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HALL AND ION SLIP EFFECTS ON MHD AG-H2O NANOFLUID BIOMEDICAL ENGINEERING APPLICATIONS

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ABSTRACT

Hall and ion slip impacts on MHD rotating free convective flow of Ag-water based nanofluids in a permeable medium past a moving vertical plate are assessed. The nanoparticles of a smaller size than that of the matrix pores are suspended in nanofluid using either surfactant or surface change technology, preventing the agglomeration and deposition of these on the porous matrix. The governing flow equations are solved empirically by perturbation appraisement. Impacts of numerous parameters on the flow are addressed by means of graphs and tables. The velocity increases with Hall and ion slip parameters. The skin friction coefficient increases with an increase in nano-particle volume fraction and it reduces with increase in Hall and ion slip parameters. The conclusions unveil that the blow of thermal convection of nanoparticles has increased the temperature distribution, which helps in destroying the cancer cells during the drug delivery process. This model for studying flow through porous media explains the development of bio-convection patterns generated by populations of gravitactic microorganisms in porous media.

KEYWORDS: Ag-H_2O nanofluid, Hall and Ion slip effects, Unsteady, Rotating frame, Heat source.

I. INTRODUCTION

The nanoparticles also hold a lot of significance in the areas of biological and medical applications. Some nanoparticles can bind many drugs, proteins, and target cancer cells. Since many nanoparticles have high atomic numbers that can produce heat, they lead to the treatment of tumor-selective photothermal therapy. A major interest of convective heat transmission of nanofluids in sciences and engineering is incredibly significant. The nanofluid was first proposed by Choi [1]. Nanofluids have applications in microelectronics, microfluidics, transportation, biomedical, X-rays, material processing, and scientific measurement. Dharmaiah et al. [2] presented the effect of chemical reaction on heat and mass transfer mhd flow Ag, TiO_2 and Cu water nano fluids over a semi infinite surface. . Dharmaiah et al. [3] examined an analysis of heat and mass transfer on mhd flow of nanofluid over a semi infinite moving surface with diffusion thermo. Vedavathi et al. [4] studied heat transfer on mhd nanofluid flow over a semi infinite flat plate embedded in a porous medium with radiation absorption, heat source and diffusion thermo effect. Vedavathi et al. [5] reported analysis of heat and mass transfer on mhd flow with Ag, Al_2O_3 and cu water nanofluids over a semi infinite surface. Vedavathi et al. [6] contested a study on mhd boundary layer flow rotating frame nanofluid with chemical reaction. Ramprasad et al. [7] experimented a study on al_2o_3-h_2o nanofluid in the presence of constant heat source. Baby Rani et al. [8] discussed hall and ion slip effects on Ag - water based mhd nano fluid flow over a semi infinite vertical plate embedded in a porous medium. In many realistic applications that require a strong magnetic field, there is a need to think both the Hall and ion-slip currents because of the significant effect they have on the vector of the current density and transitively on the magnetic force idiom. Veera Krishna and Chamkha [9] investigated the diffusion-thermo, radiation-absorption and Hall and ion slip effects on MHD free convective rotating flow of nanofluids (Ag and TiO_2) past a semi- infinite permeable moving plate with a constant heat source. Veera Krishna and Chamkha [10] discussed the MHD squeezing flow of a water-based nanofluid through a saturated porous medium between two parallel disks taking Hall current into account. Ram [11] investigated the effects of Hall and ion slip currents on MHD rotating free convective heat-generating flow. Seddeek [12] has discussed the effects of Hall and ion-slip currents and Heat transfer on magneto-micropolar fluid over a non-isothermal stretching sheet with suction and blowing. Seddeek and Abdelmeguid [13] discussed the boundary layer analysis which is used to the effects of Hall and ion-slip currents on steady magnetomicropolar fluid over a horizontal plate. Jha and Apere [14] investigated unsteady MHD Couette flow of a Newtonian fluid between two rotating parallel plates taking hall and ion-slip currents. Uddin and Kumar [15] discussed Hall and ion-slip effect on the thickness of the boundary layer flow of a micropolar fluid over a wedge.

The aforementioned studies and literature survey bear witness that the analysis of Hall and ion effects of a viscous incompressible electrically conducting nanofluid in an infinite vertical plate with rotation effect has not been presented yet. In order to fill the gap of the existing literature, the Hall and ion slip effects on the unsteady MHD free convective rotating flow of nanofluids in a porous medium past infinite vertical flat plate have been undertaken and discussed. The conclusions unveil that the blow of thermal convection of nanoparticles has increased the temperature distribution, which helps in destroying the cancer cells during the drug delivery process. This model for studying flow through porous media explains the development of bio-convection patterns generated by populations of gravitactic microorganisms in porous media.

II. MATHEMATICAL ANALYSIS

We have considered Hall and ion slip effects on the unsteady free convective flow of Ag-water based nanofluid of ambient temperature T_∞ over a vertical semi-infinite moving plate entrenched in a homogeneous porous medium under thermal buoyancy effect with a constant heat source and convective boundary conditions. We assumed both the fluid phase and nanoparticles are in a thermal equilibrium state. Also, we assume a uniform shape and sized nanoparticles. The porous medium is considered as homogeneous as well as isotropic and is in local thermal equilibrium with the nanofluid. The thermophysical properties of pure water and Ag nanoparticles are taken to be constant at a reference temperature and are given in Table 3 [17].

