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Nanomaterial treatment due to imposing MHD flow considering melting surface heat transfer

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ABSTRACT

In current modeling, nanomaterial steady flow within a rotational system has been analyzed via Runge–Kutta method. The lower plate is melting surface and Lorentz force is applied to control the nanoparticle migration. Rotation, viscosity, magnetic and melting parameters as well as concentration of nanomaterial are scrutinized factors and distribution of temperature and velocity. Outputs demonstrate that temperature enhances as a result of enhancing in concentration of nanofluid and reverse treatment was observed for melting parameter. Augmenting rotation parameters leads to increase in rotational velocity

1. Introduction

Convective heat transfer in nanofluid is very practical in engineering and science [1–5]. Due to their applications, many researchers are illustrating a high level of interest in studying nanofluids, which has various applications in different areas including—transportation, manufacturing engineering, microfluidic, medicine and saving energy [6–9]. Its benefits appear in decreasing the time of procedure, in increasing thermal rating and in growing the life span of devices. They can be utilized as coolants in autos, heat exchangers and storage bins using silver nanoparticles embedded in plastic. Such nanoparticles deteriorate bacteria from any substance recently stored in the bins leading the health risks resulted from detrimental bacteria to minimize. Additionally, they can be utilized to providing an obstacle for gasses such as oxygen or moisture condition in a plastic membrane utilized for packaging leading the possibility of food spoiling to decline. Nanomaterial has various applications and become popular in these years [10–13]. According to Iniyan and Michael investigation [14], the nanofluid CuO/H_2O can increase the heat transfer up to 6.3% when it put under forced and natural circulation with even low volume amount of nano powders (0.05%).

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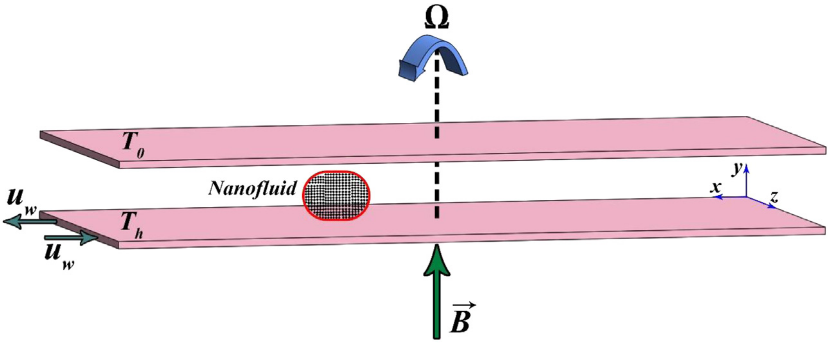

Fig. 1. Geometry of the problem.

Venkatasubbaiah and Nimmagadda [15] studied hybrid and pure nanofluids in the case of MCHS performance and found that the Nu raised around 32.46% and 21.09% by using the pure ones such as Cu and Al when had $\phi = 3\%$ compared to pure water. Charging of PCM with use of nanoparticles was performed by Sheikholeslami et al. [16] and they showed results for various times. Irreversibility analysis of nanomaterial was reported by Farshad and Sheikholeslami [17] for solar system. They utilized alumina nanomaterial to augment the performance of unit. Eiamsa-ard and Wongcharee [18] used simultaneously CuO nanofluid in the modified form of a twisted tape which has alternative shafts and gained far higher improvement in the Nu rather than the simple twisted tape, and as well as 13.8 times more efficient than the smooth one. To get the modeling results, various approaches can be employed [19–43]. Based on He et al. experiments which were the investigation of nanopowder size effects and Cu/H_2O volume amount on the functional of flat panel collector, they concluded that the more augment in the mass and size of nano powders the low performance will occur in the collector since the thermal conductivity decreases [44]. It is noteworthy that water temperature drops swiftly due to cutting down in the solar radiation. This is rooted in the fact that heat transferring of nanomaterial is greater than H_2O. A comparison of heat transfer ratio in the form of convection and friction coefficient between two nanofluids (TiO_2 and Al_2O_3) in the tube with various temperatures, was done by Azmi et al. [45]. Depend on the temperature the viscosity was varied and its highest amount was found at 30 °C. Due to the movement of nano-powders toward the tube center at the temperature 30 °C, the performance for the mixture of ethylene glycol and water was higher than TiO_2. Seven diverse types of nanofluid and as well as fin spacing impact on the function of the heat exchanger while utilizing nanofluids were investigated by Kumar et al. [46]. Although the rate of heat transfer was increased owing to the ideal value of fin spacing, at the same time decreased due to turbulence intensity drop. MWCNTs acted as the best thermo-physical feature among the chosen nanofluid. Sheikholeslami et al. [47,48] employed various shapes of fins to accelerate discharging process and they also utilized nanoparticles to augment thermal treatment. The numerically analyze about the heating transfer by means of different nanofluids which were CuO/water, Al2O3/water, Ag/water, and Cu/water by flat panel was scrutinized by Nasrin et al. [49]. They found that suspension of Ag/water had far higher heat transferring performance while the combination of Cu/water with the volume amount rate of 0∼5% had highest efficiency up to 65∼85%. In other articles various usages of nano powder were provided [50–56].

