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Influence of chemical reaction and thermal radiation on mixed convection heat and mass transfer over a stretching sheet in Darcian porous medium with Soret and Dufour effects

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ABSTRACT

Combined effects of Soret (thermal-diffusion) and Dufour (diffusion-thermo) on mixed convection over a stretching sheet embedded in a saturated porous medium in the presence of thermal radiation and first-order chemical reaction are studied. The effects of various physical parameters on the dimensionless velocity, temperature and concentration profiles are presented graphically. In addition, numerical results for the local skin friction coefficient, the local Nusselt number, and the local Sherwood number are discussed. It is found that temperature profiles increase with increase in the thermal radiation parameter and Dufour number. The effect of Soret number is to increase the concentration distribution whereas reverse effect is seen by increasing the values of the chemical reaction rate parameter on concentration distribution.

1. Introduction

Heat and mass transfer problems on mixed convection flow due to a stretching surface in a saturated porous medium have received considerable attention because of numerous applications in energy related engineering problems that include both metal and polymer sheets. For instance, it occurs in the aerodynamic extrusion of polymer sheets, a long thread traveling between a feed roll and a wind-up roll, continuous filament extrusion from a dye, cooling of an infinite metallic plate in a cooling bath and during cooling reduction in both the thickness and width take place as these strips are sometimes stretched. The temperature distribution, thickness and width reduction are function of draw ratio and stretching distance. It is important that proper cooling fluid is chosen so that flow of the cooling liquid due to the stretching sheet can be controlled in order to arrive to the desired properties for better outcome. The quality of the final product depends on the rate of heat and mass transfer at the stretching surface. Crane [1] extended this concept to a stretching sheet with linearly varying surface speed and presented an exact analytical solution for the steady two-dimensional stretching of a surface in a quiescent fluid. Minkowycz et al. [2] have discussed the effects of surface mass transfer on buoyancy-induced Darcian flow adjacent to a horizontal surface using non-similarity solutions. Lai and Kulacki [3] have reported similarity solutions for mixed convection flow over horizontal and inclined plates embedded in fluid saturated porous media in the presence of surface mass flux. Ishak et al. [4] analyzed the effects of transpiration on the flow and heat transfer over a moving permeable sheet in a parallel stream.

In many new engineering areas processes (such as fossil fuel combustion energy processes, solar power technology, astrophysical flows, and space vehicle re-entry) occur at high temperature, so knowledge of radiation heat transfer beside the convective heat transfer play very important role which cannot be neglected. Also, thermal radiation on flow and heat transfer processes is of major importance in the design of many advanced energy conversion systems operating at high temperature. Thermal radiation within these systems is usually the result of emission by the hot walls and the working fluid. Thermal radiation effects become important when the difference between the surface and the ambient temperature is large. The Rosseland approximation is used to describe the radiative heat flux in the energy equation. Kinyanjui et al. [5] investigated the magnetohydrodynamic free convection heat and mass transfer of a heat generating fluid past an impulsively started infinite vertical porous plate with Hall current and radiation absorption. The effects of thermal radiation and various injection parameters on heat transfer were studied by Seddeek [6] using a power-law non-Newtonian fluid over a stretched surface using finite element method. Mukhopadhyay [7] investigated the effect of thermal radiation on unsteady mixed convection flow of an

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Nomenclature

a, b, c	constants
C	concentration of the species
C_∞	free stream concentration
C_f	local skin friction coefficient
c_p	specific heat at constant pressure
c_s	concentration susceptibility
D	molecular diffusivity
D_f	Dufour number $\left(\frac{D_m k_T (C_w - C_\infty)}{c_s c_p \nu (T_w - T_\infty)}\right)$
D_m	coefficient of mean diffusivity
Ec	Eckert number $\left(\frac{u_w^2}{c_p (T_w - T_\infty)}\right)$
f_w	dimensionless suction velocity
g	acceleration due to gravity
Gr_c	solutal Grashof number $(g\beta_C (C_w - C_\infty) x^3/\nu^2)$
Gr_t	thermal Grashof number $(g\beta_T (T_w - T_\infty) x^3/\nu^2)$
H	non-dimensional concentration
k	permeability of the porous medium
k^*	mass absorption coefficient
k_1	porous parameter $\left(\frac{\mu\phi}{c\rho k}\right)$
Nr	thermal radiation parameter $\left(\frac{16\sigma^* T_\infty^3}{3k\kappa}\right)$
Nu_x	local Nusselt number
Pr	Prandtl number $\left(\frac{\mu c_p}{\kappa}\right)$
q_r	radiative heat flux in the y direction
R_1	chemical reaction parameter $\left(\frac{R}{c}\right)$
Re_x	local Reynolds number $\left(\frac{u_w x}{\nu}\right)$
Sc	Schmidt number $\left(\frac{\nu}{D_m}\right)$
S_r	Soret number $\left(\frac{D_m k_T (T_w - T_\infty)}{\nu T_m (C_w - C_\infty)}\right)$
Sh_x	Sherwood number
T	fluid temperature
T_m	mean fluid temperature
T_w	stretching sheet temperature
T_∞	temperature far away from the stretching sheet
u, v	velocity components in the x- and y-directions
u_w	wall velocity
v_0	suction velocity
x, y	flow directional and normal coordinates