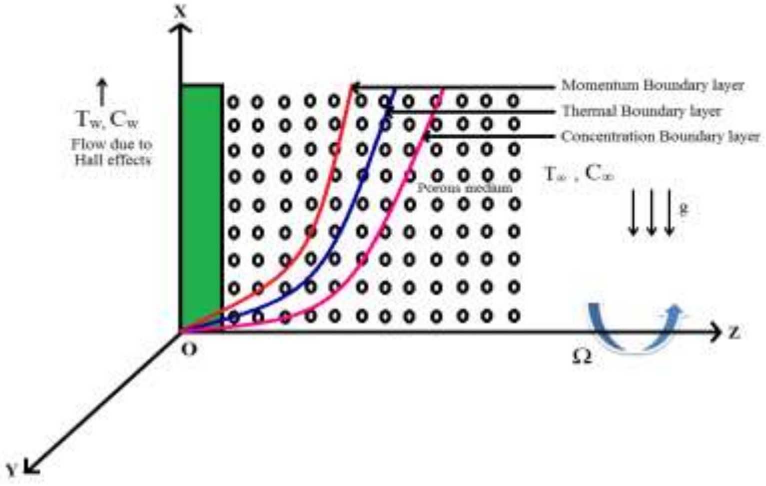

Fig. 1: Flow geometry

Figure 1 portrays the physical model of the problem. The flow is assumed to be in the x-direction which is obtained along the plate in the ascendant direction and z-axis is normal to it. The entire system rotates with an angular velocity Ω about z-axis. An unvarying peripheral magnetic field B0 is taken to be acting along the z-axis. There is no applied voltage (E = 0). The induced magnetic field is tiny compared to the external magnetic field. Due to semi-infinite plate surface assumption, all the variables are functions of z and time t only. Under the boundary layer approximations along with References [16, 17], the basic equations that describe the physical situation are given by

$$\frac{\partial w^*}{\partial z^*}=0$$

(1)

$$\frac{\partial u^*}{\partial t^*}+w^*\frac{\partial u^*}{\partial z^*}-2\Omega v^*=\frac{\mu_{nf}}{\rho_{nf}}\frac{\partial^2 u^*}{\partial {z^*}^2}+g\beta_{nf}\left[T^*-T_\infty\right]+\frac{B_0 J_y}{\rho_{nf}}-\frac{\mu_{nf}}{\rho_{nf}}\frac{u^*}{k^*}$$

(2)

$$\frac{\partial v^*}{\partial t^*}+w^*\frac{\partial v^*}{\partial z^*}+2\Omega u^*=\frac{\mu_{nf}}{\rho_{nf}}\frac{\partial^2 v^*}{\partial {z^*}^2}-\frac{B_0 J_x}{\rho_{nf}}-\frac{\mu_{nf}}{\rho_{nf}}\frac{v^*}{k^*}$$

(3)

$$\frac{\partial T^*}{\partial t^*}+w^*\frac{\partial T^*}{\partial z^*}=\alpha_{nf}\frac{\partial^2 T^*}{\partial {z^*}^2}-\frac{Q}{\left(\rho C_p\right)_{nf}}\left[T^*-T_\infty\right]$$

(4)

The corresponding boundary conditions are

$$u^*\left(z^*,t^*\right)=0,v^*\left(z^*,t^*\right)=0,T^*=T_\infty \quad for \quad t^*<0$$

(5)

$$\left.\begin{array}{c} u^*\left(0,t^*\right)=U_r\left[1+\frac{\varepsilon}{2}\left(e^{\text{int}}+e^{-\text{int}}\right)\right],v^*\left(0,t^*\right)=0,-K_{nf}\frac{\partial T^*}{\partial z^*}=h_f\left[T_w-T_\infty\right] \quad at\ z^*=0 \\ u^*(\infty,t^*)\to 0,v^*(\infty,t^*)\to 0,T^*(\infty,t^*)\to T_\infty \end{array}\right\}t^*\geq 0$$

(6)

Where $\varepsilon \ll 1$.

We consider equation (1) as

$$w^*=-w_0$$

(7)

where the constant w_0 represents the normal velocity at the plate which is positive for suction ($w_0 > 0$) and negative for blowing or injection ($w_0 < 0$).

The velocity characteristic Ur is defined as $U_r=\left[g\left(\rho\beta\right)_f\left(T_w-T_\infty\right)v_f\right]^{\frac{1}{3}}$ (8)

We considered the effective density, thermal diffusivity, heat capacitance; thermal conductivity, thermal expansion coefficient, and effective dynamic viscosity of the nanofluid are from Reference [16, 17].

The non-dimensional variables are:

$$u=\frac{u^*}{U_r}\ ;\ v=\frac{v^*}{U_r}\ ;\ z=\frac{z^*U_r}{\nu_f}\ ;\ t=\frac{t^*U_r^2}{\nu_f}\ ;\ n=\frac{n^*\nu_f}{U_r^2}\ ;\ \theta=\frac{T^*-T_\infty}{T_w-T_\infty}\ ;\ \gamma=\frac{h_f\nu_f}{K_fU_r}\ ;\ R=\frac{\Omega\nu_f}{U_r^2}\ ;$$

$$\Pr=\frac{\nu_f}{\alpha_f};$$

$$M=\frac{B_0}{U_r}\left[\frac{\sigma\nu_f}{\rho_fU_r}\right]^{\frac{1}{2}};\ S=\frac{w_0}{U_r};\ K=\frac{k^*U_r^2}{\nu_f^2};\ Q_H=\frac{Q\nu_f^2}{U_r^2k_f}.$$

Obtaining equations along with boundary conditions are

$$a_1\left[\frac{\partial u}{\partial t}-S\frac{\partial u}{\partial z}-2Rv\right]=a_3\frac{\partial^2u}{\partial z^2}+M^2\left[\alpha_2v-\alpha_1u\right]-a_3\frac{u}{K}+a_2\theta$$

(9)

$$a_1\left[\frac{\partial v}{\partial t}-S\frac{\partial v}{\partial z}+2Ru\right]=a_3\frac{\partial^2v}{\partial z^2}-M^2\left[\alpha_2u+\alpha_1v\right]-a_3\frac{v}{K}$$

(10)

$$a_4\left[\frac{\partial\theta}{\partial t}-S\frac{\partial\theta}{\partial z}\right]=\frac{1}{\Pr}\left[\frac{k_{nf}}{k_f}\frac{\partial^2u}{\partial z^2}-Q_H\theta\right]$$

