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NATURAL CONVECTION OVER AN INCLINED WAVY SURFACE EMBEDDED IN A THERMALLY STRATIFIED POROUS MEDIUM SATURATED WITH A NANOFLUID

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Introduction:

Thermal stratification on natural convection in a fluid saturated porous medium is widely accepted due to its geophysical and industrial applications such as hot dike complexes in volcanic regions for heating of ground water, development of advanced technologies for nuclear waste management, pollutant and contaminant transport in soil etc. In many practical problems, convection flows arise in a thermally stratified medium. In practical situations where heat and mass transfer takes place simultaneously, it is necessary to investigate the effect of stratification on convective transport in nanofluids. Cheng [1] studied the coupled heat and mass transfer by natural convection near a vertical wavy surface in a non-Newtonian fluid saturated porous medium with thermal and mass stratification. Rathish kumar and Shalini [2] carried out a numerical investigation to analyze the effect of surface undulations on fluid saturated Darcian flow in a thermally stratified porous enclosure. The problem of natural convection over an inclined wavy surface embedded in a thermally stratified porous medium saturated with nanofluid has not been considered so far. The present study mainly focussed on exploring the effects of thermal stratification, Brownian motion, thermoporesis amplitude and angle of inclination of the wavy plate on natural convection in Darcy porous medium saturated with nanofluid.

Formulation of the problem

Consider the steady laminar incompressible two-dimensional boundary layer natural convection flow along a semi-infinite inclined wavy surface embedded in a nanofluid saturated Darcy porous medium. The wavy plate is inclined at an angle A $(0^o \le A \le 90^o)$ to the horizontal. The coordinate system is shown in Fig. 1. The wavy surface is described by

$$y = \delta(x) = a\sin(\pi x / l) \tag{1}$$

where a is the amplitude of the wavy surface, and $2l$ is the characteristic length of the wavy surface. The wavy surface is held at constant temperature T_w and constant nanoparticle volume fraction ϕ_w and the ambient medium is assumed to be linearly stratified with respect to the temperature in the form $T_\infty(x) = T_{\infty,0} + Bx$ where B is a constant varied to alter the intensity of stratification in the medium. We consider the porous medium to be homogeneous and isotropic and is saturated with a fluid which is in local thermodynamic equilibrium with the solid matrix. The fluid has constant properties except the density in the buoyancy term of the balance of momentum equation. Using the Boussinesq approximation, the governing equations for this problem under the laminar boundary layer flow assumptions, and using the Darcy's flow through a homogeneous porous medium near the inclined wavy surface are given by

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{2}$$

$$\frac{\partial u}{\partial y}-\frac{\partial v}{\partial x}=\frac{(1-\phi_{\infty})\rho f_{\infty}\beta Kg}{\mu}\left(\frac{\partial T}{\partial y}\sin A-\frac{\partial T}{\partial x}\cos A\right)-\frac{\left(\rho_p-\rho_{f_\infty}\right)Kg}{\mu}\left(\frac{\partial \phi}{\partial y}\sin A-\frac{\partial \phi}{\partial x}\cos A\right) \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+\gamma\left\{D_B\left(\frac{\partial \phi}{\partial x}\frac{\partial T}{\partial x}+\frac{\partial \phi}{\partial y}\frac{\partial T}{\partial y}\right)+\frac{D_T}{T_\infty}\left[\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2\right]\right\} \tag{4}$$

$$u\frac{\partial \phi}{\partial x}+v\frac{\partial \phi}{\partial y}=D_B\left(\frac{\partial^2 \phi}{\partial x^2}+\frac{\partial^2 \phi}{\partial y^2}\right)+\frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{5}$$

The boundary conditions are

$$v=0,\ T=T_w,\ \phi=\phi_w,\ \text{ at }\quad y=\delta(x) \tag{6a}$$

$$u\to U_\infty,\ T\to T_\infty,\ \phi\to\phi_\infty,\ \text{ as }\quad y\to\infty \tag{6b}$$

Method of solution

A coordinate transformation is employed to transform the complex wavy surface to a smooth surface. The governing equations are transformed into a set of non-similar equations using the similarity transformation. Then a local similarity and non similarity method is applied to these equations to obtain a system of ordinary differential equations. These nonlinear ordinary differential equations are reduced to a system of linear differential equations using the successive linearization method. Then Chebyshev pseudo spectral method is used to solve linearized ordinary differential equations.

Conclusion

Natural convection heat and mass transfer over an inclined wavy surface embedded in a thermally stratified porous medium saturated with nanofluid was analyzed. Numerical solutions were obtained for different values of thermal stratification, Brownian motion parameter, thermophoresis parameter, amplitude and angle of inclination of the wavy surface. The Thermal stratification parameter significantly affects flow field i.e. increasing the thermal stratification parameter reduces the velocity, temperature, local heat and nanoparticle mass transfer rates but enhances the nanoparticle volume fraction of the fluid.

References:

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