In current paper, steady nanomaterial flow within a rotational unit with melting surface has been investigated. Runge–Kutta approach was applied to solve the final ODEs which were achieved via similarity transformation. Temperature and velocity distributions were reported for various active parameters.

2. Problem definition

Steady flow of nanomaterial inside a rotating unit with considering melting plate was analyzed in this research. As depicted in Fig. 1, magnetic field was imposed vertically and single phase model was applied for nanomaterial. The bottom surface is stretched. Copper oxide has been mixed with water and creates new testing fluid and new material properties are as same as Ref. [58]. PDEs which can explain the current problem are:

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

$$\mu_{nf}\left(\frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial x^2}\right) - \frac{\partial p^*}{\partial y} = \left(\frac{\partial v}{\partial y}u\right)\rho_{nf} \tag{2}$$

$$\rho_{nf}\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + 2\Omega w\right) = -\frac{\partial p^*}{\partial x} + \mu_{nf}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \sigma_{nf} B_0^2 u, \tag{3}$$

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

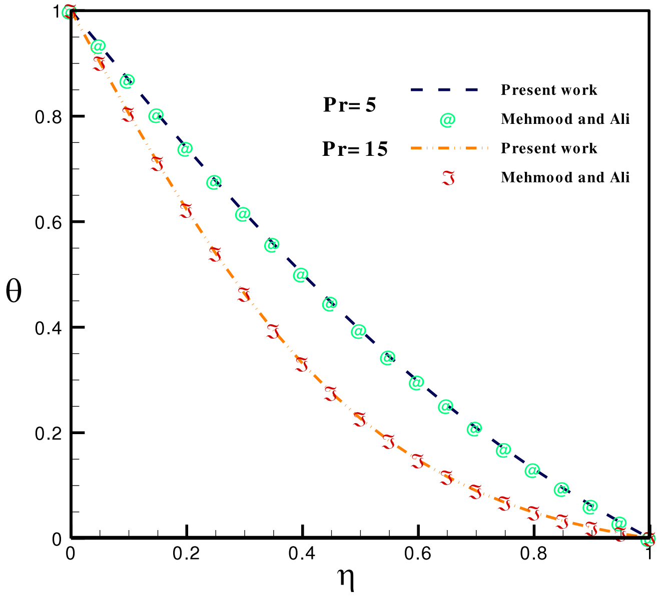

Fig. 2. Code verification with comparing outputs with [57] at $R = 0.5, \lambda = 0.5, M = 1$ and $Kr = 0.5$.

$$\begin{aligned}&(\rho C_p)_{nf}\left(w\frac{\partial T}{\partial z}+v\frac{\partial T}{\partial y}+u\frac{\partial T}{\partial x}\right)=k_{nf}\left(\frac{\partial^2 T}{\partial z^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial x^2}\right)\\&+\left(2\left[\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2+\left(\frac{\partial u}{\partial x}\right)^2\right]+\left(\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial v}{\partial z}\right)^2+\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)^2\right)\mu_{nf}\end{aligned} \tag{5}$$

$$\begin{aligned}&at \quad y=0: \quad T=T_m, \quad u=a\,x, \quad k_{nf}\left(\frac{\partial T}{\partial y}\right)\bigg|_{y=0}=\upsilon\rho_{nf}\left(-c_s\left(T_0-T_m\right)+L\right), \quad w=0,\\&at \quad y=h: \quad T=T_h, \quad w=0, \ v=0, \quad u=0,\end{aligned} \tag{6}$$

