INFLUENCES OF RADIATIVE HEAT TRANSFER ON HYDROMAGNETIC HYBRID NANOFLUID FLOW THROUGH TWO ROTATING SURFACES

by

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Original scientific paper
https://doi.org/10.2298/TSCI23S1227K

This study explores the growth of heat transfer rate for hybrid nanofluid-flow through two rotary plates fixed parallel. For improvement of thermal conductivity nanoparticles of Cu and graphene oxide have dispersed in water. The fluid-flow has been influenced by thermal radiation. Magnetic effects with strength, B_0, has employed in the normal direction the plates. The set of equations that controlled the fluid-flow system have been shifted to dimension-free form employing suitable variables. The resultant set of equations has been solved by HAM. It has revealed in this work that with upsurge in the values of magnetic and rotational factors the linear velocity retarded while micro-rotational velocity upsurge. Intensification in volumetric fractions of nanoparticles results in retardation of fluid motion in all directions and growth in thermal flow profiles. Thermal flow profiles are also supported by the augmenting values of radiation factor. It has further revealed that hybrid nanofluid has a better flow performance in contrast of traditional nanofluid.

Key words: *hybrid nanofluid, MHD, rotating channel, thermal radiation, HAM technique*

Introduction

For the progression and improvement of different operations at industrial level the exchanger system must be upgraded to transmit the thermal flow most efficiently and effectively. Researchers have established a number of techniques for enhancement of thermal flow rates of different pure fluids. Heat conductance is the most substantial and operative features of nanofluids and hybrid nanofluids in numerous applications consisting of thermal exchanger

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and coolant phenomena. Hybrid nanofluid is manufactured by mixing two kinds of nanoparticles in pure fluid for enhancement its thermal conductivity. It has proved experimentally that, such fluids have high level of conductance. The idea of suspending the small sized particles in base fluid was first floated by Choi [1] for augmenting the thermal flow characteristics of pure fluid. Huminic and Huminic [2] have reviewed the thermal flow characteristics and generation of entropy for hybrid nanofluid-flow by using different flow conditions and have revealed that the irreversibility generation has retarded with augmentation in size of nanoparticles. Manzoor *et al.* [3] analyzed the improvement in heat transfer using hybrid nanoparticles. Chu *et al.* [4] have examined evaluated model based on comparison for unsteady MHD hybrid nanofluid between two parallel infinite plates and have concluded that upsurge in magnetic factor and volumetric fractions have upsurge the thermal profiles and retarded the fluid motion.

Magnetic effects for a flow system not only create high quality industrial products but also play a pivotal role in controlling the cooling rate. The MHD is the inspection of electrically conducting materials. Many researchers have conducted numerous studies [5-10] to discuss the influences of MHD upon fluid-flow systems. Bhatti *et al*. [11] studied the impact of MHD fluid-flow between circular rotary plates suspended in a permeable medium and have concluded that an upsurge in squeezing Reynolds number has augmented the concentration of nanoparticles and microorganism profiles. Nazeer *et al*. [12] inspected theoretically the impact of MHD upon a third grade fluid-flow through a channel and have revealed that intensification in magnetic field has enhanced the thermal flow profiles while it has declined the motion of fluid. Kodi and Mopuri [13] have discussed the time-dependent MHD fluid-flow over vertical surface with chemically reactive heat absorption as well as Soret influences and revealed that fluid velocity has retarded with expansion in angle of inclination and magnetic effects. Ikram *et al*. [14] discussed MHD Newtonian fluid-flow through a symmetric channel with fractional model of nanoparticles. Ali *et al*. [15] have analyzed generalization of bi-phase MHD free convective flow of Casson fluid through a channel.

