INFLUENCE OF INCLINED MAGNETIC FIELD AND THERMOPHORESIS ON HEAT AND MASS TRANSFER WEDGE FLOW WITH VARIABLE THERMAL CONDUCTIVITY

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Abstract: **In our study, we investigate the influence of thermophoresis and a constant inclined magnetic field on a fluid flowing over a porous wedge. The effects of variable prandtl and thermal conductivity, Hartman number, wedge angle parameter, Schmidt's number, thermophoretic concentration and a constant suction or injection on the fluid flow parameters are studied numerically by the collocation method since the Prandtl number is a function of thermal conductivity and since thermal conductivity varies across the boundary layer, then prandtl number must also vary. Numerical solutions have been obtained using the collocation method. A tabulation of the effects of these parameters on skin friction, heat transfer and thermophoretic particle deposition is provided. The results of this study reveal that for this study, fluid velocity is increased by increase in magnetic inclination angle, increase in suction and an increase in Hartman number. Fluid temperature is increased by increase in thermal conductivity while fluid particle concentration only increases with increase in concentration parameter.**

Keywords: **Variable Thermal conductivity, Heat Transfer, Mass transfer, Boundary layer.**

1. PRELIMINARIES

1.1 NOTATION AND TERMINOLOGIES:

f Velocity function, Re Reynolds number, U Free stream velocity, u X-component of velocity, v Y-component of velocity, k_f Thermal conductivity, D_T Thermophoresis coefficient, P_r Prandtl number, B_0 Constant applied magnetic field, N_u Local Nusselt number.

1.2 INTRODUCTION

The study of heat and mass transfer is of great significance because of the large number of relevant applications in geothermal and geophysical engineering. In all above studies, the thermo-physical properties of the fluid, especially the thermal conductivities were assumed constant. However, it is well known that the thermal conductivity of fluid may change with temperature (Chiam. T.C., 1998); (Prasad. K., 2009); performed the effect of variable thermal conductivity in a non-isothermal sheet stretching through power law fluids. Fluid flow in a porous medium with mass and heat transfers is of considerable significance from engineering and sciences point of view.This explains why a lot of focus is put in the study of this flow. In this case we consider laminar flow of a viscous fluid over a porous wedge in the presence of inclined magnetic field, thermophoresis and variable thermal conductivity.

2. GOVERNING EQUATIONS

All The equations governing the fluid flows of any kind are based on general laws of conservation of mass, momentum and energy. They are modified to perfectly suit a particular fluid flow. Governing equations are presented and modified subject to the assumption made in order to generate specific equations. These equations are;

$$f''' + ff'' + \beta(1 - f'^2) - \left(\frac{\sigma^{m+1}}{vx^{m-1}}\right)(2 - 2f' - \eta f'') - \frac{2}{m+1}(Ha\sin\alpha)^2(f' - 1) = 0$$

$$\left.\begin{array}{l} \theta'' + \dfrac{v}{1+v}\theta'^2 + \dfrac{pr_\infty}{(1+v\theta)}f\theta' + \dfrac{\delta^m}{vx^{m-1}}\dfrac{\partial\delta}{\partial t}\dfrac{\mu c_p}{k_\infty}\eta(\theta') + \dfrac{pr_\infty}{(1+v\theta)}E_c f''^2 + \\ \dfrac{pr_\infty}{(1+v\theta)}E_c(Ha\sin\alpha)^2(f'-1)^2 = 0 \end{array}\right\}$$

$$\phi'' + s_c f\phi' + s_c\lambda\eta\phi + \frac{Ks_c}{N_t + \theta}\left[[(N_c + \phi)]\theta'' + \theta'\phi' - \left(\frac{N_c + \phi'}{N_{tc} + \theta}\right)\theta'^2\right] = 0$$

