MHD FLOW AND HEAT AND MASS TRANSPORT INVESTIGATION OVER A DECELERATING DISK WITH OHMIC HEATING AND DIFFUSIVE EFFECT

by

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The motive of this study is to investigate the spinning fluid-flow due to revolving disk for the magnetic unsteady Brownian motion of viscous nanofluid. Here the disk is assumed to have an inverse linear angular velocity. In this paper mass transfer is incorporated in the analysis with the existing problem. The array of equation for the unsteady flow firstly converted into dimensionless non-linear equation using appropriate transformation and then the dimensionless system of equation is further solved numerically utilizing MAPLE software. The different emerging parameters mainly magnetic parameter, variable viscosity, Prandtl number, Eckert number, thermophoresis, and Brownian motion parameter has been investigated through graphs and shown in tabular form also.

Key words*: heat transfer, mass transfer, ohmic heating, thermophoresis, brownian motion, nanofluid, magnetic field*

Introduction

Over the last few decades it has been seen that the unsteady motion over a revolving disk for the temperature and mass transfer is analyzed. The study has numerous applications in manufacturing and industrialized areas such as electrical motors, thermal power sector regularly. In the areas of infinite rotating disc having glutinous liquid-flow is initialized by Karman [1]. He is the originator of similarity transformation to solve physical equation by Converting them into a ODE this study of Karman was further improved by Cochran [2], who introduced the method of power series approximation. This study of time dependent flow was then added by Benton [3].

After that many researchers [4-10] applied and study different effects on MHD flow due to a revolving disk. Brownian movement and thermophoresis is applicable in all the streams such as economy physics atomic theory*, etc.* the research in this part has been done by many authors [11-16]. In the fluid mechanics a lot of useful work has been done by different researchers

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are due to vast application of heat and mass transport in many important fields of life, some of these work [17-25] is analysed in this paper. In the present time porous media has get vast attention due to its application in various fields like geothermal engineering grain storage petroleum reservoirs, *etc.* Joshi *et al.* [26] investigate the behaviour due to flowing of nanofluid on the rotating disk placed in porous medium. Eid and Mabood [27] investigate the nanofluid-flowing through revolving disk immersed in a permeable medium for the viscoelastic behaviour. Behaviour of temperature dependent viscosity is analysed for the nanofluids bi researcher [28-34].

In the present research we focus mainly on the mass transfer along with heat transfer and applied magnetic field in the model prescribed by the Walson and Wang [28]. Fluid is considered to be MHD and it flow on a revolving disk with angular velocity which is inversely proportional of the time. This study is similar to Rafiq *et al*. [20]. The solution of the governing equation is done by MAPLE and graphically presented the effect of flow on different parameters.

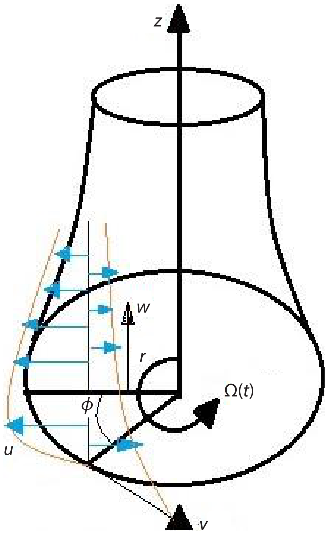

Figure 1. A schematic of the flow mode

Mathematical formulation

In fig. 1 depict the modelling of unsteady problem of convective temperature and concentration transport on a revolving porous disk, with z-axis as axis of symmetry with cylindrical polar co-ordinates (r, φ, z). It is seen that the angular movement of disk is inversely linear and follows the form $\Omega(t)=\Omega_0/(1-ct)$ (where Ω_0 is the angular speed and α – the reducion in the disk).

In this flow problem all three components of motion (u, v, w) are included.

Mathematical equations

The system of equation for the hydrodynamic flow are given:

$$\frac{\partial u}{\partial r}+\frac{u}{r}+\frac{\partial w}{\partial z}=0 \tag{1}$$

