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Effect of variable thermal conductivity and thermal radiation with CNTS suspended nanofluid over a stretching sheet with convective slip boundary conditions: Numerical study

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ABSTRACT

The problem of carbon nanotubes suspended magnetohydrodynamic (MHD) stagnation point flow over a stretching sheet for variable thermal conductivity with thermal radiation is studied in this paper. The boundary of the sheet are convective. The physical problem is modeled using a system of nonlinear partial differential equations and are then transformed into ordinary (similarity) differential equations using a proper transformation. These equations along with the corresponding boundary conditions are solved numerically using shooting technique. The solution is found to be dependent on the governing parameters. The results illustrated include the velocity and temperature profiles, as well as local skin-friction coefficient, the local Nusselt number and streamlines. Velocity profile and boundary layer thickness increases with the increase in nanoparticle volume fraction φ for SWCNT with Grashof number λ and Nanoparticle volume fraction φ for MWCNT with Grashof number λ.

1. Introduction

The cram of stream and high temperature relocate in excess of a stretching plate engrossed in an incompressible gelatinous fluid has conformist a immense pact of research curiosity appropriate to its consequence in many mechanized processes, such as in the extrusion of polymers. Crane [1] was the first who rash the flow over a linearly stretching plate and originate an exact solution for the Navier-Stokes equations. The revolutionary employment of Crane [1] has been extensive by many researchers in view of an assortment of corporeal aspects see Refs. [2–5].

In fluid dynamics, a stagnation point is a point in a flow field where the local velocity of the fluid is zero. Stagnation points exist at the surface of objects in the flow field, where the fluid is brought to rest by the object. The cram of the stagnation point flow is also a momentous theme in fluid mechanics and it ensue when a flow impinges on a solid surface. It has concerned the curiosity of many researchers because of its applications in manufacturing, including flows over the tips of aircrafts, submarines, etc. The flow over stretching plates near the stagnation point can be observed in the process of blowing and floating or spinning of fiber glass see Refs. [6–10].

Radiation heat transfer has a important impact in high temperature establishment. Many technological processes happen at high temperature and superior effective knowledge of radiative heat transfer acting an influential position in manipulative the significant apparatus. In several convenient applications depending on the surface properties and solid geometry, the radiative convey is frequently analogous with that of convective heat transfer. But, regrettably, petite is known about the possessions of radiation on the boundary layer flow of a scorching fluid. In verity, a few difficulties arise in studying radiative fluid flow. At the outset, when radiative heat transfer takes place, the radiation is captivated/emitted not only at system restrictions but also in the periphery of the system, therefore, prophecy of fluid amalgamation is a difficult chore. Secondly, the amalgamation coefficient of the fascinating emitting fluids is, in general, strongly contingent on wavelength. Thirdly, occurrence of radiation termin the energy equation makes the equation highly nonlinear. This all leads to computational complexity. Due to these difficulties, the effect of energy on convective flows has been investigated with rational simplifications. A superior prose on radiative transfer can be seen in Refs. [11–15].

The non-devotion of the fluid to a unyielding boundary, known as velocity slip, is a occurrence that has been pragmatic under convinced conditions. It is a famous fact that a viscous fluid usually firewood to the edge. But, there are many fluids, for example, particulate fluids, obscure gas etc., where there may be a slip between the fluid and the

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boundary. The belongings of slip conditions are very imperative in industrial applications such as in the polishing of synthetic heart valves and the domestic cavities. The leading study taking into account the slip boundary condition over a stretching sheet was conducted by Ref. [16,17]. It is notorious nowadays that convection boundary conditions are used to describe a linear convective temperature exchange. Heat transfer with convective boundary conditions is concerned in processes like thermal oomph storage, gas turbines, nuclear foliage, etc. see Refs. [18–20].

Due to tubular carbon particles basis, are originate to have unusual updraft possessions with great updraft conductivities. These are recognized as Carbon nanotubes (CNTs). The span of CNTs assortment from 1 nm to 100 nm and have lengths in micrometer. The thermal conductivity of single-wall CNT up to 6600 W/mK and for multi-wall CNT up to 3000 W/m.K″ has been described in [21–26]. Further related articles can be seen through Refs. [27–30].

In view of the applications described above the current problem study carbon nanotubes suspended magnetohydrodynamic (MHD) stagnation point flow over a stretching sheet for variable thermal conductivity with thermal radiation. The boundary of the sheet are convective. The physical problem is modeled using a system of nonlinear partial differential equations and are then transformed into ordinary (similarity) differential equations using a proper transformation. These equations along with the corresponding boundary conditions are solved numerically using shooting technique. The solution is found to be dependent on the governing parameters. The results illustrated include the velocity and temperature profiles, as well as local skin-friction coefficient, the local Nusselt number and streamlines.