Thermal radiation plays a substantial part in heat transfer phenomena. For its supportive behavior in heat transmission, many studies have been conducted by numerous researchers [16-20]. Waqas *et al.* [21] have discussed the influences of heat radiations and permeability on fluid motion over a porous cylinder and have concluded that fluid's thermal characteristics have been enlarged with boost in the values of thermally radiated factor and thermal Biot number. Rooman *et al.* [22] analyzed the irreversibility optimization with thermal flow phenomenon for MHD fluid over a vertical Riga plate by using impact of non-linear thermal radiations and have revealed that with growth in volumetric fraction and thermally radiative parameter the heat transfer of fluid have risen. Reddy and Sreedevi [23] have discussed heat transmission and entropy production for hydro-magnetic nanofluid-flow through a cavity with impact of thermal radiations.

This study discovers the improvement of thermal flow rate for hybrid nanofluid-flow between two rotary plates. Further:
- Nanoparticles of graphene oxide and copper have dispersed in water.
- The fluid-flow has influenced by thermal radiations.
- Magnetic effects with strength, B_0, has employed in normal direction the plates.
- The HAM has used for purpose of solution.

Problem formulation

Take a viscous incompressible hybrid nanofluid-flow amid two plates which are rotating with an angular motion Ω about vertical axis. The plates are separated by a distance h from each other as depicted in fig. 1. The nanoparticles of Cu and graphene oxide (GO) are suspended in the base fluid with a new combination (Cu + GO-water). The flow is induced by rotation of the plates. Magnetic effects have been employed in normal direction the fluid-flow system with influence of thermal radiations upon it.

Keeping in mind the aforementioned pointes the flow equations are described as [24, 25]:

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}+\frac{\partial v}{\partial y}=0 \tag{1}$$

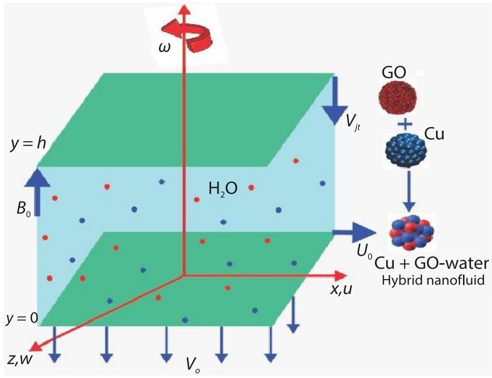


Figure 1. Geometrical view of flow problem

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+2\Omega w=-\frac{1}{\rho_{\text{hnf}}}\frac{\partial p}{\partial x}+\frac{\mu_{\text{hnf}}}{\rho_{\text{hnf}}}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{\sigma_{\text{hnf}}B_0^{\,2}}{\rho_{\text{hnf}}}u \tag{2}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\mu_{\text{hnf}}}{\rho_{\text{hnf}}}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{3}$$

$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}-2\Omega u=\frac{\mu_{\text{hnf}}}{\rho_{\text{hnf}}}\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}\right)-\frac{\sigma_{\text{hnf}}B_0^{\,2}}{\rho_{\text{hnf}}}w \tag{4}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha^*\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)-\frac{1}{\left(\rho c_p\right)_{\text{hnf}}}\frac{\partial q_r}{\partial y} \tag{5}$$

The related conditions at the boundaries [25]:

$$\begin{aligned} &u=ax,\ \ w=0,\ \ v=0,\ \ T=T_0,\ \text{at}\ \ y=0\\ &u=0,\ \ w=0,\ \ v=0,\ \ T=T_h,\ \text{at}\ \ y=h \end{aligned} \tag{6}$$

Set of suitable variables have been employed:

$$u=axf'(\eta),\ \ w=axg(\eta),\ \ v=-ahf(\eta),\ \ \theta(\eta)=\frac{T-T_h}{T_0-T_h},\ \text{with}\ \ \eta=\frac{y}{h} \tag{7}$$

The Rosseland approximation simplified q_r as [26, 27]:

$$q_r=-\frac{4}{3}\left(\frac{\sigma^*\partial T^4}{\kappa^*\partial \hat{y}}\right) \tag{8}$$

