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Effects of Heat absorption and porosity of the medium on MHD flow past an oscillating vertical plate in the presence of Hall current

U.S. Rajput[1], Neetu Kanaujia[2*]

[1,2]Department of Mathematics and Astronomy, University of Lucknow, Lucknow, India

[*]*Corresponding Author: rajputneetulko@gmail.com*

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Abstract**—** The present study is carried out to examine the effects of heat absorption and porosity of the medium on flow model. In the study of motivated by several important problems like maintenance and secular variation of earth's magnetic field, the internal rotation rate of sun, the structure of rotating magnetic stars, the planetary and solar dynamo problems. The model consists of an unsteady flow of a viscous, incompressible and electrically conducting fluid. The flow is along an impulsively started oscillating vertical plate with variable mass diffusion. The magnetic field is applied perpendicular to the plate. The fluid model under consideration has been solved by Laplace transform technique. The numerical data obtained are discussed with the help of graphs and table. The effects of velocity and skin fraction are studied for different parameters like phase angle, thermal Grashof number, mass Grashaf number, the permeability of the medium, heat absorption and rotation parameter.

Keywords— *MHD flow, mass diffusion, Hall current and porous media.*

I. INTRODUCTION

Unsteady magneto hydrodynamic flow of rotating fluids, is a classical problem that has various applications in the field of aerospace, medical, manufacturing of fibbers, aerodynamics, biofluids, MHD power generators and pumps, accelerators, aerodynamic heating, electrostatic precipitation, polymer technology, petroleum industry, purification of crude oil and fluid droplets, sprays, rotating hydro magnetic generators and vortex type MHD power generators. Garg [1] has presented on combined effects of thermal radiations and Hall current on moving vertical porous plate in a rotating system with variable temperature. Reddy et al. [2] have worked radiation and mass transfer effects on nonlinear MHD boundary layer flow of liquid metal over a porous stretching surface embedded in porous medium with heat generation. Hall effects on unsteady MHD natural convection flow of a heat absorbing fluid past an accelerated moving vertical plate with ramped wall temperature was investigated by Seth et al [3]. Ramireddy et al. [4] have studied effect of nonlinear thermal radiation on MHD chemically reacting maxwell fluid flow past a linearly stretching sheet.Unsteady heat and mass transfer from a rotating vertical cone with a magnetic field and heat generation or absorption effects were investigated by Chamkha and Mudhaf [5]. Seddeek [6] has studied finite-element method for the effects of chemical reaction, variable viscosity, thermophoresis and heat generation/absorption on a boundary-layer hydromagnetic flow with heat and mass transfer over a heat surface. Shehzad et al. [7] have studied three-dimensional MHD flow of Casson fluid in porous medium with heat generation. Zeeshan and Majeed [8] have considered effect of magnetic dipole on radioactive nondarcian mixed convective flow over a stretching sheet in porous medium. Manivannan et al. [9] have worked on Radiation and chemical reaction effects on isothermal vertical oscillating plate with variable mass diffusion. Effect of viscous dissipation and heat source on unsteady MHD flow over a stretching sheet was developed by Reddy et al. [10]. Hossain et al. [11] have worked on MHD free convection and mass transfer flow through a vertical oscillatory porous plate with Hall, ion-slip currents and heat source in a rotating system. Hossain and Rashi [12] have considered Hall Effect on Hydromagnetic Free-convection flows along a porous Flat Plate with Mass Transfer'. Ibrahim et al. [13] focused their work on Chemical reaction and thermal radiation effects on MHD micro polar fluid past a stretching sheet embedded in a non - Darcian porous medium. Sattar et al. [14] have discussed Free convection and mass transfer flow through a porous medium past an infinite vertical porous plate with Time dependent temperature and concentration. Hayat et al. [15]