(11)

$$u(z,t)=v(z,t)=0,\theta(z,t)=0\qquad for\qquad t<0$$

(12)

$$\left.\begin{array}{l} u(0,t)=1+\dfrac{\varepsilon}{2}\left[e^{\mathrm{int}}+e^{-\mathrm{int}}\right],v(0,t)=0,\dfrac{d\theta}{dz}=-\gamma\left(1-\theta(z)\right)\ at\ z=0 \\ u(\infty,t)\to0,v(\infty,t)\to0,\theta(\infty,t)\to0\qquad\qquad as\qquad z\to\infty \end{array}\right\}t\geq0$$

(13)

Let $q=u+iv$

Now we combining the equations [(9) and (10)] & [(12) and (13)] are as follows:

$$a_1\left[\frac{\partial q}{\partial t}-S\frac{\partial q}{\partial z}+2iRq\right]=a_3\frac{\partial^2q}{\partial z^2}-\left(M^2\left[\alpha_1+i\alpha_2\right]q+\frac{a_3}{K}\right)u+a_1a_2\theta$$

(14)

$$q(z,t)=0,\theta(z,t)=0\qquad for\qquad t<0$$

(15)

$$\left.\begin{array}{l} q(0,t)=1+\frac{\varepsilon}{2}\left[e^{\mathrm{int}}+e^{-\mathrm{int}}\right], \frac{d\theta}{dz}=-\gamma\left(1-\theta(z)\right)\ at\ z=0 \\ q(\infty,t)\to 0, \theta(\infty,t)\to 0 \qquad\qquad as \quad z\to\infty \end{array}\right\} t\geq 0 \tag{16}$$

To solve equations (14)-(15) with (16) we the following

$$q(z,t)=q_0\left(z\right)+\frac{\varepsilon}{2}\left[e^{\mathrm{int}}q_1\left(z\right)+e^{-\mathrm{int}}q_2\left(z\right)\right]$$

(17)

$$\theta(z,t)=\theta_0\left(z\right)+\frac{\varepsilon}{2}\left[e^{\mathrm{int}}\theta_1\left(z\right)+e^{-\mathrm{int}}\theta_2\left(z\right)\right]$$

(18)

The solutions of velocity, temperature, skin-friction and Nusselt number are given by:

$$q=N_3e^{-m_2z}+\frac{\varepsilon}{2}e^{\mathrm{int}}e^{-m_3z}+\frac{\varepsilon}{2}e^{-\mathrm{int}}e^{-m_4z}$$

(19)

$$\theta=\frac{\gamma}{m_1+\gamma}e^{-m_1z}$$

(20)

$$C_f=-\frac{1}{\left(1-\phi\right)^{2.5}}\left(\frac{\partial q}{\partial z}\right)_{z=0}=-\frac{1}{\left(1-\phi\right)^{2.5}}\left[-m_2N_3-m_3\frac{\varepsilon}{2}e^{\mathrm{int}}-m_4\frac{\varepsilon}{2}e^{-\mathrm{int}}\right]$$

(21)

$$Nu=-\frac{k_{nf}}{k_f}m_1\left(\frac{\gamma}{m_1+\gamma}\right)$$

(22)

III. RESULTS AND DISCUSSIONS

Hall and ion slip effects on MHD free convective rotating flow of nanofluids in a porous medium past a moving vertical semi-infinite flat plate are investigated. System dynamics demonstrates itself to be a powerful and easy-to-use educational tool for biomedical engineering and sciences and is also able to explain the behavior of a physiological system. Figure 2 demonstrates the effect of the suction/injection parameter S on the fluid velocity. The velocity across the boundary layer decreases for S (>0) for Ag-water nanofluid. So also as S increases, the velocity still approaches the same asymptotic value for large values of z. Thus, the thickness of the boundary layer decreases with an increase in the suction parameter S (>0). Figure 3 illustrates the velocity for an assortment of the nanoparticle volume fraction parameter ϕ. Hence, the velocity of the fluid across the boundary layer increases with the increase of ϕ. Figure 4 denotes the velocity profile with effect from the heat source parameter Q_H. The magnitude of the velocity decreases with increasing Q_H throughout the fluid region. Figure 5 represents the velocity distribution with the different values of convection parameter γ for Ag–water. Increased values of γ tend to increase the velocity and so accelerate the momentum boundary layer thickness. Figure 6 illustrates the influence of the magnetic field parameter M on the velocity distribution for Ag–water nanofluid. The velocity across the boundary layer reduces with an increase in the magnetic field parameter M and decreases asymptotically to zero at the boundary, which leads to a reduction in the layer thickness due to Lorentz force. For different values of the permeability parameter K, the velocity distribution on the porous wall is plotted in Fig. 7 for Ag–water. It is obvious that the increased values of K tend to increase the velocity on the porous wall and so enhance the momentum boundary layer thickness. The opposite effect is noticed on increasing rotation parameter R, i.e., increasing the rotation reduces the momentum boundary layer thickness (Fig. 8). Figure 9 depicts the velocity with the different values of ion slip parameter βi for Ag–water. Increased values of ion slip parameter βi tend to increase the velocity and so enhance the momentum boundary layer thickness. Figure 10 depicts the velocity with the different values of Hall parameter βe for Ag–water. Increased values of βe tend to increase the velocity and so enhance the momentum boundary layer thickness. Figure 11 demonstrates the variation of suction parameter S on temperature for Ag-water nanofluid. The magnitude of the temperature reduces with increasing suction parameter S and then thermal boundary layer thickness retarded throughout the fluid region. The influence of nanoparticle volume fraction parameter ϕ on the temperature is shown in Fig. 12 for Ag–water. The temperature profile increases with the increase in nanoparticle volume fraction parameter ϕ. Hence, the thermal boundary layer thickness improves and tends asymptotically to zero as the distance from the boundary is enhanced. Figure 13 displays the temperature profiles for various values of the heat generation parameter Q_H for nanoparticle Ag. The temperature in the boundary layer region decreases with the increase in the heat generation parameter Q_H, and as a consequence, the thermal boundary layer thickness decreases. These side views satisfy the far field boundary conditions asymptotically, which bear the mathematical results obtained. Figure 14 presents a typical profile for temperature with the convective parameter γ for Ag nanofluid. The temperature increases on increasing γ in the boundary layer region and is maximum at the surface of the plate for both nanoparticles. Thus, by escalating γ, thermal boundary layer thickness enhances. So, we can interpret that the rate of heat transfer increases with increase in convective parameter γ.