In above equations, latent heat was shown by L and capacity of solid surface was denoted by c_s. Eq. (6) is related boundary conditions and impact of melting surface was added [59]. In current investigation, copper oxide has been mixed with water and creates new testing fluid and new material properties are as same as Ref. [58]. To obtain the nanofluid properties, previous formulas have been applied in which shape factor and Brownian motion impacts were involved [60]. In order to similarity transformation, Eq. (7) should be defined:

$$\begin{aligned}&\eta=\frac{y}{h}, \qquad u=axf'(\eta), \qquad \nu=-ahf(\eta), \qquad w=ax\,g(\eta)\\&\theta(\eta)=\frac{T-T_m}{T_m-T_o}\end{aligned} \tag{7}$$

So, final equations can be explained as:

$$f^{iv}+\frac{A_1}{A_2}\left(-f''f'+ff'''\right)R-A_5f''\frac{M}{A_2}-2Kr\frac{A_1}{A_2}g'=0 \tag{8}$$

$$g''-R\frac{A_1}{A_2}\left(f'g-fg'\right)+2Kr\frac{A_1}{A_2}f'-A_5\frac{M}{A_2}g=0 \tag{9}$$

$$\theta''+Pr\frac{A_2A_3}{A_1A_4}\left[R\frac{A_1}{A_2}f\,\theta'+Ec\frac{A_1}{A_3}\left(g^2+4f'^2\right)\right]=0 \tag{10}$$

$$\begin{aligned}&f=-\frac{\delta}{Pr}\frac{A_4}{A_2}\theta', f'=1, g=0, \theta=1 \quad at \quad \eta=0\\&g=0, \ \theta=0, f=0, f'=0, \quad at \quad \eta=1.\end{aligned} \tag{11}$$

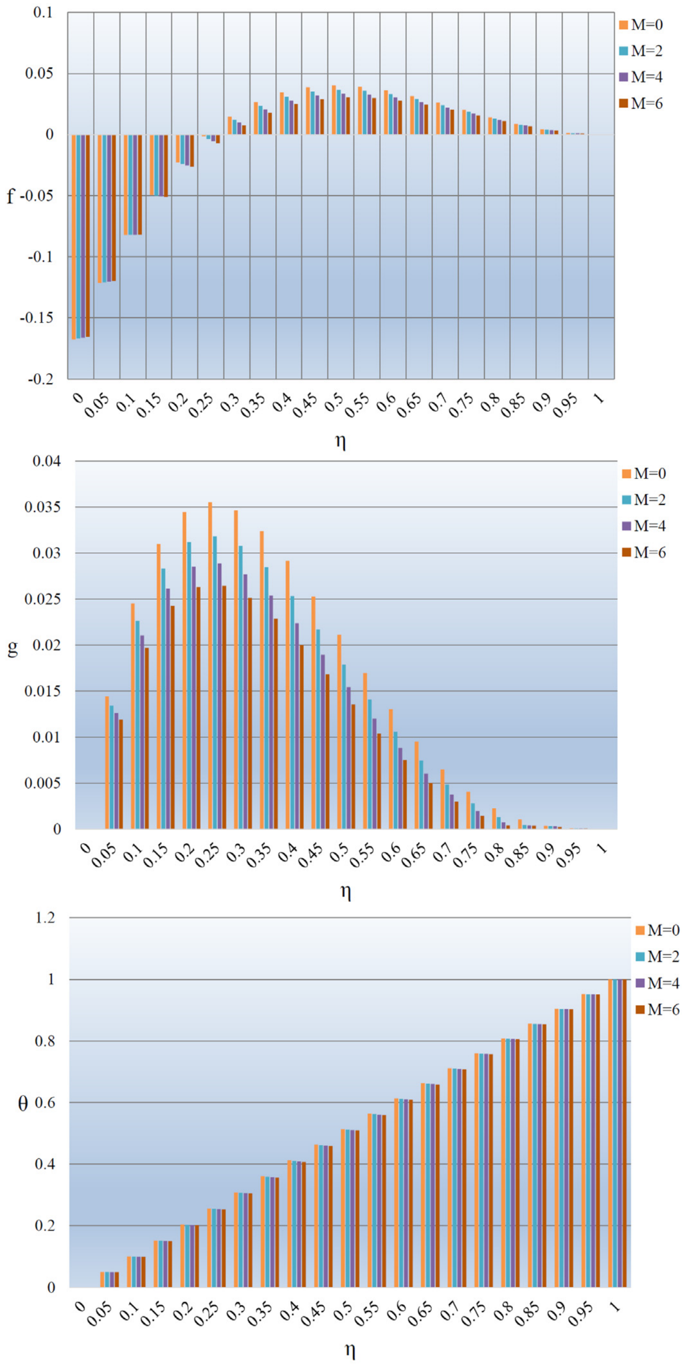

Fig. 3. Influences of M on f, g, θ at $R = 1, Ec = 0.01, Kr = 1, \delta = 1, \phi = 0.04$.