have analyzed Hall effects on the unsteady hydro magnetic oscillatory flow of a second-grade fluid. Seth et al. [16] have studied Hall effects on unsteady MHD natural convection flow of a heat absorbing fluid past an accelerated moving vertical plate with ramped temperature. Kim [17] has studied Heat and mass transfer in MHD micro polar flow over a vertical moving porous plate in a porous medium Rajput and Kanaujia [18] have worked on chemical reaction in MHD flow past a vertical plate with mass diffusion and constant wall temperature with Hall current. The main purpose of the present investigation is to study effects of heat absorption and porosity of the medium on MHD flow past an oscillating vertical plate in the presence of Hall current. The model has been solved using the Laplace transforms technique. The results are shown with the help of graphs and table.

II. MATHEMATICAL ANALYSIS

2. Mathematical Formulation

The Geometric model of the flow problem is shown in Figure-1.

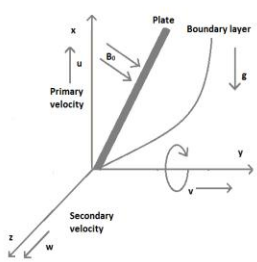

Figure1. Geometric model of the flow

A viscous, incompressible and electrically conducting fluid past an impulsively started oscillating plate is considered here. The x axis is taken in the upward direction and y normal to it. A transverse magnetic field of strength B_0 is applied on the plate which is inclined at an angle α from the vertical. Initially, it has been considered that the plate, as well as the fluid, is at the same temperature T_∞. The species concentration in the fluid is taken as C_∞. At time $t > 0$, plate starts oscillating in its own plane with frequency ω and temperature of the plate is raised to T_w. The concentration C near the plate is raised linearly with respect to time. The governing equations are as under:

$$\frac{\partial u}{\partial t} - 2\Omega w = \upsilon\frac{\partial^2 u}{\partial y^2} + g\,\beta Cos\alpha\,(T - T_\infty) +$$
$$g\,\beta^* Cos\alpha\,(C - C_\infty) - \frac{\sigma B_0{}^2}{\rho(1+m^2)}(u + mw) - \frac{\upsilon}{K}u\,, \quad (1)$$

$$\frac{\partial w}{\partial t} + 2\Omega u = \upsilon\frac{\partial^2 w}{\partial y^2} - \frac{\sigma B_0{}^2}{\rho(1+m^2)}(w - mu) - \frac{\upsilon}{K}w\,, \quad (2)$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial y^2}, \quad (3)$$

$$\rho C_p\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial y^2} - Q(T - T_\infty). \quad (4)$$

The initial and boundary conditions are

$$\left.\begin{array}{l} t \le 0: u = 0,\ w = 0,\ T = T_\infty,\ C = C_\infty \text{ for every } y, \\ t > 0: u = u_0 Cos\omega t,\ w = 0,\ T = T + (T_w - T_\infty)\dfrac{u_0{}^2 t}{\upsilon},\ C = C_\infty + (C_w - C_\infty)\dfrac{u_0{}^2 t}{\upsilon} \text{ at } y = 0. \\ u \to 0,\ w \to 0,\ T \to T_\infty,\ C \to C_\infty \text{ as } y \to \infty, \end{array}\right\} \quad (5)$$

Here u is the velocity of the fluid in x- direction (primary velocity u) w is the velocity of the fluid in z- direction (secondary velocity w), m - Hall parameter, g - acceleration due to gravity, β - volumetric coefficient of thermal expansion, β^* - volumetric coefficient of concentration expansion, t - time, C_∞ the concentration in the fluid far away from the plate, C - species concentration in the fluid, C_w species concentration at the plate, D - mass diffusion, T_∞ - the temperature of the fluid near the plate, T_w temperature of the plate, T- the temperature of the fluid, k- the thermal conductivity, υ - the kinematic viscosity, ρ - the fluid density, K - permeability of the medium σ - electrical conductivity, μ - the magnetic permeability, and C_P - specific heat at constant pressure. Here $m = \omega_e\tau_e$ with ω_e - cyclotron frequency of electrons and τ_e - electron collision time.