The notations σ^*, κ^* in eq. (8) are named as Stefan Boltzman constant and Resseland coefficient of mean absorption with $\sigma^* = 5.6697 \cdot 10^{-8}$ Wm^2/K^4. For sufficiently small thermal gradient we have [27]:

$$T^4\cong 4TT_h^3-T_h^4 \tag{9}$$

Incorporating eqs. (8) and (9) we have from eq. (5):

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha^*\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+\frac{1}{\left(\rho c_p\right)_{\text{hnf}}}\left(\frac{16\sigma^*}{3k^*}T_h^{\,3}\frac{\partial^2 T}{\partial y^z}\right) \tag{10}$$

Employing eq. (7) in eqs. (1)-(4) and (10) we have:

$$f^{(iv)}+\frac{\mu_f}{\mu_{\rm hnf}}\frac{\rho_{\rm hnf}}{\rho_{\rm f}}\left[\mathrm{Re}\left(ff'''-f'f''\right)\right]-\frac{\mu_{\rm f}}{\mu_{\rm hnf}}\left(2Krg'+Mf''\right)=0 \tag{11}$$

$$g''-\frac{\mu_{\rm f}}{\mu_{\rm hnf}}\frac{\rho_{\rm hnf}}{\rho_{\rm f}}\left[\mathrm{Re}\left(f'g-fg'\right)-2Krf'\right]-\frac{\mu_{\rm f}}{\mu_{\rm hnf}}Mg=0 \tag{12}$$

$$\frac{k_{\rm nf}}{k_{\rm f}}\left(1+\frac{4}{3}Rd\right)\theta''+\frac{\mu_{\rm f}}{\mu_{\rm hnf}}\frac{\left(\rho c_p\right)_{\rm hnf}}{\left(\rho c_p\right)_{\rm f}}\mathrm{Pr}\left(\mathrm{Re}\,\theta' f'\right)=0 \tag{13}$$

where Re is the Reynolds number, Kr – the rotational factor, M – the magnetic factor, Pr – the Prandtl number, and Rd – the radiation factor. These quantities are expressed mathematically:

$$\mathrm{Re}=\frac{ah^2}{\upsilon_{\rm f}},\ Kr=\frac{\Omega h^2}{\upsilon_{\rm f}},\ M=\frac{h^2\sigma_{\rm f}B_0{}^2}{\mu_{\rm f}},\ \mathrm{Pr}=\frac{\mu_{\rm f}\left(C_p\right)_{\rm f}}{k_{\rm f}},\ Rd=4\frac{\sigma^*}{k^*k_{\rm hnf}}T_h^3 \tag{14}$$

The thermophysical characteristics of nanoparticles are depicted as follows while their numerical values are provided in tab. 1.

$$\mu_{\rm hnf}=\frac{\mu_f}{\left\{\left(1-\varphi_1\right)\left(1-\varphi_2\right)\right\}^{2.5}},\ \left(\rho C_p\right)_{\rm hnf}=$$

$$=\left\{\left(1-\varphi_2\right)\left(\left(1-\varphi_1\right)+\varphi_1\frac{\left(\rho C_p\right)_{s1}}{\left(\rho C_p\right)_{\rm f}}\right)+\varphi_2\frac{\left(\rho C_p\right)_{s2}}{\left(\rho C_p\right)_f}\right\}\left(\rho C_p\right)_{\rm f} \tag{15}$$

$$\rho_{\rm hnf}=\left\{\left(1-\varphi_2\right)\left(\left(1-\varphi_1\right)+\varphi_1\frac{\rho_{s1}}{\rho_{\rm f}}\right)+\varphi_2\frac{\rho_{s2}}{\rho_{\rm f}}\right\}\rho_f,\ \kappa_{\rm hnf}=\frac{\kappa_{s2}+2\kappa_{\rm f}-2\varphi_2\left(\kappa_f-\kappa_{s2}\right)}{\kappa_{s2}+2\kappa_{\rm f}+\varphi_2\left(\kappa_{\rm f}-\kappa_{s2}\right)}\kappa_{\rm nf}$$

