Results in Physics 9 (2018) 527–533

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.journals.elsevier.com/results-in-physics

Slip analysis of squeezing flow using doubly stratified fluid

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ARTICLE INFO

Article history:
Received 20 January 2018
Received in revised form 25 February 2018
Accepted 26 February 2018
Available online 9 March 2018

Keywords:
Squeezing flow
Slips conditions
Double stratification

ABSTRACT

The non-isothermal flow is modeled and explored for squeezed fluid. The influence of velocity, thermal and solutal slip effects on transport features of squeezed fluid are analyzed through Darcy porous channel when fluid is moving due to squeezing of upper plate towards the stretchable lower plate. Dual stratification effects are illustrated in transport equations. A similarity analysis is performed and reduced governing flow equations are solved using moderated and an efficient convergent approach i.e. Homotopic technique. The significant effects of physical emerging parameters on flow velocity, temperature and fluid concentration are reporting through various plots. Graphical explanations for drag force, Nusselt and Sherwood numbers are stated and examined. The results reveal that minimum velocity field occurs near the plate, whereas it increases far away from the plate for strong velocity slip parameter. Furthermore, temperature and fluid concentration significantly decreases with increased slip effects. The current analysis is applicable in some advanced technological processes and industrial fluid mechanics.

Introduction

Slip effects over stretching sheet has fascinated the many investigators due to its significance in certain manufacturing fluid dynamics systems. It has been discovered in the literature that most of the analysis were assumed the no slip conditions at surfaces. However, in various physical situations where the said conditions are no longer applicable, it is essential to have slip conditions in replaced of no slip conditions. Slip conditions have shown to be significant in chemically treated or lubricated hydrophobic surfaces, shear skin, wire nettings and perforated plates, porous or rough surfaces, hysteresis and spurts effects and super-hydrophobic nano-surfaces. Some more examples of industrial thermal problems when slip occurs are the fluid flow on multiple interfaces, polishing of artificial heart valves and rarefied fluid problems. The initial studies on linear slip flow were carried out by Navier [1] and Maxwell [2]. Rao and Rajagopal [3] discussed the fluid motion obeying the slip effects. Ibrahim and Shanker [4] explored the heat transfer in MHD nano-fluid flow over stretchable plate with slips conditions. Hayat et al. [5] illustrated the effect of slip conditions on flow of stagnant Casson fluid through a thermally stratified channel. Awais et al. [6] described the MHD nano-fluid flow with slip effects. Rana et al. [7] disclosed the slip analysis of nano-liquid flow through variable thicked sheet with varying magnetic field and thermal radiation. Moghaddam and Jamiolahmady [8] exhibited the slip effects on fluid flow in porous channel. Ullah and Zaman [9] exposed the impact of slip properties on MHD flow of tangent hyperbolic fluid towards a stretchable plate. Hayat et al. [10] depicted the dual stratified flow of magneto-hydrodynamic nano-fluid with slip conditions.

Phenomenon of double stratification in many industrial and natural processes is achieved by temperature variation, differences in concentration or fluids with varying densities. Process of double stratification is extensively used in various practical applications such as oceans, ground-water reservoirs, rivers, different heterogeneous mixtures, thermal stratification of reservoirs, manufacturing processing, density stratification of atmosphere and many others. The biological processes occurring in reservoirs make the water in the bottom anoxic. Further, stratification process could be utilized in energy storage process and solar engineering. Daniel et al. [11] examined the effect of dual stratification on MHD nano-fluid flow with Ohmic heating and mixed convection. Babu and Sandeep [12] presented the dual stratified UCM flow through melting surface with cross-diffusion effects. Farooq et al. [13] disclosed the doubly stratified stagnant nano-fluid flow with melting surface condition. Srinivasacharya and Surender [14] explored the mixed convection effects on double Stratification over a vertical sheet inserted in a non-darcy Porous Media. Double stratified MHD flow of Maxwell nano-fluid with mixed convection and solar thermal energy is disclosed by Hussain et al. [15]. Dual stratified

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https://doi.org/10.1016/j.rinp.2018.02.066
2211-3797/

radiative flow of MHD nano-fluid with dissipation effects is explored by Daniel et al. [16]. Doubly stratified radiative flow of magneto Jeffrey nano-fluid through inclined shrinking cylinder with presence of heat generation/absorption is examined by Ramzan et al. [17]. Double stratified flow of squeezed viscous fluid with modified Fick's and Fourier's theories is exhibited by Muhammad et al. [18]. Rehman et al. [19] described the dual stratification in chemically reactive Casson fluid flow with mixed convection.

Aforementioned works indicate that no attempt has been discovered where the combined effects of slip (velocity, thermal and solutal) conditions and double stratification is used in squeezing flow analysis. Therefore our objective here is to examine the heat, mass and fluid flow of squeezed Newtonian fluid through porous medium with slips conditions and double stratification using the homotopy analysis method [21–31]. The effects of interested parameters on velocity, temperature and concentration fields are highlighted through the assistance of graphs. The plots of skin friction coefficient, Nusselt and Sherwood numbers are sketched against various involved parameters. The article is managed as fellows: A formulation of flow problem is presented in Section "Problem formulation". Solution procedure is addressed in Section "Homotopic procedure". The results are discussed in Section "Results and discussion". The article is concluded in Section "Closing remarks".