Greek symbols

β_T	coefficient of thermal expansion
β_C	coefficient of expansion with concentration
δ	solutal buoyancy parameter $\left(\frac{Gr_C}{Re_x^2}\right)$
η	similarity variable
κ	thermal conductivity
λ	thermal buoyancy parameter $\left(\frac{Gr_T}{Re_x^2}\right)$
Λ	viscous ratio parameter $\left(\frac{\tilde{\mu}}{\mu}\right)$
μ	dynamic coefficient of viscosity
$\tilde{\mu}$	effective dynamic coefficient of viscosity
ν	coefficient of kinematic viscosity
ϕ	porosity of the porous medium
ρ	density of the fluid
ψ	stream function
σ^*	Stephan–Boltzmann constant
θ	non-dimensional temperature

optically thick viscous and incompressible fluid over porous stretching surface in a porous media by taking into account of Rosseland diffusion approximation. Pal [8] analyzed heat and mass transfer in two-dimensional stagnation-point flow of an incompressible viscous fluid over a stretching vertical sheet in the presence of buoyancy force and thermal radiation. Pal and Mondal [9] have investigated on the combined convection flow of an optically dense viscous incompressible fluid over a vertical surface embedded in a fluid saturated porous medium of variable porosity in the presence of thermal radiation and heat generation/absorption effects. Pal and Chatterjee [10] studied heat and mass transfer in MHD non-Darcian flow of a micropolar fluid over a stretching sheet embedded in a porous medium with non-uniform heat source and thermal radiation. Dehkordi and Mohammadi [11] studied the transient forced convection with viscous dissipation to power-law fluids in thermal entrance region of circular ducts with constant wall heat flux.

In many transport processes existing in nature and industrial applications in which heat and mass transfer is a consequence of buoyancy effects caused by diffusion of heat and chemical species. The study of such processes is useful for improving a number of chemical technologies such as in polymer production. Many practical diffusive operations involve the molecular diffusion of species in the presence of a chemical reaction within the boundary layer. The presence of a foreign mass in air or water causes some kind of chemical reaction. During a chemical reaction between two species, heat is also generated. A reaction is said to be first-order if the rate of reaction is directly proportional to concentration itself. Chamkha et al. [12] obtained similarity solution for unsteady heat and mass transfer from a stretching surface embedded in a porous medium with suction/injection and chemical reaction effects. Rashed and El-Khabeir [13] analyzed the influence of chemically reactive studies on heat and mass transfer on mixed convection boundary layer flow over a stretching sheet in a porous medium.

Dufour effect (or diffusion-thermo) corresponds to the energy flux caused by a concentration gradient in a binary fluid or mixture whereas Soret effect (or thermal diffusion) corresponds to species differentiation developing in an initial homogeneous mixture submitted to a thermal gradient. The Soret effect, for instance, has been utilized for isotope separation, and in mixture between gases with very light molecular weight (H_2, H_e) and of medium molecular weight (N_2, air). In many studies, Dufour and Soret effect are neglected on the basis that they are of a smaller order of magnitude than the effects described by Fourier's and Fick's. The Dufour effect was found to be of the order of considerable magnitude so that it cannot be ignored [14]. Alam and Rahman [15] investigated the Dufour and Soret effects on mixed convection flow past a vertical porous flat plate with variable suction. Influence of chemical reaction on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects are studied by Postelnicu [16]. Mansour et al. [17] analyzed the effects of chemical reaction and thermal stratification on MHD free convection heat and mass transfer over a vertical stretching surface embedded in a porous media considering Soret and Dufour effects. Tsai and Huang [18] examined the effects of Soret and Dufour on Hiemenz flow through a porous medium onto a stretching surface. Hayat et al. [19] investigated heat and mass transfer on mixed convection boundary layer flow over a stretching vertical surface in a porous medium in a viscoelastic fluid with Soret and Dufour effects. Recently, Pal and Mondal [20] studied MHD non-Darcian mixed convection heat and mass transfer over a stretching sheet with non-uniform heat source/sink and Soret and Dufour effects.

In view of the above discussions, authors envisage to investigate the combined effects of Soret and Dufour in the presence of suction or injection, thermal radiation and first-order chemical reaction for the steady two-dimensional mixed convection and mass transfer flow past a semi-infinite vertical porous plate embedded in the porous medium. The problem addressed here is a fundamental