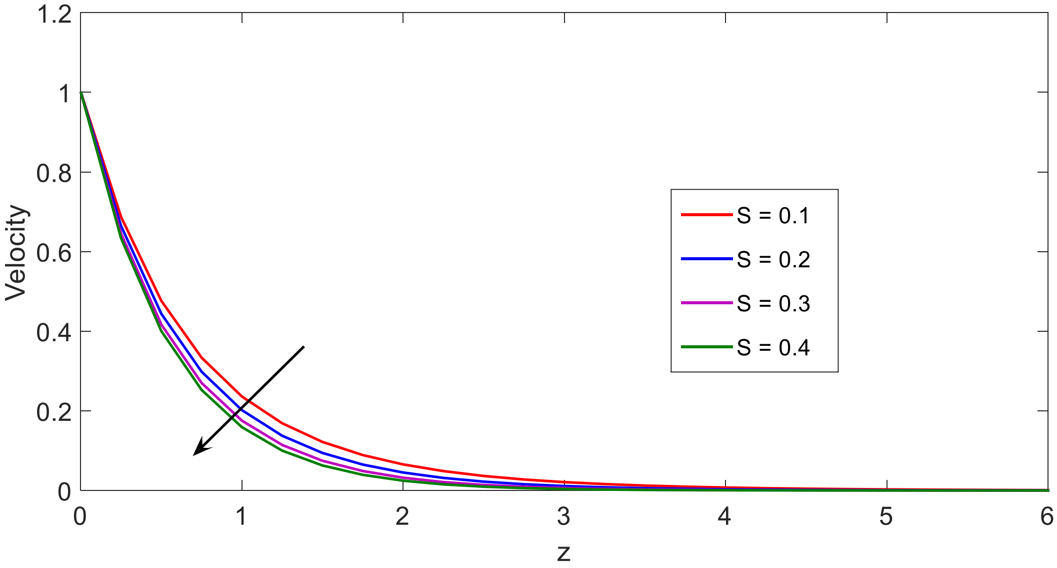

Fig. 2: Velocity profiles for Suction parameter

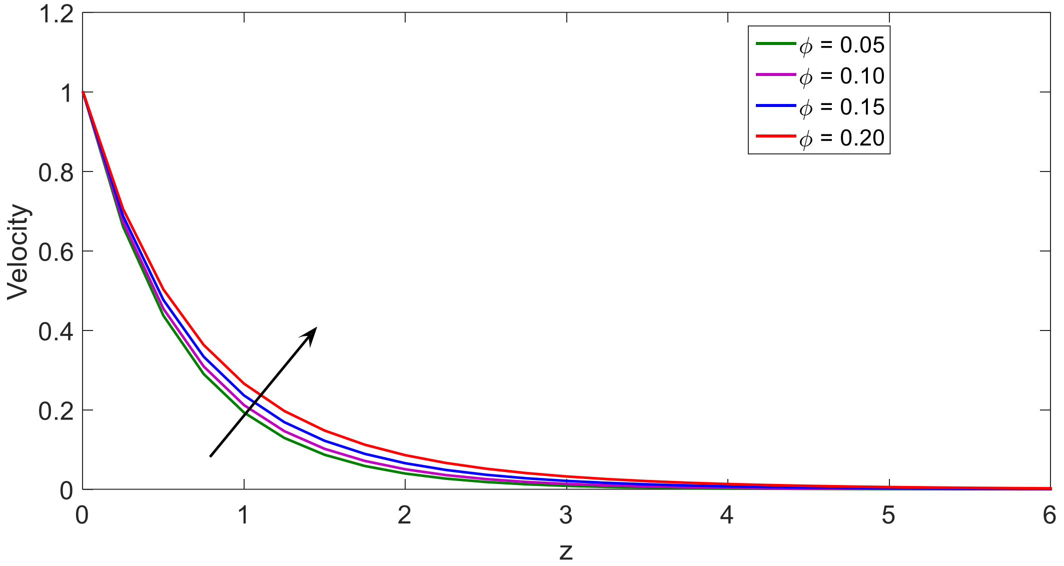

Fig. 3: Velocity profiles for solid volume fraction of nano particle

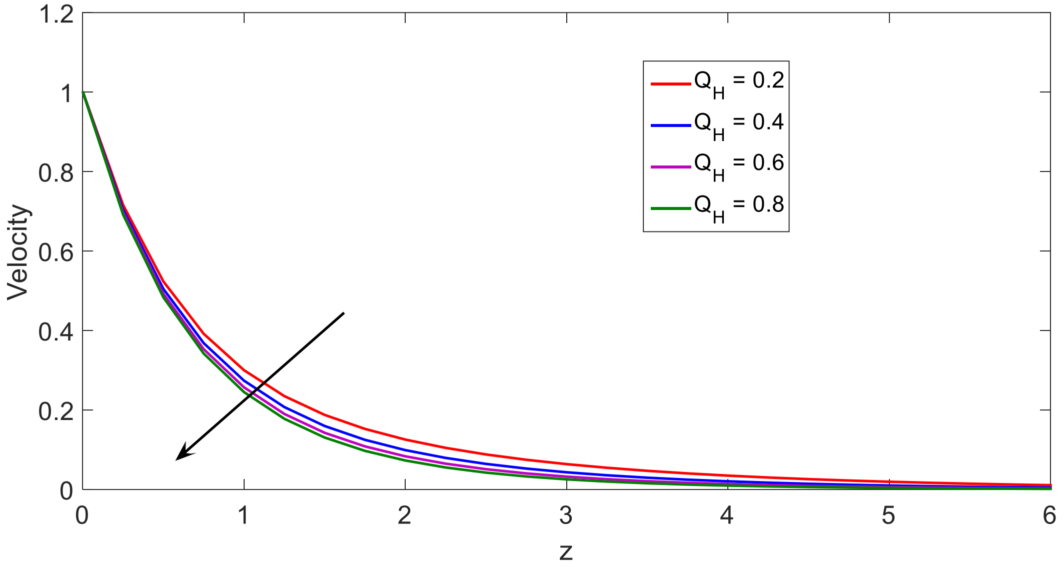

Fig. 4: Velocity profiles for Heat source parameter

The variation of the skin friction coefficient Cf and the Nusselt number Nu/Rex with M, K, βe, βi, R, γ, QH, S, and ϕ are shown in Tables 1 and 2, respectively. Table 1 shows that the skin friction coefficient Cf decreases with increasing parameters K, βe, βi, and γ whereas the skin friction coefficient increases with increasing M, R, Q_H and ϕ for both nanofluids with Ag nanoparticles. Also, from Table 2, the Nusselt number increases with the increase in all parameters γ, QH, S, and ϕ for both nanofluids with Ag nanoparticles. The variation of Nusselt number is much more considerable for nanofluids.