3. RESULTS AND DISCUSISION

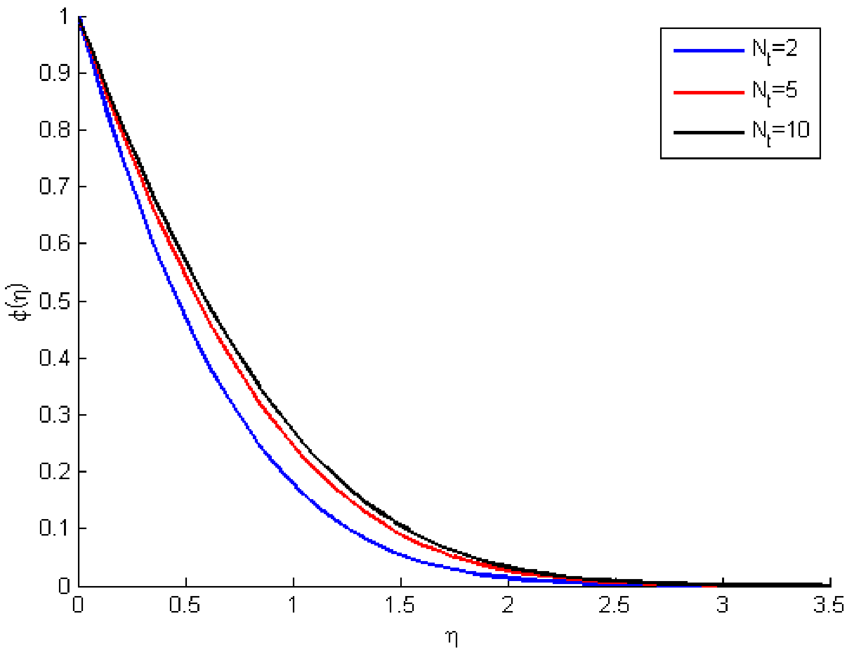

Figure 5: Effect of variation of N_t on concentration

Effects of variation of fluid suction ($f_w > 0$)

From the results of figure1 it is found that the inclusion of fluid suction ($f_w > 0$) on the flow increases the fluid velocity. This is in excellent agreement with Rahman et, al .This is because suction causes the thermal boundary layer to grow thinner while wall injection $f_w<0$) causes the thermal boundary layer to grow thicker and therefore the fluid velocity reduces with increase in injection. The figure reveals that maximum velocity is achieved at maximum suction. The decreasing thickness of the concentration layer is caused by two effects the direct action of suction, and the indirect action of suction causing a thinner thermal boundary layer as shown in figure2 and 3 respectively. A thin boundary layer, which corresponds to low temperature as seen in figure 2. As expected figure reveals that fluid temperature decreases with increase in suction, while it increases with increase in injection. This is true as fluid suction increases fluid velocity by removing of decelerated fluid particles, which in turn increases sheared heating at the wedge surface. This occurs at a high temperature gradient and therefore the thermophoretic force is increased as well as increase in the concentration gradient, which explains the decrease in concentration as suction increases. Suction therefore acts as a powerful mechanism for cooling the flow and such features are important in high temperature energy systems such as magneto hydrodynamic power generators, nuclear energy processes.