Table 1. Numerical values of base fluid and nanoparticles for thermosphysical characteristics

Properties	Cu-nanoparticles	GO-nanoparticles	Water base fluid
ρ [kgm^{-3}]	8933	1800	997.1
C_p [Jkg^{-1}K^{-1}]	385	717	4179
κ [WmK^{-1}]	400	5001	0.613

The related conditions are described:

$$\begin{gathered}f(0)=0,\ f'(0)=1,\ g(0)=0,\ \theta(0)=1,\ \text{at}\ \eta=0\\ f(1)=0,\ f'(1)=0,\ g(1)=0,\ \theta(1)=0,\ \text{at}\ \eta=h\end{gathered} \tag{16}$$

Interested quantities

The coefficient of skin friction and Nusselt number are expressed mathematically:

$$C_{\rm f}=\frac{h\mu_{\rm nf}}{\rho_{\rm f}u}\frac{\partial\hat{u}}{\partial\hat{y}}\bigg|_{y=0},\ \mathrm{Nu}=\frac{h}{k_{\rm f}\left(T_0-T_{\rm h}\right)}\left(k_{\rm hnf}+\frac{16\sigma^*T_h{}^3}{3k^*}\right)\frac{\partial T}{\partial y}\bigg|_{y=0} \tag{17}$$

Using eq. (7) in eq. (17) we have:

$$C_f = (1-\phi_1-\phi_2)^{2.5} f''(0), \ \text{Nu} = \frac{k_{hnf}}{k_f}\left(1+\frac{4}{3}Rd\right)\theta'(0) \tag{18}$$

Solution method

The solution of eqs. (11)-(13) with the help of eq. (16) has carried out by making use of semi-numerical technique HAM. This method is fast convergent and provides the solution of modeled equations in functional form. This method which is used for solution of non-linear equations needs some starting values known as initial guess as described:

$$\widehat{f}_0(\eta) = (\gamma+2\lambda-2\alpha)\eta^3 + (3\alpha-2\lambda-2\gamma)\eta^2 + \lambda\eta - \alpha, \ \widehat{\Theta}_0(\eta) = 1-\eta \tag{19}$$

Whereas the linear-operators are described:

$$L_f(f) = f''' - f', \ L_\Theta(\Theta) = \theta'' - \theta \tag{20}$$

Such that:

$$L_f\left(d_1 + d_2 e^{\eta} + d_3 e^{-\eta}\right) = 0, \ L_\Theta\left(d_4 e^{\eta} + d_5 e^{-\eta}\right) = 0 \tag{21}$$

where d_i for i = 1, 2, 3, 4, 5 are fixed values used as constants.

Discussion of results

This study explores the improvement of thermal flow rate for fluid through a channel. The fluid-flow has influenced by thermal radiations. Magnetic effects with strength B_0 has employed in normal direction the plates. The set of equations that controlled the fluid-flow system have been shifted to dimension-free form employing suitable set of variables. The resultant equations have been solved by HAM. Various substantial parameters revealed in this study are discussed theoretically with the help of graphical view in following paragraphs.

Figure 2 depicts the impact of rotational factor, Kr, upon-linear and micro-rotational velocities profiles. It has noticed that augmenting values of Kr implies the growth in rotational behavior and a reduction in linear behavior of motion due to resistance in direction opposite to linear fluid motion. Hence greater values of Kr opposes $f(\eta)$ and supports $g(\eta)$ as depicted in figs. 2(a) andd 2(b). Figure 3 presents the influence of magnetic effects, M, on both profiles. Since higher values of M generates Lorentz force in fluid-flow system that results in resistive force in opposite direction of linear motion whereas in this