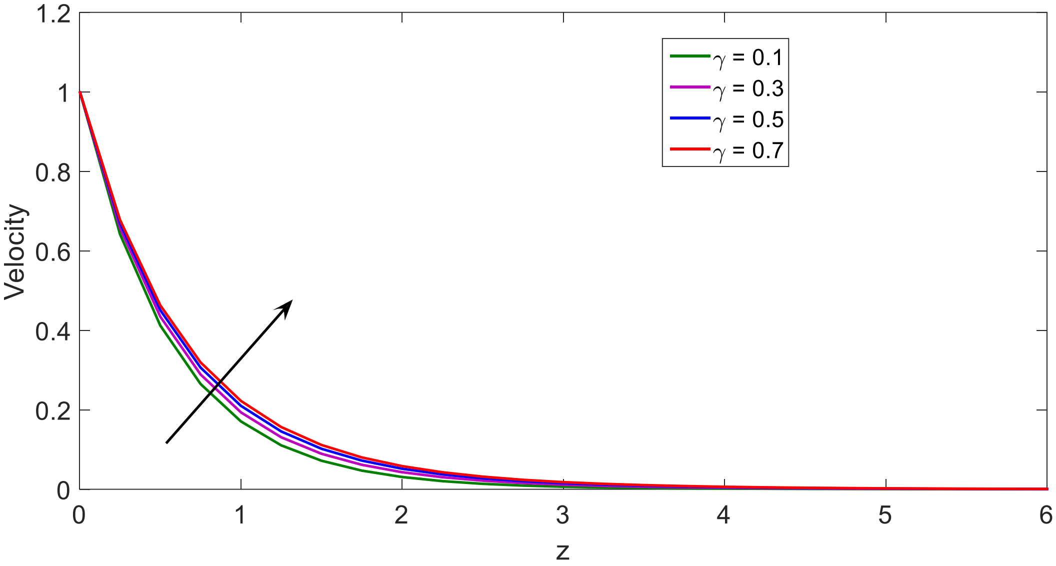

Fig. 5: Velocity profiles for Convective parameter

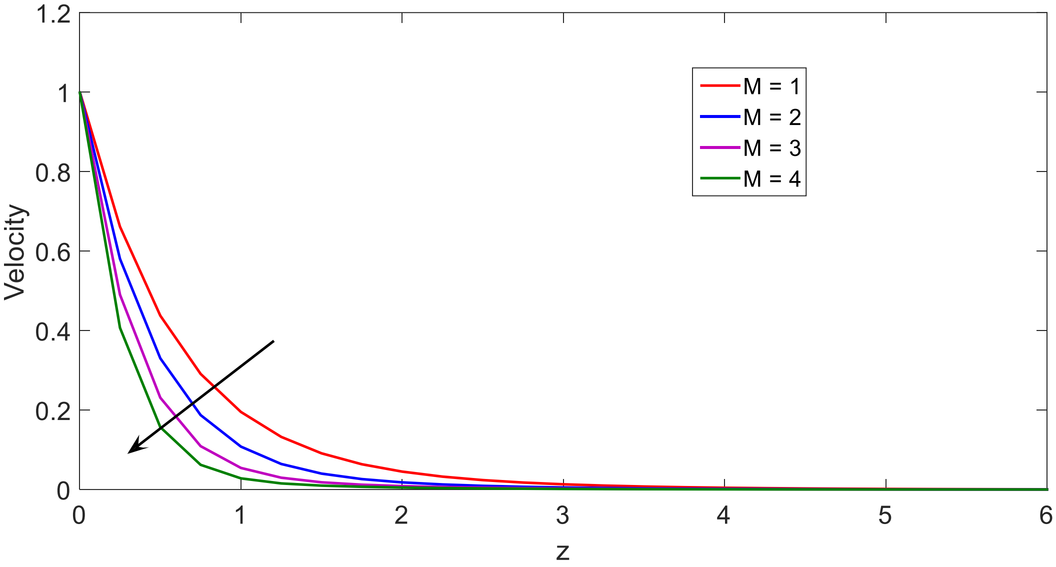

Fig. 6: Velocity profiles for Magnetic parameter

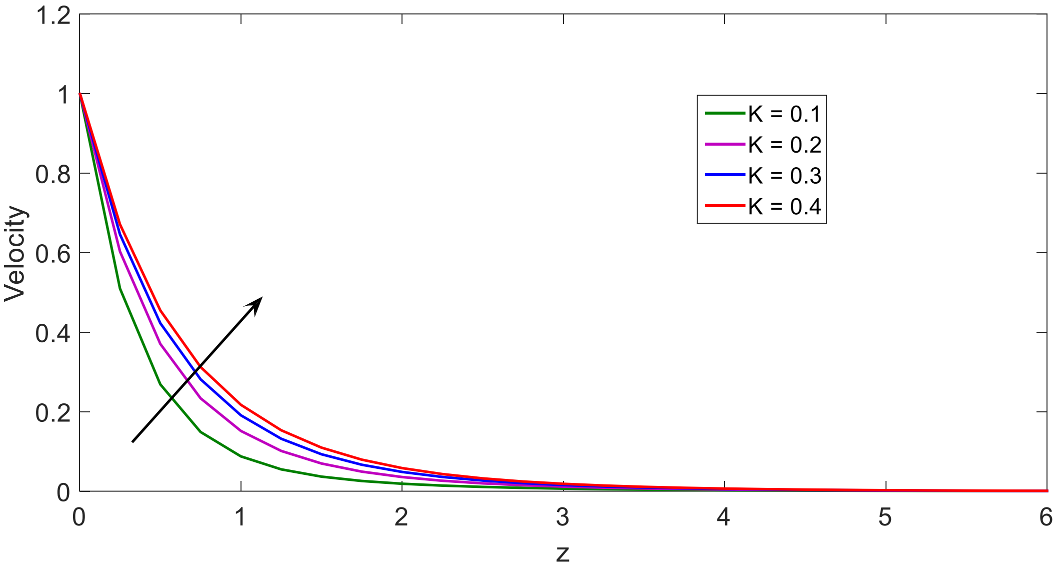

Fig. 7: Velocity profiles for Permeability parameter

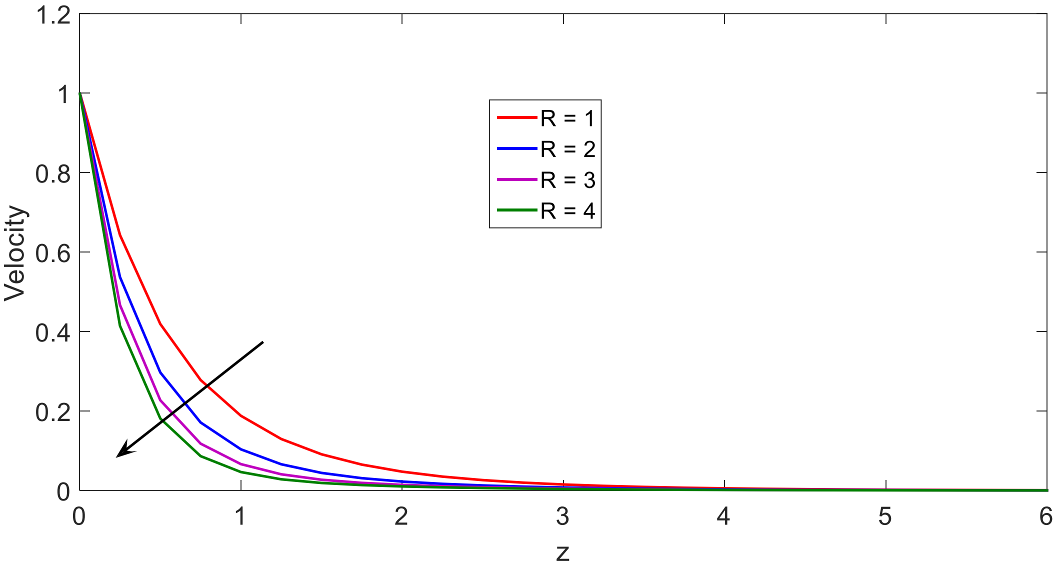

Fig. 8: Velocity profiles for Rotation parameter

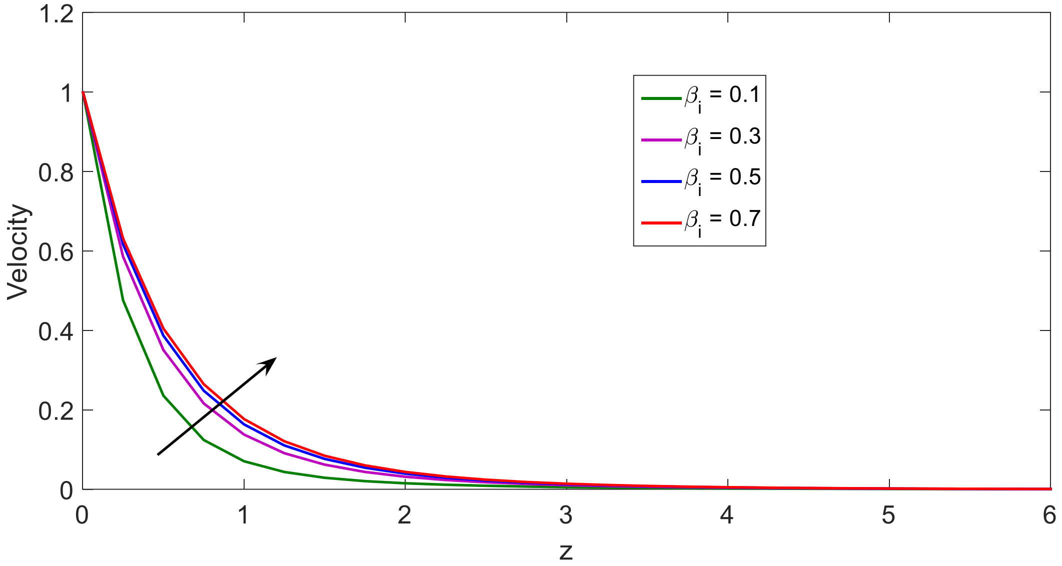

Fig. 9: Velocity profiles for Ion-slip parameter

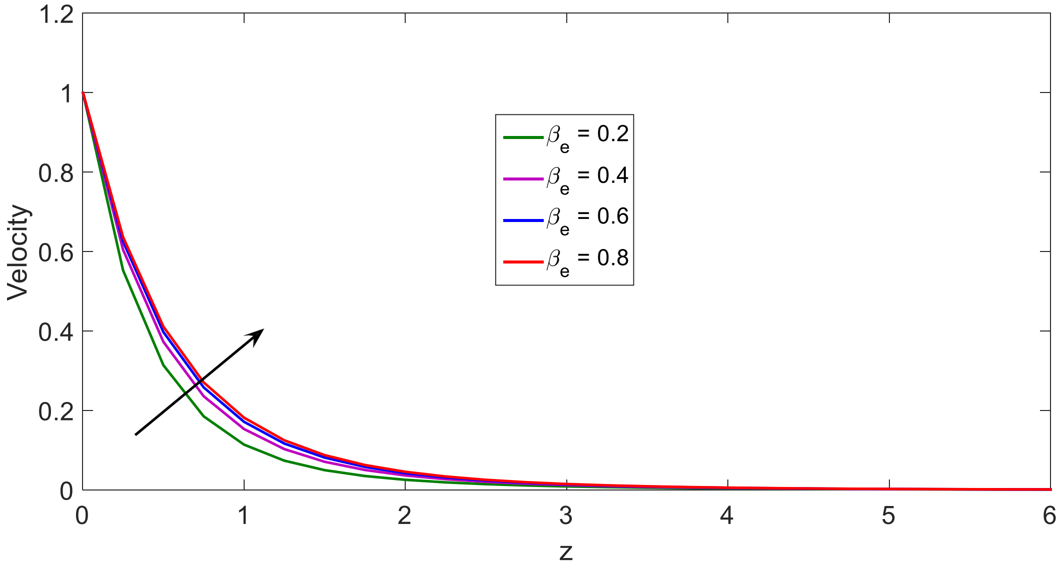

Fig. 10: Velocity profiles for Hall parameter

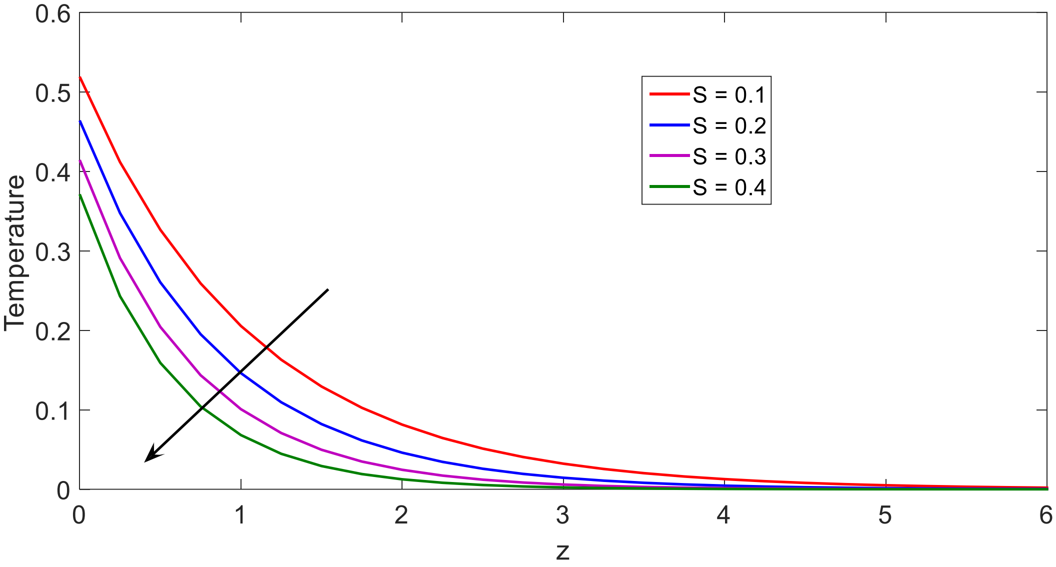

Fig. 11: Temperature profiles for Suction parameter

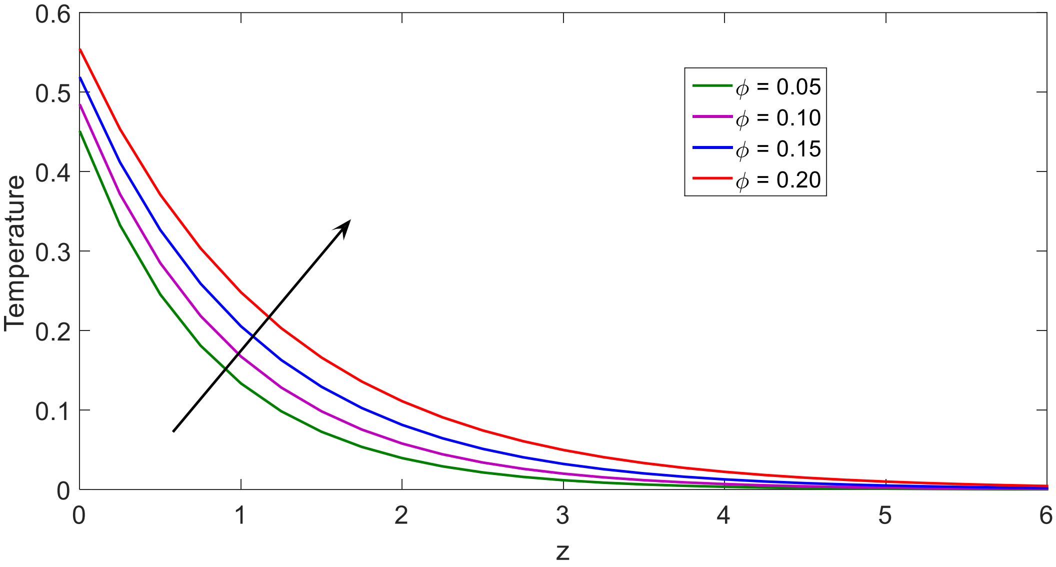

Fig. 12: Temperature profiles for solid volume fraction of nano particle

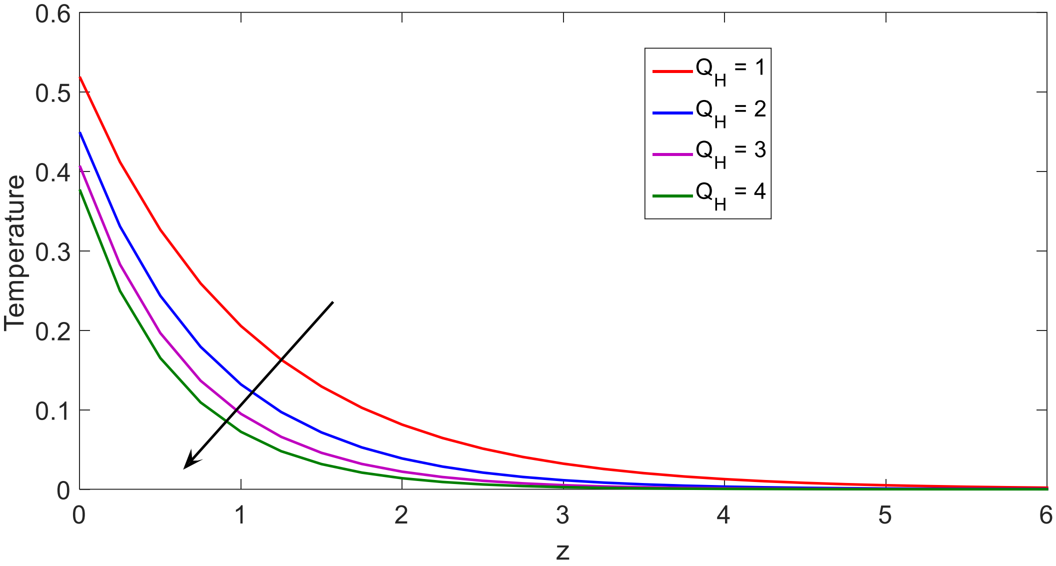