Problem formulation

We demonstrate the flow of squeezed viscous fluid inside the two parallel plates. Let $h(t) = \sqrt{\upsilon(1-\gamma t)/a}$ be the gap width between the plates. The motion of fluid is assumed as unsteady and laminar subjected to Darcy porous medium. The co-ordinate system $(x, y)$is chosen to analyze the flow in which x -axis is assumed along the axis of lower sheet while y -axis is directed normal to it (See Fig. 1). It is assumed that lower fixed sheet is stretched in direction with velocity $U_w(x)$ while upper plate is subjected to squeeze with vertical velocity υ_h. Double stratification effects are accounted. Current attempt is carried out when velocity, thermal and solutal slip conditions hold. The mathematical expressions describing the flow, heat and mass transport after utilizing the fundamental conservative laws are stated as [23]

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

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + \upsilon\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\nu\phi^*}{k^*}u, \tag{2}$$

$$\frac{\partial \upsilon}{\partial t} + u\frac{\partial \upsilon}{\partial x} + \upsilon\frac{\partial \upsilon}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \nu\left(\frac{\partial^2 \upsilon}{\partial x^2} + \frac{\partial^2 \upsilon}{\partial y^2}\right) - \frac{\nu\phi^*}{k^*}\upsilon, \tag{3}$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + \upsilon\frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right), \tag{4}$$

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + \upsilon\frac{\partial C}{\partial y} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\right). \tag{5}$$

Here u and υ are velocity components along x and y direction respectively. ρ represents fluid density, p represents fluid pressure, ν represents kinematics viscosity, ϕ^* represents porosity of porous medium, k^* represents permeability of porous medium,T represents fluid temperature, $\alpha = k/\rho C_p$ represents thermal diffusivity, k represents thermal conductivity, C_p represents specific heat capacity at constant pressure, C represents fluid concentration and D represents diffusion co-efficient.

The appropriate boundary conditions are given below [10]:

$$\begin{aligned}
&u = U_w(x) + L\frac{\partial u}{\partial y}, \quad \upsilon = 0, \quad T = T_w(x) + K_1\frac{\partial T}{\partial y},\\
&C = C_w(x) + K_2\frac{\partial C}{\partial y} \quad at\ y = 0,\\
&u = 0, \quad \upsilon = \upsilon_h = \frac{dh}{dt} = -\frac{\gamma}{2}\sqrt{\frac{\nu}{a(1-\gamma t)}}, \quad T = T_h(x),\\
&C = C_h(x) \quad at\ y = h(t),\\
&U_w(x) = \frac{ax}{1-\gamma t}, \quad T_w(x) = T_0 + \frac{dx}{1-\gamma t}, \quad C_w(x) = C_0 + \frac{ex}{1-\gamma t},\\
&T_h(x) = T_0 + \frac{d_1 x}{1-\gamma t}, \quad C_h(x) = C_0 + \frac{e_1 x}{1-\gamma t}.
\end{aligned} \tag{6}$$

In the above equation, $U_w(x)$ represents stretching velocity, L represents velocity slip factor, $T_w(x)$ represents variable surface temperature, K_1 represents temperature slip factor, $C_w(x)$ represents variable surface concentration, K_2 represents solutal slip factor, $T_h(x)$ represents variable upper plat e temperature, $C_h(x)$ represents variable upper plate concentration, T_0 represents reference temperature, C_0 represents reference concentration and $d, d_1, e, e_1, a, \gamma$ are dimensional constants.

In order to adopt similarity function formulation, we define [20]

$$\eta = \frac{y}{h(t)}, \quad \Psi = \sqrt{\frac{a\nu}{1-\gamma t}}xf(\eta), \quad \theta(\eta) = \frac{T-T_h}{T_w-T_0}, \quad \phi(\eta) = \frac{C-C_h}{C_w-C_0}, \tag{7}$$

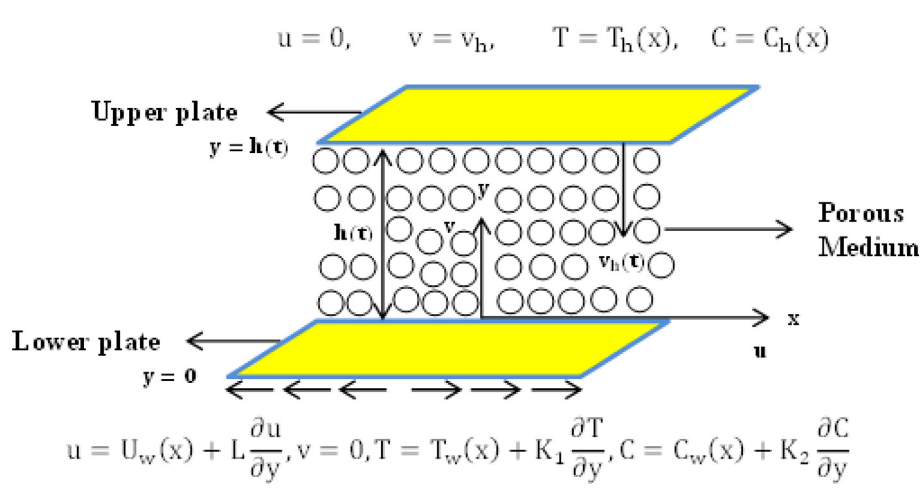

Fig. 1. Model diagram.