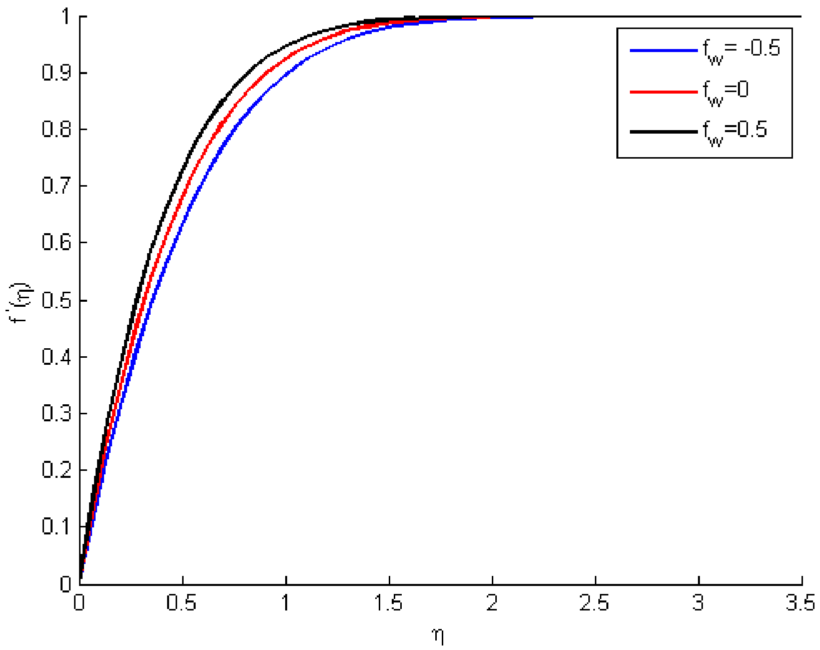

Figure 1: Effect of variation of f_w on velocity

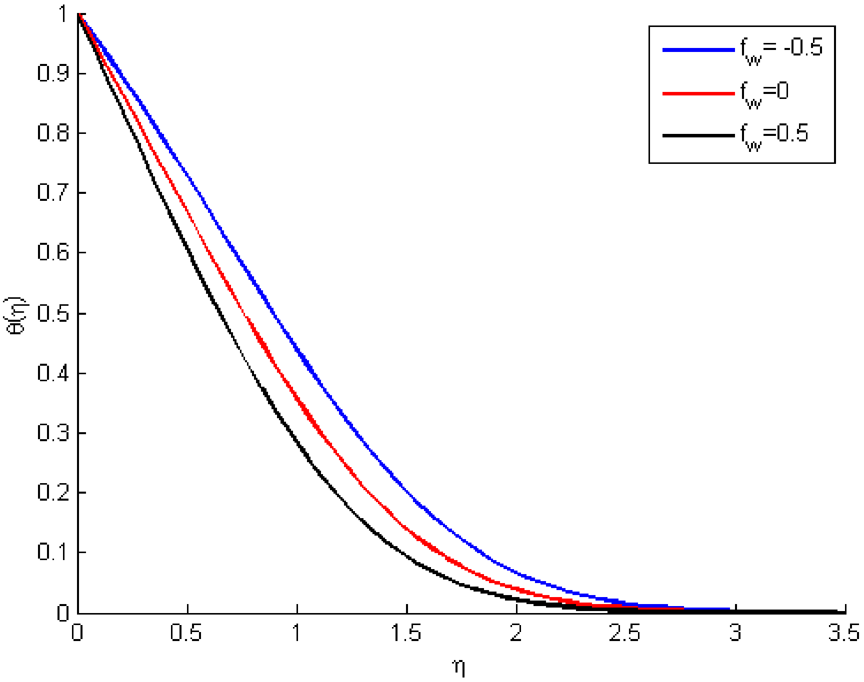

Figure 2: Effect of variation of f_w on temperature

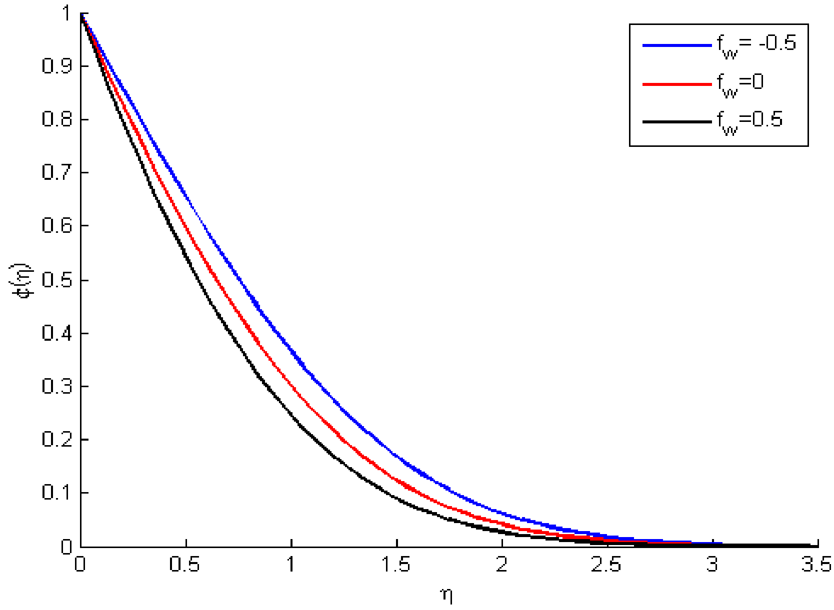

Figure 3: Effect of variation of f_w on concentration.