To write the equations (1) - (4) in dimensionless form, we introduce the following non - dimensional quantities:

$$\left.\begin{array}{l} \bar{y} = \dfrac{yu_0}{\upsilon},\ \bar{u} = \dfrac{u}{u_0},\ \bar{w} = \dfrac{w}{u_0},\ \theta = \dfrac{(T - T_\infty)}{(T_w - T_\infty)},\ Sc = \dfrac{\upsilon}{D},\ \mu = \rho\upsilon, \\ Pr = \dfrac{\mu C_p}{k}, H = \dfrac{Q\upsilon}{u_0^2\rho C_p}, \bar{\Omega} = \dfrac{\upsilon\Omega}{u_0^2} Gr = \dfrac{g\beta\upsilon(T_w - T_\infty)}{u_0{}^3},\ \bar{K} = \dfrac{u_0{}^2 K}{\upsilon^2} \\ M = \dfrac{\sigma B_0^2\upsilon}{\rho u_0^2},\ Gm = \dfrac{g\beta^*\upsilon(C_w - C_\infty)}{u_0{}^3},\ \bar{C} = \dfrac{(C - C_\infty)}{(C_w - C_\infty)},\ \bar{t} = \dfrac{tu_0^2}{\upsilon}. \end{array}\right\} \quad (6)$$

where $\bar{u}$ - the dimensionless primary velocity, $\bar{w}$ - the secondary velocity, $\bar{b}$ - dimensionless acceleration parameter, t - dimensionless time, θ - the dimensionless temperature, $\bar{C}$ - the dimensionless concentration, $\bar{K}$ - the dimensionless permeability parameter, Ω - rotation parameter, H - heat absorption parameter, Gr - thermal Grashof number, Gm - mass Grashof number, K_c - Chemical reaction parameter, μ - the coefficient of viscosity, Pr - the

Prandtl number, *Sc* - the Schmidt number, *M* - the magnetic parameter.

The following non-dimensional quantities are introduced to transform equations (1), (2), (3) and (4) into dimensionless form:

The dimension less flow model becomes:

$$\frac{\partial\bar{u}}{\partial\bar{t}}-2\bar{\Omega}\bar{w}=\frac{\partial^2\bar{u}}{\partial\bar{y}^2}+GrCos\alpha\theta+GmCos\beta\bar{C}-\frac{M(\bar{u}+m\bar{w})}{(1+m^2)}-\frac{\bar{u}}{K}, \quad (7)$$

$$\frac{\partial\bar{w}}{\partial\bar{t}}+2\bar{\Omega}\bar{u}=\frac{\partial^2\bar{w}}{\partial\bar{y}^2}-\frac{M(\bar{w}-m\bar{u})}{(1+m^2)}-\frac{\bar{w}}{K}, \quad (8)$$

$$\frac{\partial\bar{C}}{\partial\bar{t}}=\frac{1}{Sc}\frac{\partial^2\bar{C}}{\partial\bar{y}^2}, \quad (9)$$

$$\frac{\partial\theta}{\partial\bar{t}}=\frac{1}{Pr}\frac{\partial^2\theta}{\partial\bar{y}^2}-H\theta. \quad (10)$$

The corresponding boundary conditions become

$$\left.\begin{array}{l}\bar{t}\le 0:\bar{u}=0,\ \bar{w}=0,\ \theta=0,\ \bar{C}=0\ \text{for every}\ \bar{y}.\\ \bar{t}>0:\bar{u}=Cos\bar{\omega}\bar{t},,\ \bar{w}=0,\ \theta=\bar{t},\ \bar{C}=\bar{t}\ at\ \bar{y}=0,\\ \bar{u}\to 0,\ \bar{w}\to 0,\ \theta\to 0,\ \bar{C}\to 0\ \text{as}\ \bar{y}\to\infty.\end{array}\right\} \quad (11)$$