Fig. 13: Temperature profiles for Heat source parameter

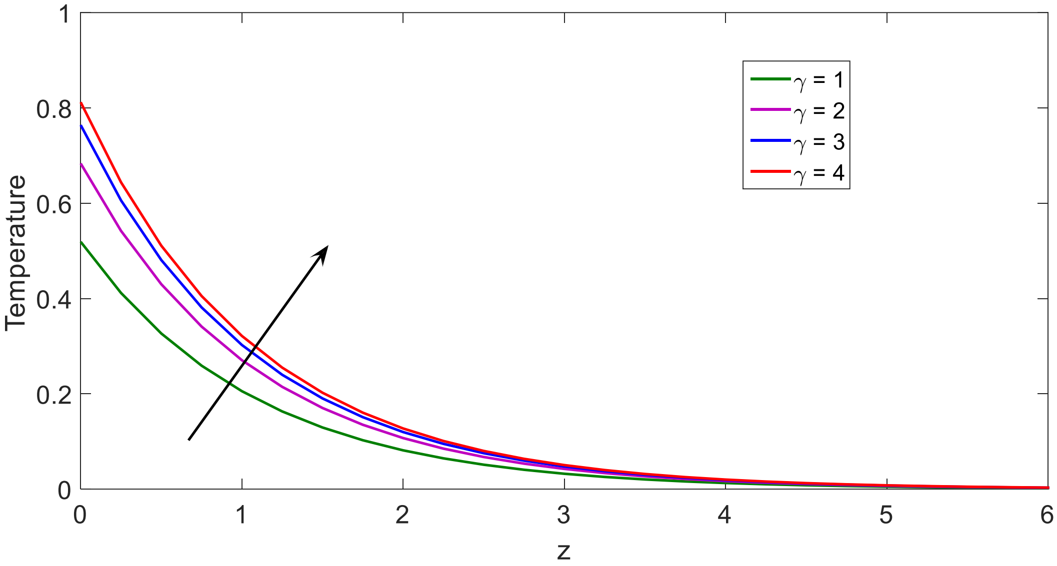

Fig. 14: Temperature profiles for Convective parameter

Table 1: Skin-friction values for different factors

β_e	βi	R	K	M	ϒ	QH	φ	Cf
0.1 0 .2 0 .3 0 .4								2 .6846 2 .6830 2 .6814 2

								.6799
	1							2.6473
	2							2.6344
	3							2.6290
	4							2.6261
		0.1						0.4879
		0.3						0.9365
		0.5						1.2758
		0.7						1.5528
			1					1.2581
			2					0.9028
			3					0.7614
			4					0.6848
				0.1				1.7079
				0.2				1.7184
				0.3				1.7357
				0.4				1.7596
					0.1			2.5752
					0.2			2.4260
					0.3			2.3011
					0.4			2.1950
						0.2		1.7810
						0.4		1.8051
						0.6		1.8102
						0.8		1.8242
							0.01	1.3046
							0.02	1.3442
							0.03	1.3820