Effects of variation of thermal conductivity γ

The effect of variation of thermal conductivity is presented in figure 4. From the figure, we observe that the non-dimensional temperature profile increases with the increase of the thermal conductivity parameter as expected. Its decrease therefore decreases the diffusivity of heat generated by viscous dissipation in the wedge, leading to accumulation of heat in the flow and hence raising the fluid temperature . When thermal conductivity of the fluid increases, the value of the Prandtl number decreases which then increases the temperature of the fluid. That is temperature of the fluid increases, if the Prandtl number decreases. This figure clearly establishes that the Prandtl number varies significantly within the boundary layer when the fluid thermal conductivity varies with temperature. There is no effect on deposition and velocity. As gamma is increased, the prandtl number decreases since they are inversely proportional. Physically, an increase in prandtl number increases thermal diffusivity of the fluid. Similarly, an increase in variable thermal conductivity leads to an increase in the value of the dimensionless temperature in the thermal boundary layer. Heat transfer therefore decreases steadily.

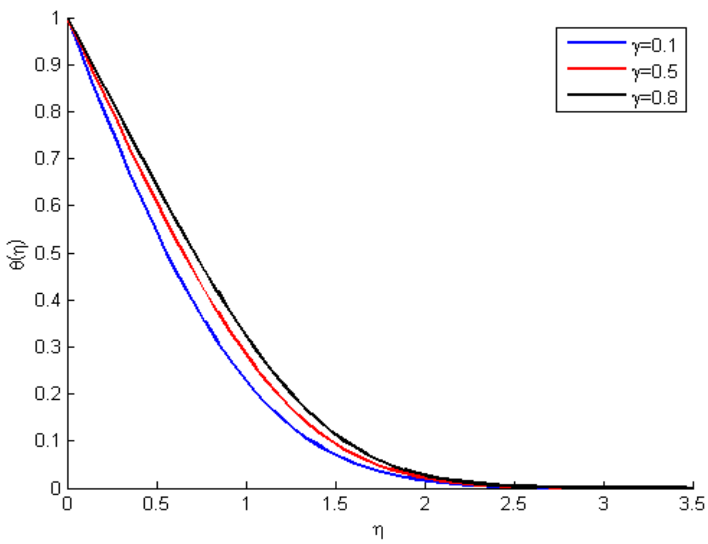

Figure 4: Effect of variation of γ on temperature profile.

Effects of variation of Schmidt's number (S_c)

Increase in Schmidt's number decreases the concentration boundary layer. From figure 5, increase in Schmidt's number decreases molecular diffusion which has an effect of reducing the viscous diffusion rate. Therefore concentration is higher at small values of Schmidt's and lowers at higher values of Schmidt's number. Schmidt's number has no effect on temperature and velocity profiles since it is not a function of the two.

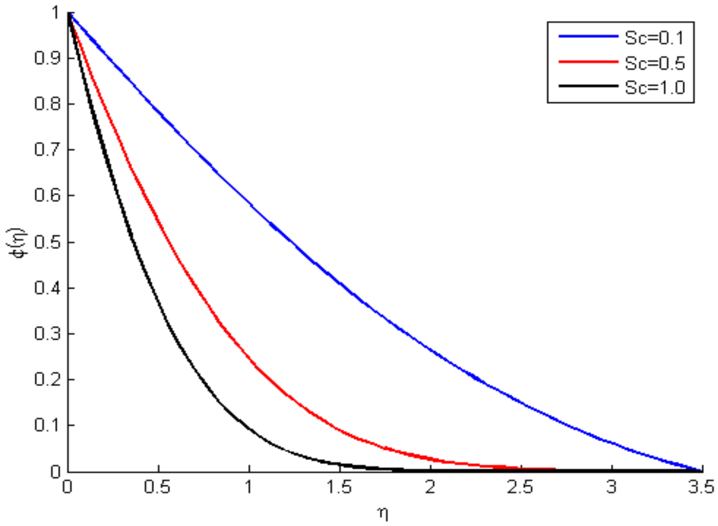

Figure 6: Effect of variation of Sc on concentration profile.

Effects of variation of Hartman number (Ha)

Fluid velocity increases with increase in Hartman number, in the boundary layer as shown in figure 7. This is because of the development of a thinner boundary layer, which shows a general tendency to introduce electromotive force to the free stream motion of MHDS hence the velocity increase as shown in figure 7. It is worth noting that the Hartman's number is a product of the magnetic inclination angle and therefore their effects on the fluid are similar. This is because the Hartman's number helps to reduce the thermal and concentration boundary layer thickness whose effect is reduction in temperature and concentration respectively as shown on figure 7 and 8 respectively. Conventially, increase in velocity reduces the contact time between the wedge and the fluid.