New parameter should be defined as:

$$A_3 = \frac{\left(\rho C_p\right)_{nf}}{\left(\rho C_p\right)_f}, A_4 = \frac{k_{nf}}{k_f}, A_5 = \frac{\sigma_{nf}}{\sigma_f}$$

$$\delta = \frac{\left(\rho C_p\right)_f}{\rho_f} \frac{(T_m - T_h)}{-1 - c_s\,(T_m - T_0)},$$

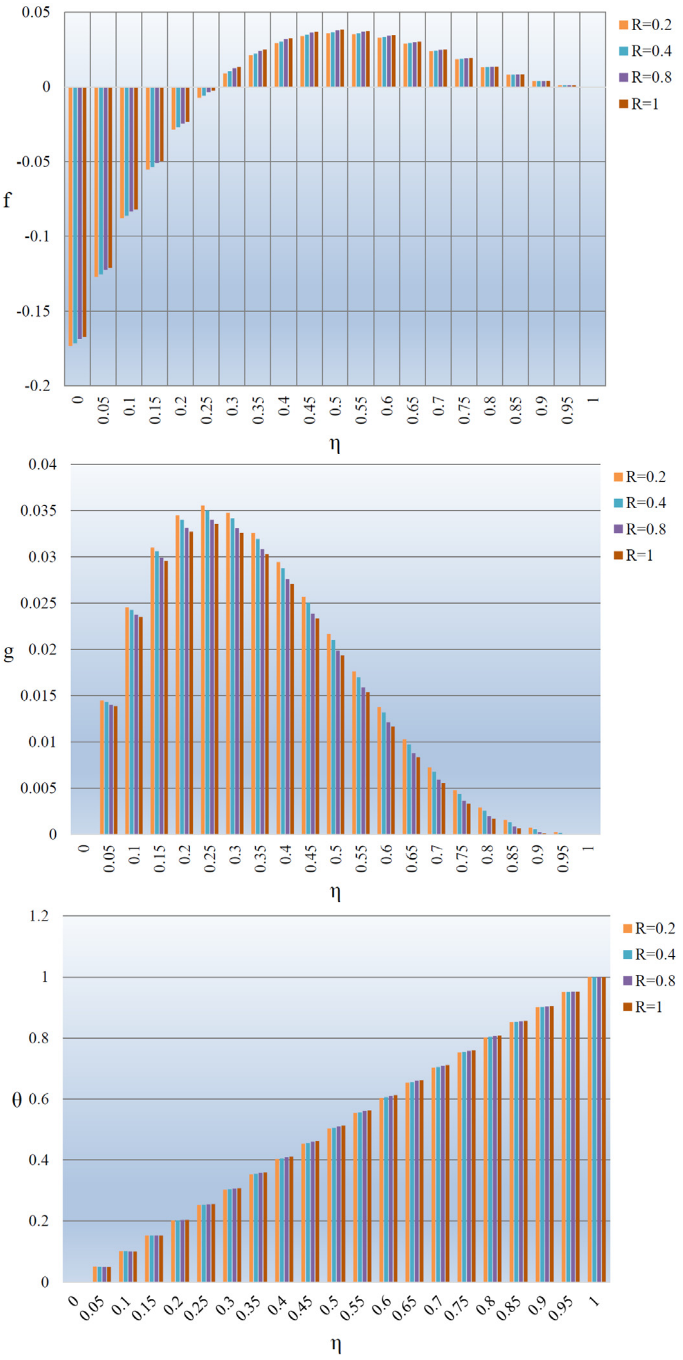

Fig. 4. Influences of R on f, g, θ at $M = 1, \phi = 0.04, \delta = 1, Ec = 0.01, Kr = 1$.

$$
\begin{aligned}
&Ec = \frac{\rho_f a^2 h^2}{\left(\rho C_p\right)_f (\theta_0 - \theta_h)}, \quad R = \frac{ah^2}{\upsilon_f}, \;\; M = \left(\upsilon_f \rho_f\right)^{-1} h^2 {B_0}^2 \sigma_f, \\
&Kr = h^2 \Omega \left(\upsilon_f\right)^{-1}, Pr = \left(\rho_f k_f\right)^{-1} \left(\rho C_p\right)_f \mu_f, \\
&A_1 = \frac{\rho_{nf}}{\rho_f}, A_2 = \frac{\mu_{nf}}{\mu_f},
\end{aligned}
\tag{12}
$$