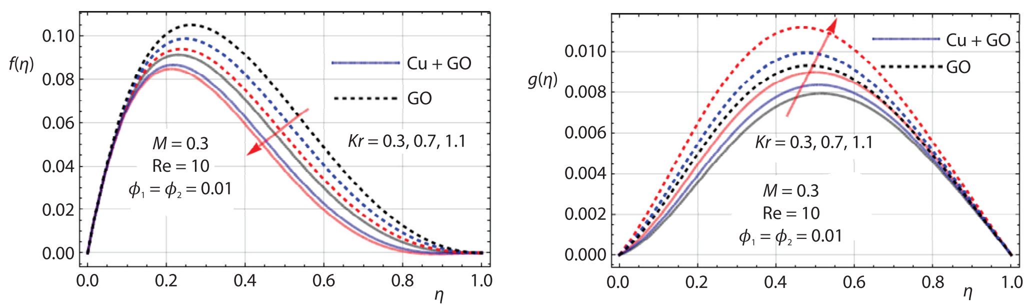


Figure 2. Influence of *Kr* on *f*(*η*) (a) and *g*(*η*) (b)

phenomenon swirling motion is supported. Hence values of $f(\eta)$ are declining and $g(\eta)$ are augmenting with growth in M as exposed in figs. 3(a) and 3(b). With augmentation in ϕ_1, ϕ_2 the fluid's density upsurge and more resistance is offered to fluid motion. In this process the skin friction enhances whereas fluid motion declines in all directions as depicted in figs. 4(a) and 4(b). Moreover, maximum thermal transmission results with augmenting values of solid nanoparticles as presented in fig. 4(c). With growing values of Reynolds number the viscous forces are more dominant that condenses the fluid motion. Hence upsurge in Reynolds number results a reduction in linear and micro-rotational motions as depicted in figs. 5(a) and 5(b). In this physical process the thermal flow profiles enhance as illustrated in fig. 5(c). Figure 6 presents the impact of radiation parameter, Rd, upon thermal profiles. Since with upsurge in Rd the width of thermal boundary-layer grows up that enhances the thermal profiles as depicted in fig. 6.

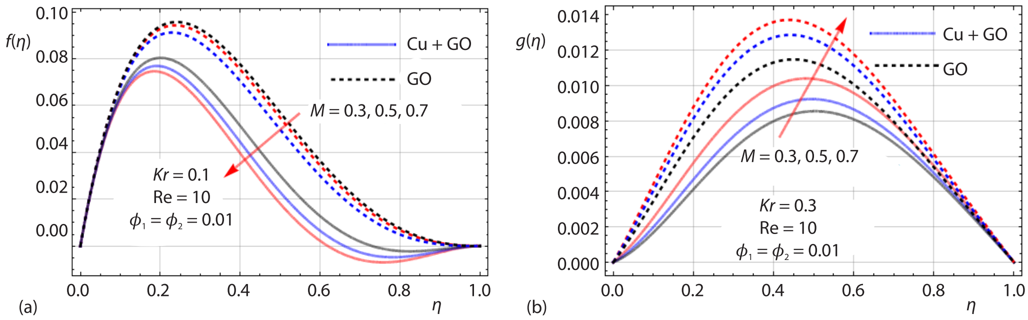
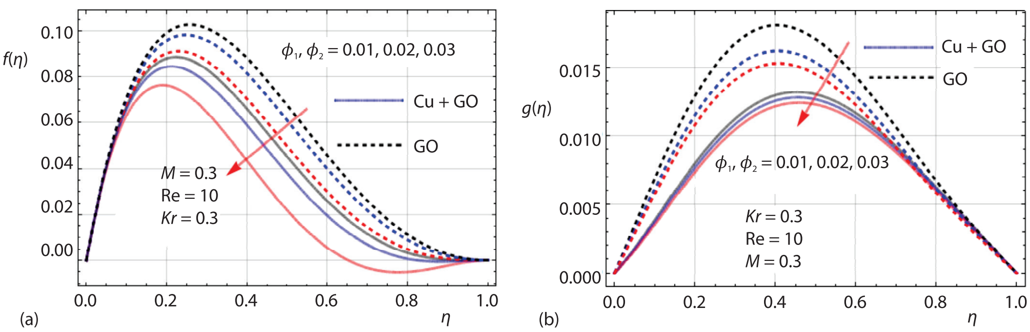