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}-\frac{v^2}{r}+w\frac{\partial u}{\partial z}\right)+\frac{\partial p}{\partial r}=\frac{\partial}{\partial r}\left(\mu(T)\frac{\partial u}{\partial r}\right)+\frac{\partial}{\partial r}\left(\mu(T)\frac{u}{r}\right)+\frac{\partial}{\partial z}\left(\mu(T)\frac{\partial u}{\partial z}\right)-\sigma B^2(t)u \tag{2}$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial r}+\frac{uv}{r}+w\frac{\partial v}{\partial z}\right)=\frac{\partial}{\partial r}\left(\mu(T)\frac{\partial v}{\partial r}\right)+\frac{\partial}{\partial r}\left(\mu(T)\frac{v}{r}\right)+\frac{\partial}{\partial z}\left(\mu(T)\frac{\partial v}{\partial z}\right)-\sigma B^2(t)v \tag{3}$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial r}+w\frac{\partial w}{\partial z}\right)+\frac{\partial p}{\partial z}=\frac{\partial}{\partial r}\left(\mu(T)\frac{\partial w}{\partial r}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(\mu(T)w\right)+\frac{\partial}{\partial z}\left(\mu(T)\frac{\partial w}{\partial z}\right) \tag{4}$$

$$\begin{aligned}(\rho c)_f\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial r}+w\frac{\partial T}{\partial z}\right)=&\left[\frac{\partial}{\partial r}\left(k(T)\frac{\partial T}{\partial r}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(k(T)T\right)+\frac{\partial}{\partial z}\left(k(T)\frac{\partial T}{\partial z}\right)\right]+\\ &+\sigma B^2(t)\left(u^2+v^2\right)+(\rho c)_p\left[D_B\left(\frac{\partial T}{\partial z}\frac{\partial C}{\partial z}+\frac{\partial T}{\partial r}\frac{\partial C}{\partial r}\right)+\frac{D_T}{T_\infty}\left[\left(\frac{\partial T}{\partial r}\right)^2+\left(\frac{\partial T}{\partial z}\right)^2\right]\right]\end{aligned} \tag{5}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial r}+w\frac{\partial C}{\partial z}=D_B\left(\frac{\partial^2 C}{\partial r^2}+\frac{1}{r}\frac{\partial C}{\partial r}+\frac{\partial^2 C}{\partial z^2}\right)+\frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}\right) \tag{6}$$

The given non-linear eqs. (1)-(6) are solved wwith the limiting conditions:

$$\begin{gathered} u=0, v=r\Omega(t),\ w=-V(t),\ T=T_w,\ C=C_\mathrm{w}\ \text{ at }\ z=0 \\ u\to 0,\ v\to 0,\ T\to T_\infty,\ C\to C_\infty\ \text{ as }\ z\to\infty \end{gathered} \tag{7}$$

Presumptions and clarification of the problem

Unsteady MHD flow on revolving disk is considered and to solve this flow problem (1)-(6) With boundary condition (7) some assumptions are made:

- Here we assume that the viscosity function $\mu(T)$ [24] is inversely linear and dependent on the temperature where μ_∞ is liquid viscosity, γ is a invariable function and represents the case where fluid is assume to be gas or liquid if it has positive or negative value:

$$\mu(T)=\frac{\mu_\infty}{\gamma(T-T_\infty)+1} \tag{8}$$

- It is also assumed that thermal conductivity is time dependent and it follows the given function:

$$k(T)=k_\infty\left[1+\varepsilon\left(\frac{T-T_\infty}{T_w-T_\infty}\right)\right] \tag{9}$$

where K_∞ is the ambient fluid thermal conductivity. Now to solve eqs. (1)-(6) numerically some similarity transformation are considered:

$$\begin{gathered} u=r\Omega(t)U'(\eta),\ v=r\Omega(t)V(\eta),\ w=-2\sqrt{\nu_\infty\Omega(t)}U(\eta) \\ p=-\mu\Omega(t)P(\eta),\ T-T_\infty=(T_w-T_\infty)\theta(\eta),\ C-C_\infty=(C_\mathrm{w}-C_\infty)\phi(\eta) \\ \eta=\sqrt{\frac{\Omega(t)}{\nu_\infty}}z \end{gathered} \tag{10}$$

where the given similarity transformation satisfies the equation of continuity. Using assumption 1 and 2 and eq. (10) the following eqs. (2)-(6) altered into joined non-linear differential equation:

$$F'''-(\theta-\theta_e)^{-1}F''\theta'+\left\{\frac{\theta-\theta_e}{\theta_e}\right\}\left\{F'^2-G^2-2FF''+\left(\frac{A\eta F''}{2}\right)+AF'+MF'\right\}=0 \tag{11}$$

$$G''-(\theta-\theta_e)^{-1}\theta'G'+\left\{\frac{\theta-\theta_e}{\theta_e}\right\}\left\{2(F'G-G'F)+AG+\left(\frac{A\eta G'}{2}\right)+MG\right\} \tag{12}$$

