Three-dimensional flow of a nanofluid over a permeable stretching/shrinking surface with velocity slip: A revised model

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ABSTRACT

A reformulation of the three-dimensional flow of a nanofluid by employing Buongiorno’s model is presented. A new boundary condition is implemented in this study with the assumption of nanoparticle mass flux at the surface is zero. This condition is practically more realistic since the nanoparticle fraction at the boundary is latently controlled. This study is devoted to investigate the impact of the velocity slip and suction to the flow and heat transfer characteristics of nanofluid. The governing partial differential equations corresponding to the momentum, energy, and concentration are reduced to the ordinary differential equations by utilizing the appropriate transformation. Numerical solutions of the ordinary differential equations are obtained by using the built-in bvp4c function in Matlab. Graphical illustrations displaying the physical influence of the several nanofluid parameters on the flow velocity, temperature, and nanoparticle volume fraction profiles, as well as the skin friction coefficient and the local Nusselt number are provided. The present study discovers the existence of dual solutions at a certain range of parameters. Surprisingly, both of the solutions merge at the stretching sheet indicating that the presence of the velocity slip affects the skin friction coefficients. Stability analysis is carried out to determine the stability and reliability of the solutions. It is found that the first solution is stable while the second solution is not stable.

A massive collection of literature has accumulated in the field of the boundary layer flow over the past several decades. In a thin layer, the effect of the viscosity will result in the fluid adjacent to the surface of the body that becomes attached to the surface (no slip condition) and viscosity effects will only be felt by the layer known as the boundary layer. In this thin layer, the friction force should be considered. The significant roles of friction between solid and liquid interfaces in mechanical devices are liquid-floated gyroscopes and high speed bearing.1 Furthermore, application of the concept and theory of the boundary layer is also encountered in the calculation of friction drag of bodies in a flow, such as the airfoil design of airplanes, streamlined body of an automobile, and friction drag of a ship. Because of its numerous applications, the problem of flow and heat transfer in the boundary layer over a stretching surface has attracted many researchers. Thenceforward, the study of the boundary layer is extended to the problem of the flow and heat transfer over a stretching/shrinking surface. This has been a topic of interest for many years due to its extensive applications such as manufacture of plastic and rubber sheets, hot rolling, extrusion, glass-fiber production, continuous casting, wire drawing, extraction of polymer, annealing and tinning of copper wires, melt-spinning, and electrolyte analytical solution for the boundary layer flow of an incompressible viscous fluid over a stretching and shrinking sheet. Afterwards, many researchers continued the study of fluid flow over a stretching/shrinking sheet with consideration of various physical conditions.9–13 Dash et al.14 pointed out the fact that shrinking of the boundary surface associated with the heat source overrides the resistive force generated due to the magnetic field and the skin friction decreased with the increment of shrinking velocity. Mahmood et al.15 concluded that a rise in nonlinear stretching/shrinking parameter increased the velocity of the fluid. Besides, investigation on the heat transfer in the turbulent boundary layer also has attracted many researchers. It is worth mentioning the very interesting papers by Li et al.16 on the heat transfer in a spatially developing turbulent boundary layer, Wu and Moin17 on the turbulent boundary layer with the heat transfer, and Li et al.18 on the turbulent boundary layer with passive scalar transport.

Limitation in the thermal conductivity of conventional fluid drives to the new invention of heat transfer fluid. Ever since the inception of the concept of nano-meter sized metallic particles as the potential agent for achieving higher heat transfer rates,19–21 the literature has seen an exponential growth in the number of studies reported. Nanofluid is a modern class of nanotechnology-based heat transfer fluid which is created by the suspension of nano-sized particles with the base fluid like water, ethylene glycol, oil, and grease.19 Irrespective of the approach followed, the primary interest is to