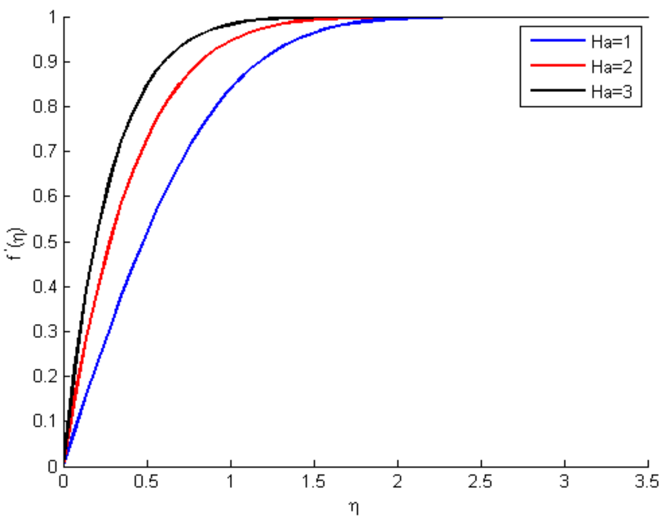

Figure 7: Effect of variation of Ha on velocity profile

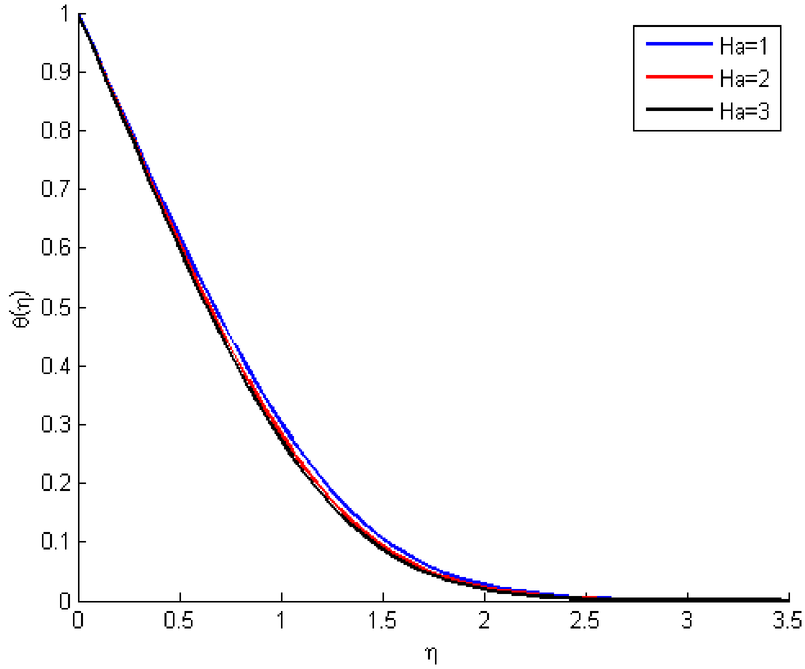

Figure 8: Effect of variation of Ha on temperature

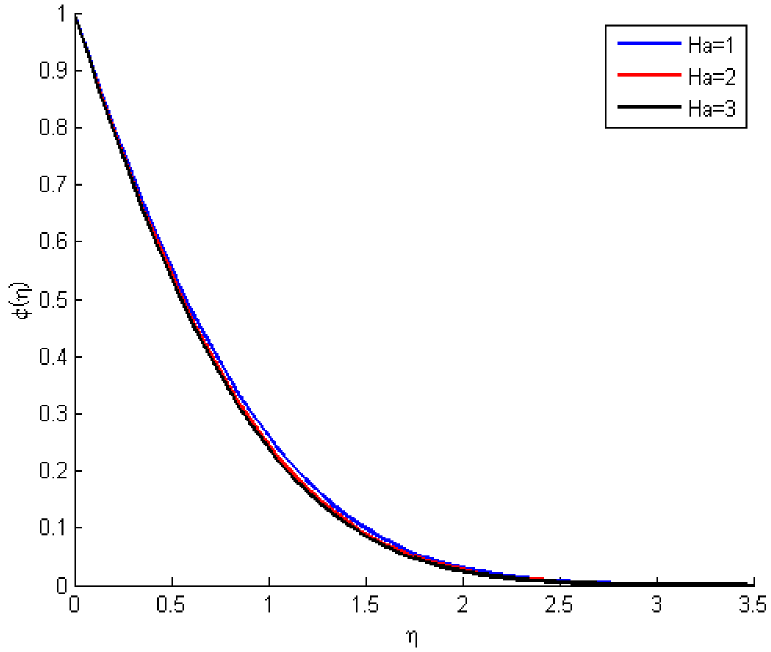

Figure 9:Effect of variation of Ha on concentration

Effects of variation of wedge angle parameter (β)