Dropping bars in the above equations and combined equation (7) and (8) by using (q = u+iw), the model becomes

$$\frac{\partial q}{\partial t}=\frac{\partial^2 q}{\partial y^2}-\left(\frac{M}{1+m^2}(1-mi)+2i\Omega+\frac{1}{K}\right)q \quad (12)$$
$$+Gr\theta+GmC,$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}, \quad (13)$$

$$\frac{\partial\theta}{\partial t}=\frac{1}{Pr}\frac{\partial^2\theta}{\partial y^2}-H\theta. \quad (14)$$

Finally, the boundary conditions become:

$$\left.\begin{array}{l}t\le 0: q=0,\theta=0,C=0,\ for\ every\ y.\\ t>0: q=Cos\omega t,\ \theta=t,\ C=t\ \ at\ y=0\\ t>0: q=Cos\omega t,\theta=t,C=t,at\ \ y=0,\\ q\to 0,\ \theta\to 0,\ C\to 0,as\ y\to\infty.\end{array}\right\} \quad (15)\ (15)$$

The dimensionless governing equations (12) to (14), subject to the boundary conditions (15), are solved by the usual Laplace - transform technique. The solution obtained is as under:

$$q=\frac{1}{2}exp(bt-\sqrt{a+b}y)A_{33}+\frac{1}{4}\{\frac{GrCos\alpha}{(a+H\,Pr)^2}[(at+Pr(1+Ht)-1)(e^{-\sqrt{a}y}A_3$$
$$-exp(-\sqrt{H\,Pr}y)A_{11})+exp(-\sqrt{a}y)A_4\sqrt{a}(1+\frac{H\,Pr}{a})+A_{14}(1-Pr)(A_5-A_{12})$$
$$-\frac{1}{2i\sqrt{H}}y\,exp(-\sqrt{H\,Pr}yi)A_{10}\sqrt{Pr}(H\,Pr+a)]+\frac{GmCos\alpha}{a^2}[2A_6\,exp(-\sqrt{a}y)(1-at)$$
$$+exp(-\sqrt{a}y)(y\sqrt{a}A_8+2A_9Sc)+2A_{15}A_7(1-Sc)]-\frac{2GmCos\alpha}{a^2\sqrt{\pi}}[2ay\sqrt{tSc}\,exp(-\frac{y^2Sc}{4t})$$
$$+A_{16}\sqrt{\pi}(ay^2Sc+2at+2Sc-2)+A_{13}A_{15}\sqrt{\pi}(1-Sc)]\}.$$

$$C=t\left\{(1+\frac{y^2Sc}{2t})erfc[\frac{\sqrt{Sc}}{2\sqrt{t}}]-\frac{y\sqrt{Sc}}{\sqrt{\pi}\sqrt{t}}e^{-\frac{y^2}{4t}}Sc\right\},$$

$$\theta=\frac{1}{4Hi}exp(-yi\sqrt{H\,Pr})\left\{\begin{array}{l}-2i\sqrt{H}t(A_1-exp(-yi\sqrt{H\,Pr})A_2-2)\\ +y\sqrt{Pr}(A_1+exp(-yi\sqrt{H\,Pr})A_2-2)\end{array}\right\}.$$

II. 1 SKIN FRACTION

The dimensionless skin friction at the plate y = 0 is computed by

$$\left(\frac{dq}{dy}\right)_{y=0}=\tau_x+i\tau_z$$

III. INTERPRETATION OF RESULTS

The velocity, skin friction has been computed for different parameters. Figures 2, 3, 5 and 6 show that *u* decreased when *α, H,* Ω and *ωt* are decreases. Figure 4 show that *K* is increased. Figures 7, 8, 9 and 11 show that w decreases when *α, H, K,* and *ωt* are increased. Further, it is deduced from figure 10 that w increase when Ω is increased. These results are in agreement with the actual flow of the fluid. From table - 1 it is deduced that τ_x increases with increase in *K*, and *ωt* and it decreases when *α, H* ,and Ω are increased. The value of τ_z increases with increase in *H* and *ωt*. Further, it decreases when *α,* Ω*,* and *K* are increased.