Figure 3. Influence of M on $f(\eta)$ (a) and $g(\eta)$ (b)



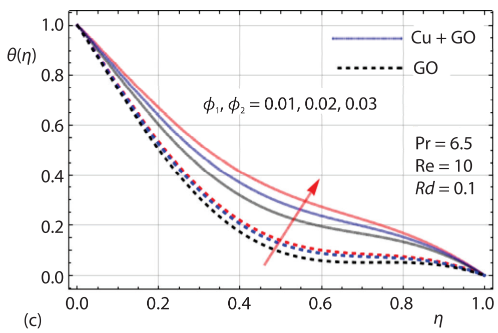


Figure 4. Influence of ϕ_1, ϕ_2 on $f(\eta)$ (a), $g(\eta)$ (b), and $\theta(\eta)$ (c)

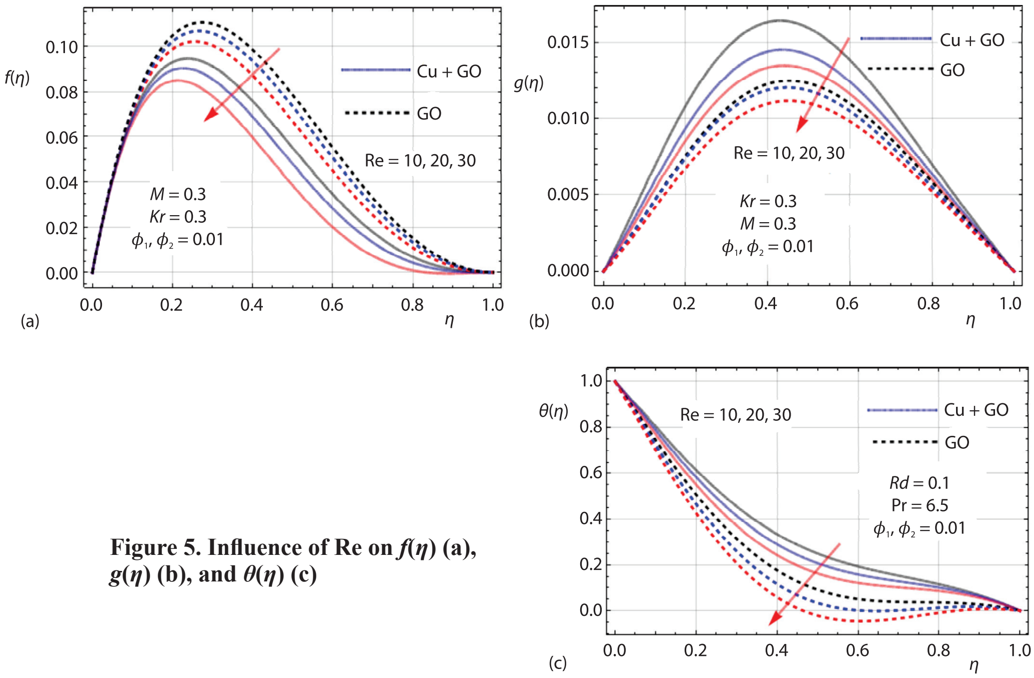


Figure 5. Influence of Re on $f(\eta)$ (a), $g(\eta)$ (b), and $\theta(\eta)$ (c)

Discussion of tables

Table 1 depicts the numerical values for thermophysical properties of base fluid and nanoparticles. It has observed in this study that magnetic effects, rotational factor and Reynolds number are offering more resistance to fluid motion that decline velocity and enhance skin friction as illustrated in tab. 2. It has also noticed from this table that the impact is more significant for hybrid nanoparticles. Since a growth in magnetic and radiation parameters results in augmentation of width of thermal boundary-layer. Hence Nusselt number upsurge with augmentation in values of these parameters as depicted on tab. 3.