It is clear from figure 10 that velocity of the fluid within the boundary layer slightly decreases with the increasing values of wedge angle parameter β .This is due to fact that fluid always flows along the direction of the negative pressure gradient, i.e. high pressure to low pressure positive values of β, velocity profiles squeeze closer and closer to the surface of the wedge. This is because for increasing values of β the driving force of the fluid motion reduces which then retards the fluid flow and carries more heat from the surface of the wedge to the fluid. Therefore, the temperature at the surface of the wedge decreases.

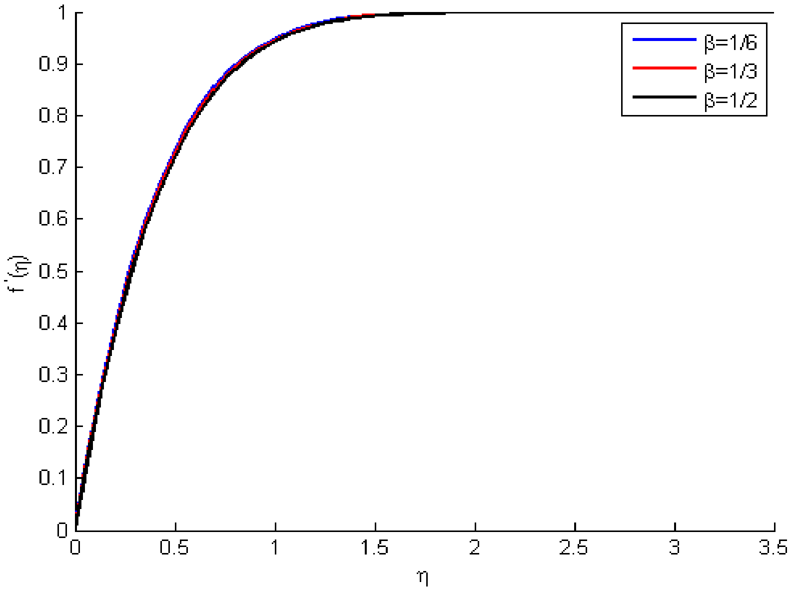

Figure 10: Effect of variation of wedge angle parameter on velocity profile.

Effects of Parameters Variation On The Skin Friction c_f, Nusselt number Nu and thermophoretic concentration V_d

Effect of variation of suction/injection on The Skin Friction c_f, Nusselt number Nu and thermophoretic particle deposition V_d

It was observed that the suction parameter $(f_w > 0)$ tends to increase the local skin friction. This is because suction gives rise to a thinner velocity boundary layer, thereby causing an increase in the velocity of the fluid. As velocity increases, the rate at which molecules contact the wedge increases hence also increases the skin friction. The local Nusselt number is the ratio between convection and conduction. Suction increases convection by reducing the boundary layer and this explains why the Nusselt number increases with increase in suction.

Effect of variation of magnetic field on The Skin Friction c_f, Nusselt number Nu and thermophoretic particle deposition V_d

The skin friction increases with increasing magnetic field intensity as displayed . This is because magnetic field is associated with high thermal conductivity which increases conduction and therefore thermal boundary layer becomes thinner and as a result increases the temperature of the fluid which is associated with the skin friction. From this study, it has also been found that magnetic field increases the fluid velocity. This is explained in that high velocity increases the friction drag since they are directly proportional. I.e. friction increases with the square of velocity. The increase in Nusselt number was because of enhancement of heat transfer through the fluid as a result of convection relative to conduction across the fluid. Thermophoretic deposition increases with increase in Hartman number due to temperature difference as shown by the behavior of Nusselt number.

Effect of variation of inclination angle on The Skin Friction c_f, Nusselt number Nu and thermophoretic particle deposition V_d

The increase in angle of inclination has exactly the same effect of the above parameters as in the case of the Hartman number. This is because the Hartman number varies directly with the angle of inclination of the magnetic field as shown from the equations.