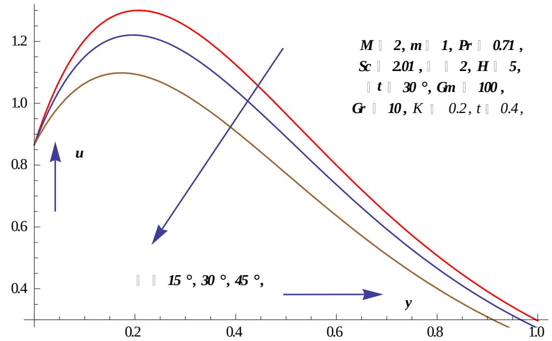

Fig 2. u vs y for different values of α

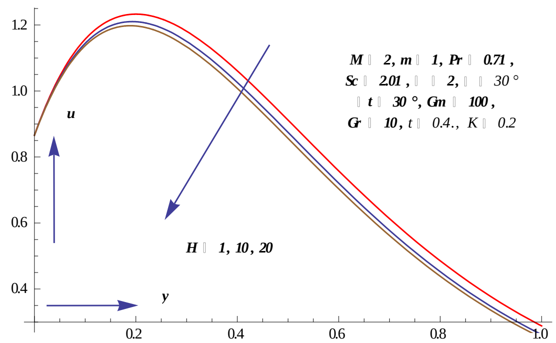

Fig 3. u vs y for different values of H

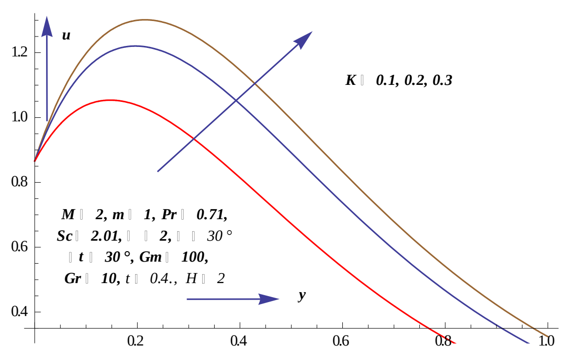

Fig 4. u vs y for different values of K

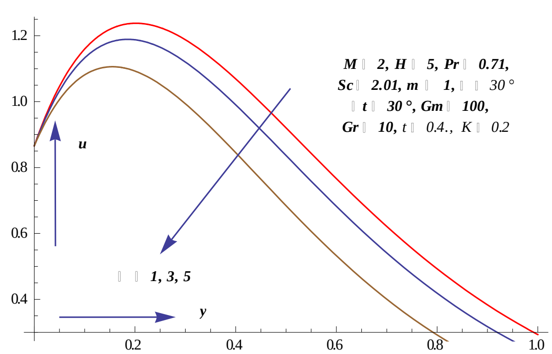

Fig 5. u vs y for different values of Ω

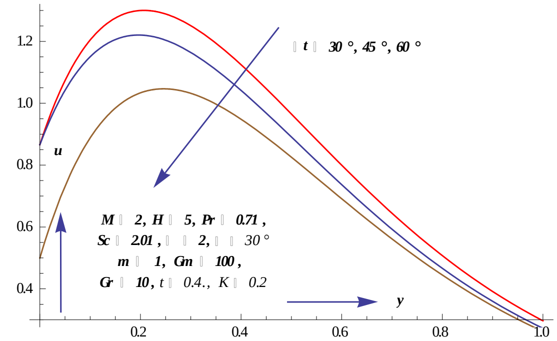

Fig 6. u vs y for different values of ωt

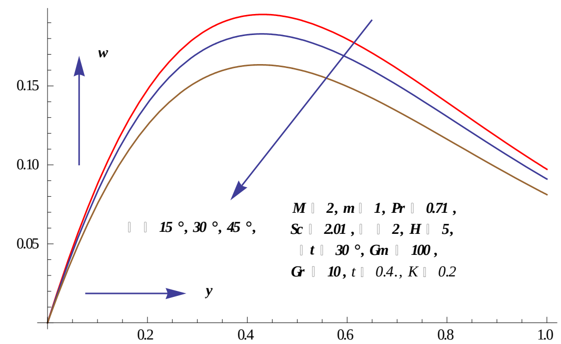

Fig 7. w vs y for different values of α

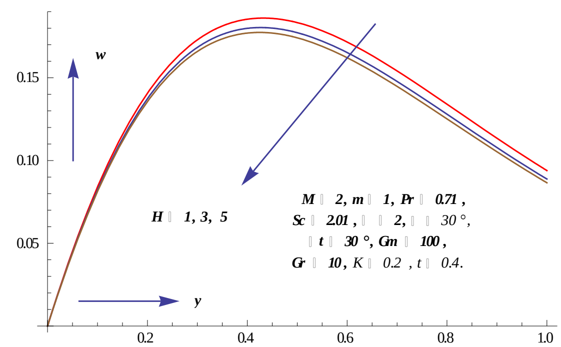

Fig 8. w vs y for different values of H

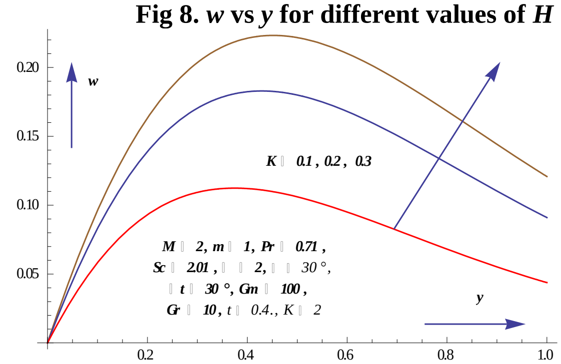

Fig 9. w vs y for different values of K

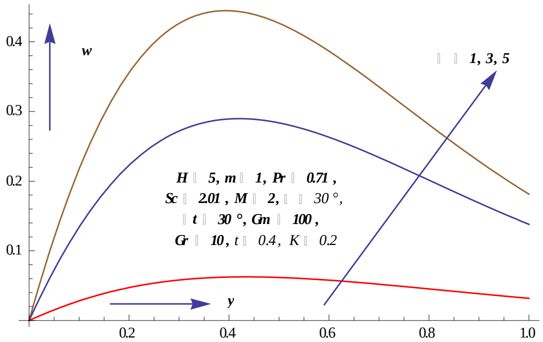

Fig 10. *w* vs *y* for different values of Ω

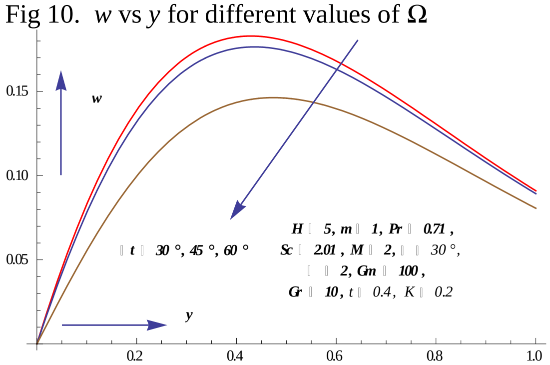

Fig 11. *w* vs *y* for different values of ωt

IV CONCLUSION

In this paper, a theoretical analysis has been done to study effects of heat absorption and porosity of the medium on MHD flow past an oscillating vertical plate in the presence of Hall current. It is observed that the primary velocity decreases with increasing the values of heat absorption, rotation parameter, and phase angle. The effect is similar to the secondary velocity except for the case of heat absorption. Primary velocity increases with increasing the permeability of the medium that is the secondary velocity increases when permeability of the medium and rotation parameter are increased.