							0.04	1.4185

Table 2: Nusselt values for different factors

Q_H	ϒ	S	φ	Nu
1				0.8907
2				1.0197
3				1.0980
4				1.1535
	0.1			0.1672

	0.2			0.3046
	0.3			0.4197
	0.4			0.5174
		0.2		0.9927
		0.4		1.1646
		0.6		1.2905
		0.8		1.3814
			0.01	0.5992
			0.02	0.6163
			0.03	0.6338
			0.04	0.6519

Table 3: Thermo physical properties - (Baby Rani et al.[17])

	ρ	**Cp**	**K**	**βx10-5**
water	997.1	4179	0.613	21
Ag	10,500	235	429	1.89

IV. CONCLUSIONS

Hall and ion slip effects on MHD free convective rotating flow of nanofluids in a porous medium past a moving vertical semi-infinite flat plate are investigated. The conclusions are made as the following. The resultant velocity decreases with an increase in Hartmann number, suction parameter, heat source parameter and rotation parameter but an opposite effect is noticed for Hall and ion slip parameters, solid volume fraction of nanoparticles, convective and permeability parameters. An increase in convection and solid volume fraction of nanoparticles led to increase the thermal boundary layer thickness but a reverse trend occurs for the heat source parameter. The skin friction coefficient increases with solid volume fraction of nanoparticles, the intensity of the magnetic field, heat source parameter, and rotation parameter and reduces with Hall and ion slip parameters. Increasing values of convection parameter, heat source parameter, suction parameter, and solid volume fraction of nanoparticles are to increase the rate of heat transfer for Ag nanofluid.

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