$$\theta''-(1+\epsilon\theta)^{-1}\left\{\mathrm{Pr}\theta'\left(\frac{A\eta}{2}-2F\right)-\epsilon\theta'^2-M\mathrm{Ec}\mathrm{Pr}\left(F'^2+G^2\right)-Nt\mathrm{Pr}\theta'\phi'-Nb\mathrm{Pr}\theta'^2=0\right. \tag{13}$$

$$\phi''-\left(\frac{A\eta\mathrm{Sc}\phi'}{2}\right)+2\mathrm{Sc}F\phi'+\left(\frac{Nb}{Nt}\right)\theta''=0 \tag{14}$$

and the boundary conditions (7) transforms:

$$F'(0)=0,\ G(0)=1,\ F(0)=\frac{S}{2},\ \theta(0)=1,\ \phi(0)=1$$
$$F'\to 0,\ G\to 0,\ \theta\to 0,\ \phi\to 0 \text{ as } \eta\to\infty \tag{15}$$

$$\text{where } V(t)=\frac{V_0}{(1-\alpha t)^{1/2}},\ P_r=\frac{\mu_\infty C_p}{k_\infty},\ A=\frac{\alpha}{\Omega_0},\ S=\frac{V_0}{(\nu_0\Omega)^{1/2}}$$

The suction parameter which is proportional to initial suction velocity, V_0, can be given any positive value depending upon how more or less velocity is considered into fluid motion at the surface.

To solve eqs. (11)-(14) along with boundary condition (15) we use MAPLE 2019. With the help of this software we find graph of different physical parameters and we analyse these and reached to useful resuls which can be applied by many other researchers and engineers also.

Results and discussion

The Unsteady flow of nanofluid over a revolving disc whose velocity is inversely proportional to time with applied magnetic field is taken for the current study. This phenomena was numerically solved by the MAPLE 2019 software. Hear the effect of different parameters are obtained and represented through graphs on radial $F'(\eta)$ and tangential $G(\eta)$ velocity profile,Temperature profile and Concentration profile was illustrated. All the work has been done by fixing the values as $M=1$, $A=-1$, $\epsilon=1$, Sc = 1, $S=1$, Ec = 0.5, Pr = 5, $Nt=0.1$, $\theta_e=-2.5$.

Table 1 shows the arithmetical results of outspread wall tension and lateral wall stress for various parameters involved. Table 2 showcase the analysis data of non-dimensionalnusselt number and sherwood number, respectively. To justify the finding after present study the values of outspread and lateral skin friction number has been set against the findings of Rafiq *at el*. [20] in tab. 3 and finds that they are very good match so the results achieved in the current study are justified.

Table 1. The radial and lateral skin-friction factor for several dimensionless parameters

A	M	Pr	$F''(0)$	$G'(0)$
0			0.2844091	–2.1844097
–2			0.4102848	–1.5210265
–3			0.4885410	–1.1541750
–4			0.5743449	–0.7729627
–5			0.6663830	–0.3809762
	1		0.3416708	–1.8708305
	2		0.2474960	–2.3436274
	3		0.2014150	–2.6888448
	4		0.1736006	–2.9590523
	5		0.1545958	–3.1811505
		5	0.3426657	–1.8669945
		6	0.3449816	–1.8714885
		7	0.3489060	–1.8751751
		8	0.3489060	–1.8782553
		9	0.3505736	–1.8808610
		10	0.3520792	–1.8830980

Table 2. The skin friction and nusselt number for the different dimensionless parameters

Nt	Nb	$-\theta'(0)$	$-\phi'(0)$
1		1.5927280	1.37365615
2		0.7550885	3.76768668
3		0.2820150	1.62664260
4		0.0269633	2.58221688
5		0.2843200	8.67405192
	0	1.9092728	2.00358736
	0.5	0.9445088	4.00054676
	1	0.5524820	1.99852664
	1.5	0.0069633	3.15762582
	2	0.5238843	9.02475267

Table 3. Comparison of $F''(0)$ and $G'(0)$ obtained by [20] when $M = 0$, Sc = 0, Ec = 0, $Nt = 0$, and $Nb = 0$

A	$F''(0)$			$G'(0)$		
	Current	[20]	Variation	Current	[20]	Variation
0	0.276348	0.276229	0.000119	–0.728566	–0.717747	–0.010819
–2	0.398457	0.383317	0.015140	–0.300357	–0.259630	–0.040727
–3.179941	0.445856	0.439443	0.006413	–0.000008	0.0000000	–0.000008
–5	0.6015400	0.519050	0.082490	0.398784	0.389722	0.009062

Figures 2-5 represents the distribution of $F'(\eta)$, $G(\eta)$, $\theta(\eta)$, and $\phi(\eta)$ for distinct values of unsteadiness parameter. Figure 2 shows the reduction in velocity profile as increment in A. While fig. 3 shows that mass concentration reduces as values of A increases and temperature profile rises. Figures 6 and 7 showcase that the speed profile reduces as the magnetic parameter rises. When magnetic parameter rises which produces Lorentz Force, this force acts in reducing the motion and hence the velocity profile decelerates. In figs. 8 and 9 it has been seen that temperature as well as concentration profile up lift as the magnetic parameter increases but it is also noted in fig. 9 that after the critical value ($\eta = 0.704$) the concentration profile shows a dual behaviour.