Appendix:

$$A_0 = \frac{u_0^2 t}{\upsilon}, \qquad A_1 = erfc\left[\frac{2Hit - y\sqrt{P_r}}{2\sqrt{t}}\right],$$

$$A_2 = erfc\left[\frac{2Hit + y\sqrt{P_r}}{2\sqrt{t}}\right],$$

$$A_3 = (-1 - A_{17} + e^{2\sqrt{a}y}(A_{18} - 1)),$$

$$A_4 = (1 + A_{17} + e^{2\sqrt{a}y}(A_{18} - 1)),$$

$$A_5 = (-1 + A_{19} + e^{2y\sqrt{\frac{(a+H)P_r}{Pr-1}}}(A_{20} - 1)),$$

$$A_6 = (1 + A_{21} + e^{2\sqrt{a}y}(1 - A_{22})),$$

$$A_7 = (-1 + A_{23} + e^{2y\sqrt{\frac{aS_c}{S_c-1}}}(A_{24} - 1)),$$

$$A_8 = (1 + A_{21} + e^{2\sqrt{a}y}(A_{22} - 1)),$$

$$A_9 = (-1 - A_{21} + e^{2\sqrt{a}y}(A_{22} - 1)),$$

$$A_{10} = (1 + A_{25} + e^{2Hiy\sqrt{P_r}}(A_{26} - 1)),$$

$$A_{11} = (1 - A_{25} + e^{2Hiy\sqrt{P_r}}(A_{26} - 1)),$$

$$A_{12} = (-1 - A_{27} + e^{2y\sqrt{\frac{(a+H)P_r}{P_r-1}}}(A_{28} - 1)),$$

$$A_{13} = (-1 - A_{29} + e^{2y\sqrt{\frac{aS_c}{S_c-1}}}(A_{30} - 1)),$$

$$A_{14} = e^{\frac{at}{P_r-1} - y\sqrt{\frac{(a+H)P_r}{P_r-1}} + \frac{HtP_r}{P_r-1}}, \qquad A_{15} = e^{\frac{at}{S_c-1} - y\sqrt{\frac{aS_c}{S_c-1}}},$$

$$A_{16} = (-1 + erf(\frac{y\sqrt{S_c}}{2\sqrt{t}})), \qquad A_{17} = erf(\sqrt{at} - \frac{y}{2\sqrt{t}}),$$

$$A_{18} = erf(\sqrt{at} + \frac{y}{2\sqrt{t}}),$$

$$A_{19} = erf(\frac{y}{2\sqrt{t}} - \sqrt{\frac{(a+H)tP_r}{P_r - 1}}),$$

$$A_{20} = erf(\frac{y}{2\sqrt{t}} + \sqrt{\frac{(a+H)tP_r}{P_r - 1}}), \quad A_{21} = erf(\frac{\sqrt{at} - y}{2\sqrt{t}}),$$

$$A_{22} = erf(\frac{\sqrt{at} + y}{2\sqrt{t}}), \qquad A_{23} = erf(\frac{y - 2t\sqrt{\frac{aS_c}{S_c - 1}}}{2\sqrt{t}}),$$

$$A_{24} = erf(\frac{y + 2t\sqrt{\frac{aS_c}{S_c - 1}}}{2\sqrt{t}}),$$

$$A_{25} = erf\left(Hi\sqrt{t} - \frac{y\sqrt{P_r}}{2\sqrt{t}}\right), \qquad A_{26} = erf\left(Hi\sqrt{t} + \frac{y\sqrt{P_r}}{2\sqrt{t}}\right),$$

$$A_{27} = erf\left(\sqrt{t}\sqrt{\frac{a+H}{P_r-1}} - \frac{y\sqrt{P_r}}{2\sqrt{t}}\right), \qquad A_{28} = erf\left(\sqrt{\frac{(a+H)t}{P_r-1}} + \frac{y\sqrt{P_r}}{2\sqrt{t}}\right),$$

