon nanotubes effects in the stagnation point flow towards a nonlinear stretching sheet with variable thickness

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ABSTRACT

The aim of present communication is to investigate the stagnation point flow of viscous nanofluid towards a nonlinear stretching surface with variable thickness. Analysis for both single-wall carbon nanotubes (SWNTs) and multi-wall carbon nanotubes (MWNTs) is presented and compared. Water and kerosene oil are employed as the ordinary (or base) fluids. Mathematical modeling and analysis are attended in the presence of porous medium, melting heat transfer and homogeneous and heterogeneous reactions. Diffusion coefficients for autocatalyst and reactant are treated similar. Series solutions of the governing nonlinear modeled problems have been constructed by using optimal homotopy analysis method (OHAM). This method is very efficient for development of series solutions of highly nonlinear differential equations. Computations for residual errors are prepared. Comparison of present study with the previous published work is also made. The velocity, temperature, concentration, skin friction coefficient and Nusselt number are discussed for different influential variables entering into the problems statements. The flow decreases for higher values of variable thickness parameter when $m < 1$ and it enhances when $m > 1$. Higher velocity profile is observed for volume fraction parameter in case of kerosene oil carbon nanotubes when compared with the water carbon nanotubes. The skin friction can be reduced by increasing ratio parameter and it advances by increasing volume fraction parameter. It is observed that MWCNTs has maximum heat transfer and minimum thermal resistance due to low density of MWCNTs when compared with SWNTs for water. The flow accelerates in case of MWCNTs than SWNTs for both base fluids namely water and kerosene oil. Comparison for the results of SWNTs and MWNTs is highlighted. Homogeneous reaction parameter corresponds to decrease in the concentration distribution and opposite behavior is observed for heterogeneous reaction parameter. Such consideration may play a vital role in industrial process as a cooling agent.

1. Introduction

It is now recognized fact that the use of nanofluids can overcome the limitation of low thermal conductivity of several fluids like water, kerosene oil, and ethyle glycol. Nanofluid is composed by base liquid and nanoscale particles. The nanofluids are examined quite useful in thermal engineering, heat exchangers, electronic chemical process, cancer therapy, biomedicine, etc. Nanofluids are the new production coolants that have much excellent heat transfer character than the ordinary liquid carrier. It is now shown that effective thermal conductivity for nanofluids is measurably elevated and hence potential applications to micro-scale cooling are obvious. Specially two phase flow model of nanofluids is significant in petroleum, usage of waste water, combustion and smoke emission from automobiles process. Choi [1] observed that the thermal conductivity of water is enhanced by dispersing copper nanoparticles. He firstly used the terminology of nanofluids. Solar thermal energy is pleasant, convenient and a friendly connection for many heating development in industrial sciences. A mechanism that converts solar radiation into heat energy is the solar collector. Nanofluid substitutes water to boost up the efficiency of these collectors. The improved heat transfer capability can also be engaged to many noteworthy applications including the cooling of microelectronics such as microchips in computer processors, space cooling, enhancing the efficiency of

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hybrid-powered engines, transformer oil cooling and many others. With this view point Rashidi et al. [2] investigated entropy generation in magnetohydrodynamic (MHD) flow of nanofluid by a rotating porous disk. Sheikholeslami et al. [3] reported heat transfer analysis in stretched flow of nanofluid saturating porous medium. Bhattacharyya et al. [4] examined the boundary layer flow of nanofluid past an exponentially shrinking surface. Natural convection flow of nanofluid with thermal management is studied by Sheikholeslami et al. [5]. Hayat et al. [6] examined homogenous–heterogeneous reactions and Newtonian heating effects in nanofluid flow. Turkyilmazoglu [7] examined unsteady boundary layer flow of nanofluid by a vertical flat plate. Malvandi et al. [8] analyzed influence of nanoparticle migration on force convection of alumina/water nanofluid in the presence of cooled parallel-plate channel. Kameswaran et al. [9] examined the convective/radiative heat transfer for nanofluid flow past a permeable surface via convective conditions. Zhang et al. [10] reported the magnetohydrodynamic flow of nanofluid in the presence of chemical reaction. Effect of magnetic field in natural convective flow of Cu–water nanofluid in a cavity is examined by Sheikholeslami et al. [11]. Magnetic field effect on unsteady time-dependent nanofluid flow between parallel plates is further discussed by Sheikholeslami et al. [12]. MHD free convection flow of nanofluid in an eccentric semi-annulus is studied by Sheikholeslami et al. [13]. Hsiao [14] considered MHD mixed convection flow over a stretching sheet with partial slip condition. Hajmohammadi et al. [15] examined influence of Cu and Ag nano-particles in the flow and heat transfer by permeable surfaces.

The investigation of heat transfer in flow over a stretching surface has powerful effect in the industrial and technological processes including cooling of metallic plates, paper production, glass fibers, etc. The quality of resulting products highly depends on heat transfer at stretched surface. Crane [16] firstly investigated two-dimensional flow over a stretching surface in a quiescent fluid. Rashidi et al. [17] discussed thermal radiative flow of nanofluid by a stretching sheet. Exact solution for the flow of couple stress fluid by a stretching surface is developed by Turkyilmazoglu [18]. Mukhopadhyay [19] studied stagnation point flow towards a permeable stretching surface subject to thermal radiations.