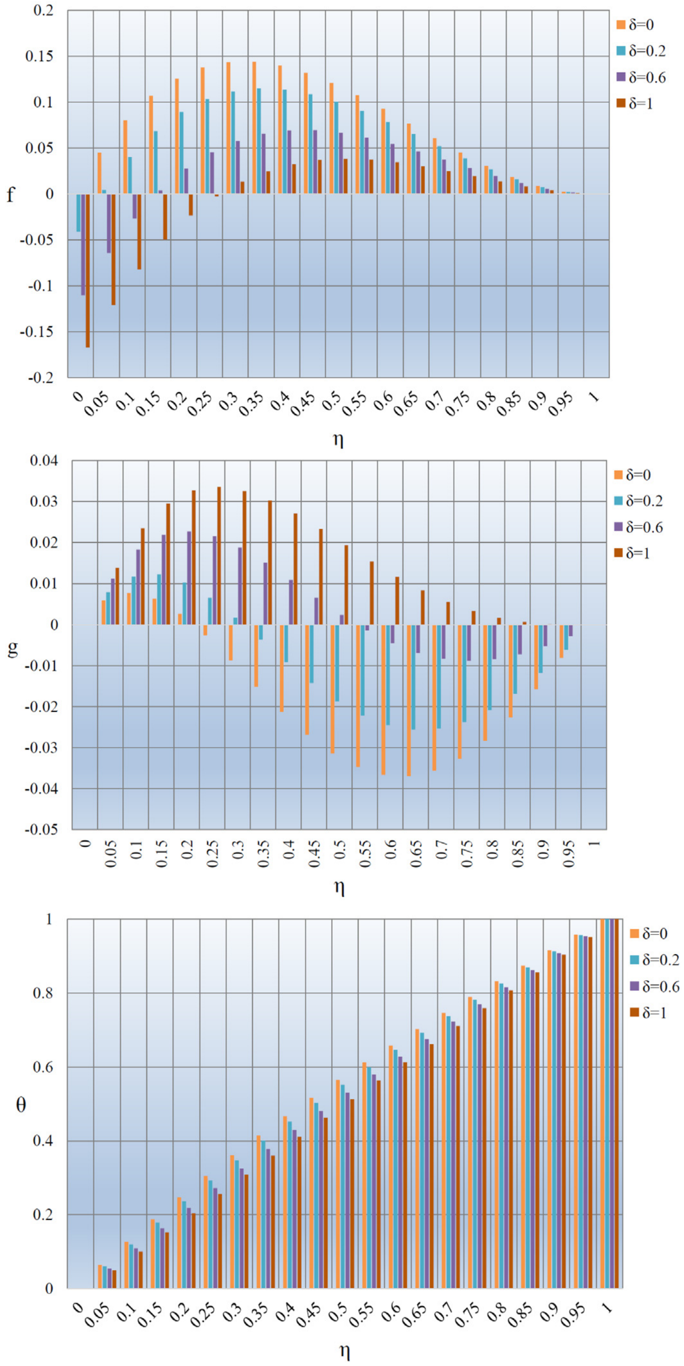

Fig. 5. Influences of δ on f, g, θ at $R = 1, M = 1, Ec = 0.01, Kr = 1$.

Combination of Stefan numbers for liquid and solid phases create new parameters namely δ.

3. Results and discussions

Rotating system with involving copper oxide-H_2O as testing fluid was analyzed in appearance of melting surface and Lorentz force. By considering homogeneous model and similarity transformation, final ODEs were extracted and solved via Runge–Kutta approach. The written MAPLE code was verified as depicted in Fig. 2. Temperature profile has small deviation with [57]. Profiles for various values of magnetic, rotation, melting parameters were examined in following results.