Figures 10-13 demonstrated the behaviour of variable viscosity parameter on all three profiles. It is observed that as viscosity rises the velocity margin layer decreases and heat and concentration boundary-layer increases.

Figures 14-17 give a description about the effect of parameter Nt. It shows that the temperature and concentration profile rises as the Nt increases and motion of practical slow down due to increment of Nt. The reduction and enhancement of motion and concentration profile due to Brownian motion parameter and Nb is seen in figs. 18-21, respectively.

Impact of Prandtl number over velocity distribution is uplifted by the increasing the values of Prandtl number add and reduces due to increment in values of Prandtl number, in fig. 22 an opposite behaviour is noticed after the critical value $\eta = 0.65539$.

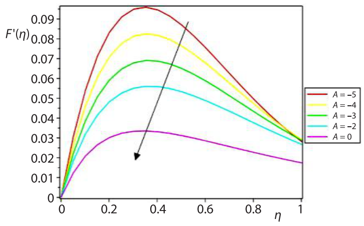

Figure 2. Effect of *A* on velocity profile

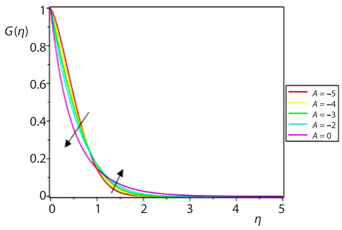

Figure 3. Effect of *A* on velocity profile

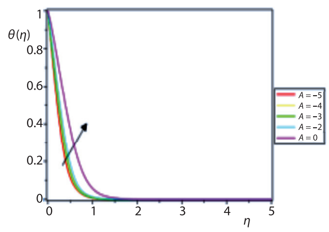

Figure 4. Effect of *A* on velocity profile

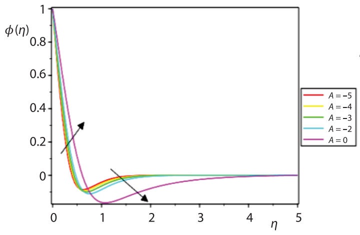

Figure 5. Effect of *A* on concentration profile indeterminate

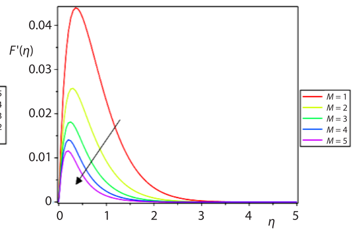

Figure 6. Effect of *M* on velocity profile

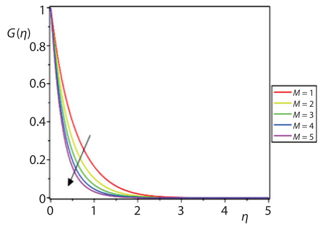

Figure 7. Effect of *M* on velocity profile

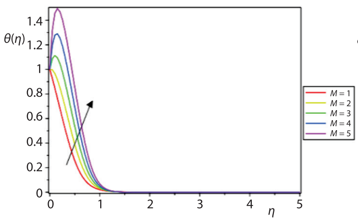

Figure 8. Effect of *M* on temperature profile

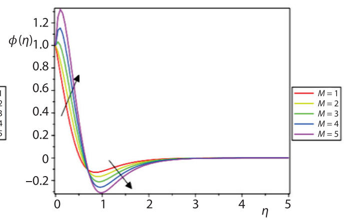

Figure 9. Effect of *M* on concentration profile

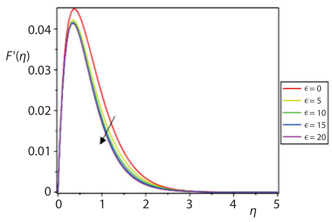

Figure 10. Effect of ϵ on velocity profile

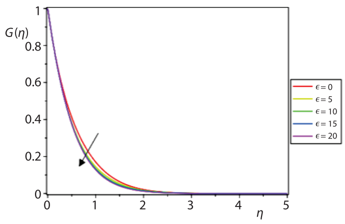

Figure 11. Effect of ϵ on velocity profile

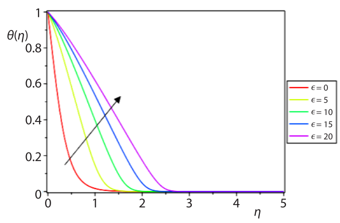

Figure 12. Effect of ϵ on temperature profile

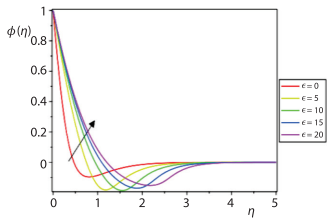