Melting characteristics phenomenon and solidification have received much attention by its widespread utilization in the industries and technologies. Scientists and engineers thus have keen interest to develop more sustainable, efficient and low cost energy storage technologies. These technologies are interlink with solar energy, waste heat recovery and plants of heat and power. Sensible heat energy, latent heat energy and chemical thermal energy are the main storage of energy. Latent heat is economically more suitable and efficient way of energy storage by changing the phase of material. Thermal energy stored through latent heat in materials can be recovered by freezing it. These processes are found in freezing of soil in ground based pump, magma solidification, the freeze treatment of sewage, the preparation of semiconductor material, the casting and welding of manufacturing process. Rahman et al. [20] analysed melting heat phenomenon in magnetohydrodynamic (MHD) steady flow and heat transfer by a moving surface with thermal radiation. Melting heat transfer of ice slab placed in the stream of hot air is studied first time by Robert [21]. Das [22] examined thermal radiation and melting effects in magnetohydrodynamic boundary layer flow over a surface. Hayat et al. [23] analyzed Soret and Dufour effects and melting heat characteristics in boundary layer flow of viscoelastic fluid over a surface. Farooq et al. [24] discussed melting heat transfer in stagnation point flow of Powell Eyring fluid. Yacob et al. [25] reported boundary layer stagnation point flow of micropolar fluid with melting heat towards a plate. Khader et al. [26] demonstrated boundary layer flow and slip velocity due to a stretching sheet with a variable thickness.

Chemical reactions associated internally with heterogeneous–homogeneous reactions. Except the involvement of catalyst many reactions have the ability to progress slowly or not at the moment. Homogeneous and heterogeneous reactions have very composite relation between them. These reaction have different rates by the reactant species together within the fluid and on the catalyst surface. These reactions appear in burning, catalysis and biochemical mechanism. Unsteady couple stress fluid flow in presence of chemical reaction is addressed by Hayat et al. [27]. Rashidi et al. [28] investigated mixed convection in boundary layer flow with chemical reaction. Batacharyya [29] examined stagnation point boundary layer flow in presence of chemical reaction.

The purpose here is to advance the stagnation point flow of nanofluid towards a stretching surface into five directions. Firstly to examine melting heat transfer. Secondly to predict the impact of h omogeneous–heterogeneous reactions. Thirdly to analyze the porous space features. Fourth to investigate CNTs (single wall and multi wall carbon nanotubes) effects for different base fluids. Fifth to consider nonlinear stretching sheet with variable thickness. Incoming dimensionless nonlinear analysis is analyzed by BVPh 2.0 which is based on homotopy analysis method [35–43]. Results for quantities of interest are computed, interpreted and compared. The individual and total square residual errors are calculated for the momentum, energy and concentration equations.

Carbon nanotubes (CNTs) are cylinders of seamless type having one or more layers of graphene (denoted single-wall, SWNT or multi-wall, MWNT) with open or closed ends. Pure CNTs have all carbons bonded except at their ends in a hexagonal lattice whereas deficiency in mass produced CNTs results pentagons, heptagons and other weaknesses in the sidewalls that generally degrade required properties. Diameters of SWNTs and MWNTs are typically 0.8–2 nm and 5–20 nm respectively although MWNT diameters can exceed 100 nm. Currently it is observed thermal, mechanical and electrical properties of CNT macro-structures like yarns and sheets keep significantly lower than those of individual CNTs. Chemical vapor deposition (CVD) is the powerful mode of high-volume CNT production and commonly uses fluidized bed reactors that empower uniform gas diffusion and heat transfer to metal catalyst nanoparticles. Graphene oxide has unique electrical, chemical and mechanical properties like large surface area, outstanding conductivity and ease of functionalisation and mass production [44–47]. For this reason, SWNTs and MWNTs with homogeneous–heterogeneous reactions is one of the most exciting analysis under investigation. In the present analysis we use single wall carbon nanotubes and multi wall carbon nanotubes with homogeneous–heterogeneous reactions using water and kerosene oil as a base fluid.

2. Problems development

The stagnation point boundary layer flow of nanofluid towards an impermeable nonlinear stretching sheet with variable thickness is considered here. Incompressible fluid saturates the porous medium. Impacts of melting phenomenon and homogeneous and heterogeneous reactions are accounted. The sheet thickness is described by $y = B(x+b)^{\frac{1-m}{2}}$. Here B is very small constant so that the sheet is sufficiently thin, m is velocity power index and b is dimensionless constant. If T_∞ and T_{m^*} denotes the ambient and melting surface temperature respectively then it is assumed that $T_\infty > T_{m^*}$. Single wall and multi wall carbon nanotubes are treated as nanoparticles. Water and kerosene oil are used as the base fluids. The heat generated throughout the irreversible reaction is not accounted. The cubic autocatalysis in homogeneous reaction case is (see Fig. 1)

$$\mathbf{A}^{**} + 2\mathbf{B}^{**} \rightarrow 3\mathbf{B}^{**}, rate = k_1 a^{**} b^{**2}. \tag{1}$$