Effect of variation of gamma (γ) on The Skin Friction c_f, Nusselt number Nu and thermophoretic particle deposition V_d

The effects of the thermal conductivity variation parameter on the non-dimensional temperature profiles have been displayed. As expected, the thermal conductivity of the fluid increases, the value of the Prandtl number decreases, which then increases the temperature of the fluid. This is because the higher the thermal conductivity the higher the heat transfer by thermal conduction. Temperature of the fluid increases, if the Prandtl number decreases. This explains why we have an increase in the Nusselt number. As the wedge gains temperature, deposition decreases.

Effect of variation of thermophoresis parameter N_t on The Skin Friction c_f, Nusselt number Nu and thermophoretic particle deposition V_d

Thermophoretic particle deposition of the fluid decreases for the increasing values of thermophoresis parameter N_t . This is because increasing values of thermophoresis parameter N_t , increases temperature at the surface of the wedge since it is a ration between ambient temperature and relative temperature of the fluid and the wedge. For this reason, the particles tend to dissolve in the fluid increasing its concentration and reducing deposition on the wedge.

Effect of variation of Schmidt number (s_c) on The Skin Friction c_f, Nusselt number Nu and thermophoretic particle deposition V_d

Increase in Schmidt's number decreases molecular diffusion and increases viscous diffusion. Viscous diffusion involves movement of particles due to concentration gradient. Deposition therefore does not occur at higher viscous diffusion and therefore concentration is higher at lower values of S_c . When concentration increases, deposition of the thermophoretic particle is adversely reduced.

Effect of variation of wedge angle parameter β on The Skin Friction c_f, Nusselt number Nu and thermophoretic particle deposition V_d

As the wedge angle is increased, as expected velocity of the fluid velocity decreases. This in turn increases thermophoretic deposition .This occurs because there is increased heat enhancement as shown by the increase in Nusselt number which shows increased heat enhancement as a result of convection across the fluid. Deposition decreases with increasing temperature as the wedge angle parameter reduces velocity and increases convective heat transfer.

Computation showing the effect of variation of suction and injection on skin friction, local Nusselt number and thermophoretic particle deposition V_d

fw	cf	Nu	Vd
-0.5	0.087	12.30396	34.4478
0	0.1001	15.4763	42.6814
0.5	0.1142	19.2859	51.5613

Computation showing the effect of variation of Hartman number on skin friction, local Nusselt number and thermophoretic particle deposition V_d

Ha	cf	Nu	Vd
1	0.0562	18.8093	50.1539
2	0.1142	19.2958	51.5613
3	0.1711	19.4921	52.4299

Computation showing the effect of variation of angle of inclination (α) on skin friction, local Nusselt number and thermophoretic particle deposition V_d

α	cf	Nu	Vd
$\frac{\pi}{2}$	0.1117	19.5410	50.0531
$\frac{\pi}{3}$	0.0996	19.4184	49.7522
$\frac{\pi}{6}$	0.0627	18.9556	48.6499

Computation showing the effect of variation of gamma (γ) on skin friction, local Nusselt number and thermophoretic particle deposition V_d

γ	cf	Nu	Vd
0.1	0.0996	23.7696	49.8693
0.5	0.0996	19.4184	49.7522
0.8	0.0996	17.2528	49.6890

Computation showing the effect of variation of thermophoretic parameter N_t on skin friction, local Nusselt number and thermophoretic particle deposition V_d

N_t	cf	Nu	Vd
2	0.0996	19.4184	60.6472
5	0.0996	19.4184	49.7522
10	0.0996	19.4184	45.997

Computation showing the effect of variation of Schmidt number (s_c) on skin friction, local Nusselt number and thermophoretic particle deposition V_d

(s_c)	cf	Nu	Vd
0.1	0.0996	19.4184	109.2197
0.5	0.0996	19.4184	49.7522
1.0	0.0996	19.4184	37.9198

Computation showing the effect of variation of wedge angle parameter β on skin friction, local Nusselt number and thermophoretic particle deposition V_d

β	cf	Nu	Vd
$\frac{1}{6}$	0.0969	18.5375	47.4831
$\frac{1}{3}$	0.0969	19.4184	49.7522
$\frac{1}{2}$	0.0996	20.4421	52.3897

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