$$A_{29} = erf\left(\frac{1}{2\sqrt{t}}\left(\sqrt{\frac{at}{S_c-1}} - y\sqrt{S_c}\right)\right),$$

$$A_{30} = erf\left(\frac{1}{2\sqrt{t}}\left(\sqrt{\frac{at}{S_c-1}} + y\sqrt{S_c}\right)\right),$$

$$A_{31} = e^{-y\sqrt{a+i\omega}} + e^{-yy\sqrt{a-i\omega}},$$

$$A_{32} = e^{-y\sqrt{a+i\omega}+2it\omega} + e^{y\sqrt{a-i\omega}+2it\omega},$$

$$A_{33} = A_{31} + A_{32} - e^{-y\sqrt{a+i\omega}} A_{34} - e^{-y\sqrt{a+i\omega}+2it\omega} A_{35},$$

$$a = \frac{M}{1+m^2}(1-im) + 2i\Omega + \frac{1}{K}.$$

$$A_{34} = erf\left[\frac{y-2t\sqrt{a-i\omega}}{2\sqrt{t}}\right] + erf\left[\frac{y+2t\sqrt{a-i\omega}}{2\sqrt{t}}\right],$$

$$A_{35} = erf\left[\frac{y-2t\sqrt{a+i\omega}}{2\sqrt{t}}\right] + erf\left[\frac{y+2t\sqrt{a+i\omega}}{2\sqrt{t}}\right],$$

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Table – 2 Skin friction

m	*Gr*	*Gm*	*M*	α **(degree)**	*H*	*Sc*	*K*	*Pr*	*Ω*	ωt **(degree)**	*t*	τ_x	τ_z
1.0	10	100	2.0	**15**	5.0	2.01	0.2	0.71	2.0	30	0.4	4.4563	-0.9900
1.0	10	100	2.0	**30**	5.0	2.01	0.2	0.71	2.0	30	0.4	6.1615	-1.7059
1.0	10	100	1.0	**45**	5.0	2.01	0.2	0.71	2.0	30	0.4	6.0523	-1.8295
1.0	10	100	3.0	30	**1.0**	2.01	0.2	0.71	2.0	30	0.4	4.0348	-0.9490
1.0	10	100	2.0	30	**10**	2.01	0.2	0.71	2.0	30	0.4	3.9056	-0.9315
1.0	10	100	2.0	30	**20**	2.01	0.2	0.71	2.0	30	0.4	3.8297	-0.9218
1.0	10	100	2.0	30	5.0	2.01	**0.1**	0.71	2.0	30	0.4	2.6698	-0.6839
1.0	10	100	2.0	30	1.0	2.01	**0.3**	0.71	2.0	30	0.4	4.5014	-1.07325
1.0	10	100	2.0	30	1.0	2.01	0.2	0.71	**1.0**	30	0.4	4.06136	-0.31806
1.0	10	100	2.0	30	1.0	2.01	0.2	0.71	**3.0**	30	0.4	3.7852	-1.51997
1.0	10	100	2.0	30	1.0	2.01	0.2	0.71	**5.0**	30	0.4	3.2560	-2.4944
1.0	10	100	2.0	30	1.0	2.01	0.2	0.71	2.0	**45**	0.4	4.4793	-0.8750
1.0	10	100	2.0	1.0	1.0	2.01		0.71	2.0	**60**	0.4	5.1391	-0.7898

AUTHORS PROFILE

Dr. Uday Singh Rajput is a faculty member in the department of mathematics and astronomy, University of Lucknow, India. He has more than 25 years of teaching experience at UG and PG levels and also guided students for Ph. D. degree. He has published more than 80 research articles. His research areas include MHD flows, Graph Theory and Operations Research.

Neetu Kanaujia is a research student in the department of mathematics and astronomy, University of Lucknow, India.