2. Formulation of the problem

Here we discuss two dimensional boundary layer flow over a stretching sheet with nanoparticles. Sheet is stretched with the different velocity u_w, v_w beside the x-axis and $y-$ axis respectively. Further, we have revealed the constant temperature T_w at wall and the ambient temperature T_∞ see Fig. 1.

Underneath the above conventions the main governing equations with the boundary layer approximations can be defined as follow

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \tag{1}$$

$$\rho_{nf}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\mu_{nf}\left(\frac{\partial^2 u}{\partial y^2}\right)+g(\rho\beta)_{nf}(T-T_\infty)-\sigma B_o^2 u, \tag{2}$$

$$\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\frac{1}{(\rho C_p)_{nf}}\frac{\partial}{\partial y}\left(k_{nf}*\frac{\partial T}{\partial y}-q_r\right). \tag{3}$$

The corresponding boundary conditions are stated as

$$u=u_w+A\frac{\partial u}{\partial y}, v=-v_w, \text{-k}_f\frac{\partial T}{\partial y}=h_f(T_w-T_\infty), \quad at \quad y=0, \tag{4a}$$

$$u\to 0, \quad T\to T_\infty, \quad as \quad y\to\infty. \tag{4b}$$

In above equations u and v are the velocity components along the x and $y-$ axes, respectively, u_w is velocity at wall, T is the temperature, ρ_{nf} is the nanofluid density, μ_{nf} is the viscosity of nanofluid and α_{nf} is the thermal diffusivity of nanofluid, T_w is the wall temperature, T_∞ is the ambient fluid temperature, g is the acceleration due to gravity, σ is the electric conductivity, B_0 is the uniform magnetic field strength, and q_r. is the radiative heat flux. A is the velocity slip factor, v_w is the wall mass flux with $v_w<0$ for suction and $v_w>0$ for injection, respectively k_f is the thermal conductivity of the ordinary fluid and h_f is the convective heat transfer coefficient.

The variable thermal conductivity (Reddy et al. [17]), is considered to vary linearly with temperature as given below

$$k*=k(1+\varepsilon\theta), \tag{5}$$

By using the Rosseland diffusion approximation (Reddy et al. [17]), the radiative heat flux is given by

$$q_r=-\frac{4}{3}\frac{\sigma*}{k*}\frac{\partial T^4}{\partial y}, \tag{6}$$

where σ^* is the Stefan-Boltzmann constant and k^* is the mean absorption coefficient. It should be noted that, by using the Rosseland approximation, the present analysis is limited to optically thick fluids. Taking the refractive index of the gas medium to be constant, unidirectional radiation flux [17]

$$T^4\cong 4T_\infty{}^3T-3T_\infty{}^4, \tag{7}$$

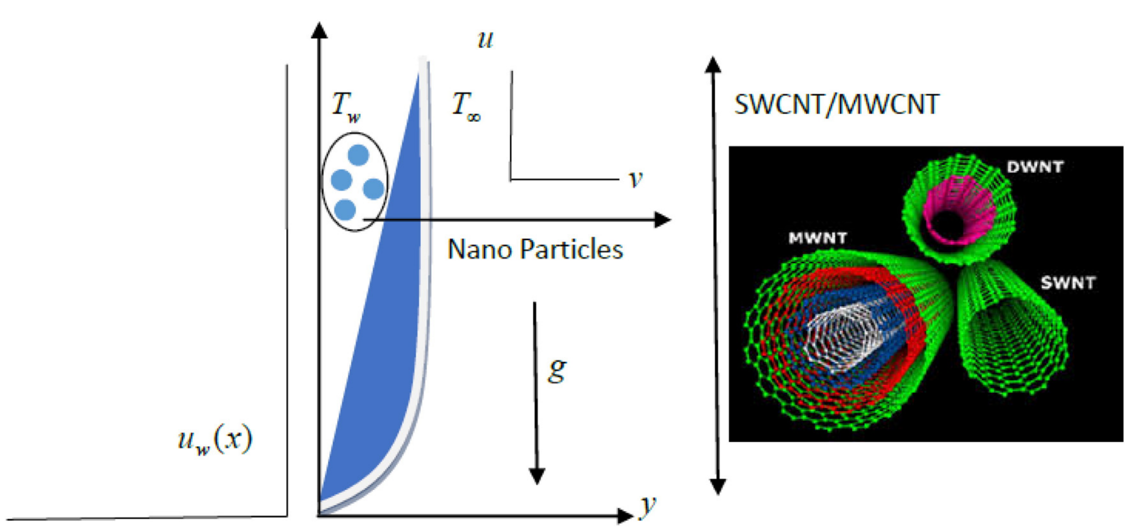

Fig. 1. Geometry of the problem.