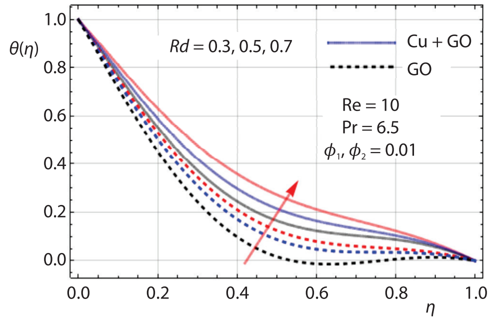


Figure 6. Influence of *Rd* on $\theta(\eta)$

Table 2. Various parameters *vs.* skin friction $-f''(0)$ over the lower plate

Kr	*M*	Re	$-f''(0)$ $\phi_1 = 0.01$ Nanofluid	$-f''(0)$ $\phi_1, \phi_2 = 0.01$ Hybrid nanofluid	$-f''(0)$ $\phi_1 = 0.02$ Nanofluid	$-f''(0)$ $\phi_1, \phi_2 = 0.02$ Hybrid nanofluid
0.1	0.1	0.1	0.28765400	0.327632100	0.292108660	0.335227620
0.3			0.31874522	0.3452187250	0.327658755	0.354104530
0.5			0.34568311	0.3.65434360	0.353256842	0.3764265440
	0.3		0.29821067	0.312982200	0.301298230	0.3202171260
	0.5		0.30828410	0.332878380	0.317282750	0.3432132830
		0.3	0.42765421	0.467432560	0.435427654	0.4754267420
		0.5	0.63287601	0.695423277	0.645728650	0.7025195420

Table 3. Various parameters *vs*. Nusselt number – $\theta'(0)$ over lower plate

Rd	M	$-\theta'(0)$ $\phi_1 = 0.01$ Nanofluid	$-\theta'(0)$ $\phi_1, \phi_2 = 0.01$ Hybrid nanofluid	$-\theta'(0)$ $\phi_1 = 0.03$ Nanofluid	$-\theta'(0)$ $\phi_1, \phi_2 = 0.03$ Hybrid nanofluid
0.1	0.1	2.46210000	2.52034620	2.54214520	2.632152021
0.3		2.69821000	2.74216980	2.75326780	2.852374212
0.5		2.87321020	2.942187320	2.92318630	3.103942176
	0.3	2.67321070	2.735673200	2.77246630	2.85473566
	0.5	2.68921255	2.701689200	2.82689410	2.89670177
		2.21087000	2.234210870	2.32321050	2.321234223
		2.10659220	2.141080650	2.20106580	2.210141112

Conclusions

This study explores the improvement of thermal flow rate for fluid-flow through a channel. The fluid-flow has influenced by thermal radiations. Magnetic effects with strength B_0 has employed in normal direction the plates. The set of equations that controlled the fluid-flow system have been shifted to dimension-free form employing suitable set of variables. The resultant set of equations has been solved by HAM. Various substantial parameters revealed in this study are discussed theoretically with the help of graphical view. Succeeding points have been highlighted after detail investigation of the topic, are as follows.

- With upsurge in the values of magnetic and rotational factors the linear velocity retarded while micro-rotational velocity upsurge.
- Intensification in volumetric fractions results in retardation of fluid motion in all directions and progression in thermal flow profiles.
- Growth in Reynolds number causes a decline in all flow profiles.
- Thermal flow profiles are supported by the augmenting values of radiation factor.
- It has revealed that hybrid nanofluid has a better flow performance in contrast of traditional nanofluid.

Declaration of competing interest

The autors have declared no conflict of interest.

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Paper submitted: June 17, 2022
Paper revised: June 28, 2022
Paper accepted: July 4, 2022