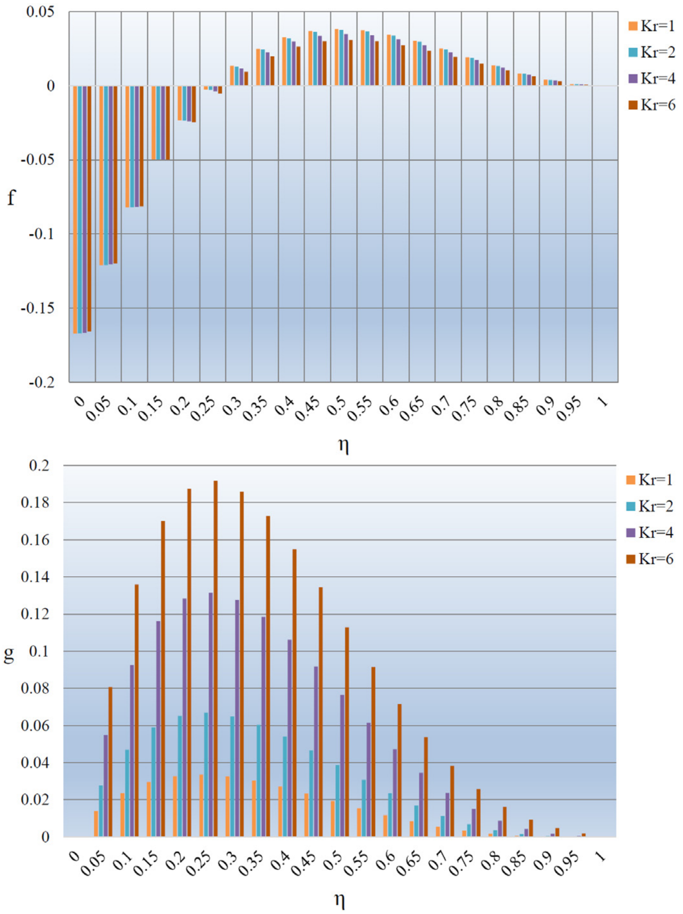

Fig. 6. Influences of Kr on f, g at $M = 1, \phi = 0.04, \delta = 1, R = 1, Ec = 0.01$.

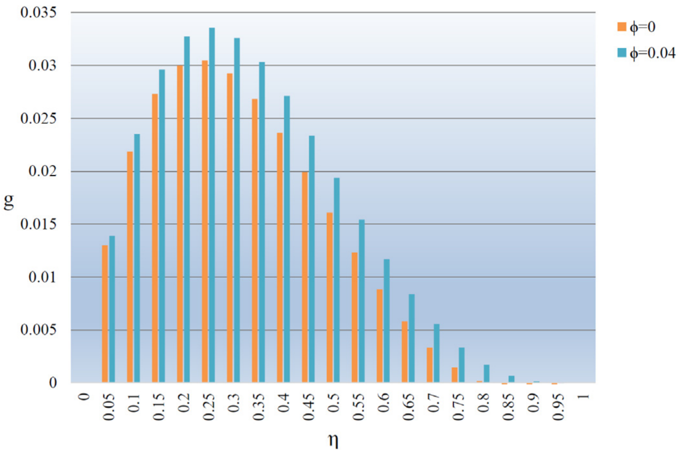

Fig. 7. Impact of ϕ on g at $M = 1, R = 1, \delta = 1, Ec = 0.01, Kr = 1, Pr = 6.2$.

Figs. 3 and 4 depict the influences of magnetic and viscosity parameter on hydrothermal distribution. Influence of M on g profile is more sensible than other profiles. Velocity declines as a consequence of imposing magnetic field. No sensible changes occur for temperature when magnetic forces become stronger. Temperature augments with rise of R while rotational velocity has inverse relationship with R. Augmentation in f occurs with augment of R and boundary layer thickness augments. Maximum values of rotational velocity occur near the lower plate which is starching surface.

Figs. 5 and 6 illustrated the impacts of δ and Kr on nanomaterial behavior. Considering melting effect augments the back flow and rotational velocity direction reverse with rise of δ. Temperature declines with augment of δ. Greater rotational flow occurs with considering greater Kr and horizontal velocity reduces. To demonstrate impact of dispersing nanoparticles on temperature distribution, Fig. 7 has been shown. Greater movement of nanoparticles lead to better thermal behavior and temperature enhances with rise of concentration of nanofluid.

4. Conclusions

Nanomaterial movement with insertion of melting surface was demonstrated in current article. Constant magnetic force was added to control the migration of nanoparticles and single phase approach was selected for estimating properties of nanomaterial. Imposing nanoparticles make temperature to augment owing to increasing in interaction of nanoparticles. No sensible changes occur for temperature when magnetic forces become stronger while rotational velocity declines with rise of M. Temperature reduces with augment of melting factor and also back flow become stronger for greater values of this factor.

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