Figure 13. Effect of ϵ on concentration profile

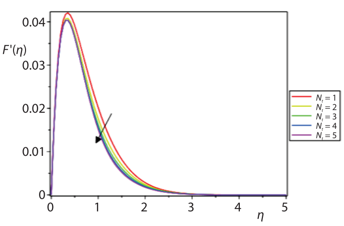

Figure 14. Effect of *Nt* on velocity profile

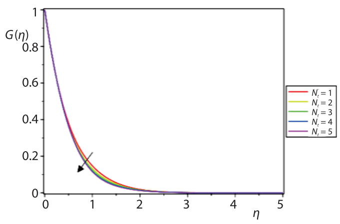

Figure 15. Effect of *Nt* on velocity profile

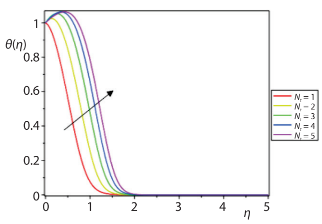

Figure 16. Effect of *Nt* on temperature profile

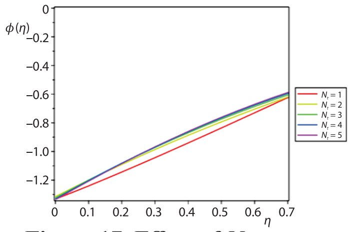

Figure 17. Effect of *Nt* on concentration profile

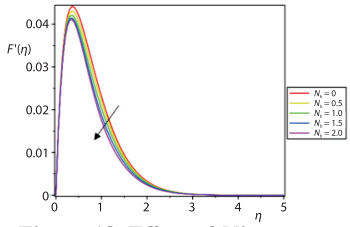

Figure 18. Effect of *Nb* on velocity profile

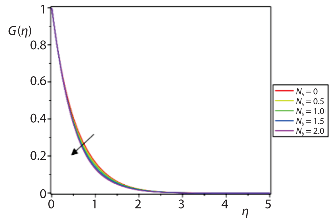

Figure 19. Effect of *Nb* on velocity profile

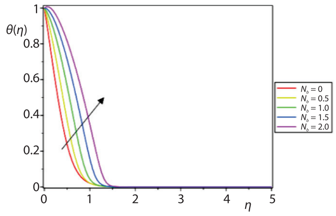

Figure 20. Effect of *Nb* on temperature profile

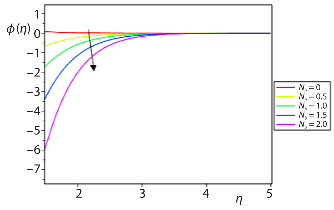

Figure 21. Effect of *Nb* on concentration profile

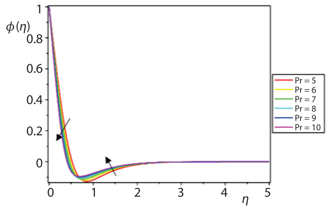

Figure 22. Effect of Pr on concentration profile

Conclusion

Unsteady MHD motion of fluid consists of nanoparticle is investigated along with thermophoresis and Brownian motion for heat and mass concentration in the present research many noticeable results are drawn here are some useful conclusions are as follows.

- The unsteady parameter gives a special condition ($A^* = –5.75988$) for which the torque [$G'(0)$] vanishes and it validates that the disk is rotating freely without torque and when $A < A^*$ the torque is negative which notify that liquidneighbouring the disk revolve quicker than the disk.
- The magnetic parameters show a dual behaviour in concentration profile it has been seen that after a critical value $\eta = 0.\ 704$ the concentration profile reduces drastically.
- A dual behaviour is also noticed in concentration profile as the parameter Pr increases after a critical value of $\eta = 0.65539$.

Nomenclature

C_w – concentration near-wall
C_∞ – concentration far from the wall
D_B – coefficient of Brownian diffusion
D_T – coefficient of thermophoresis diffusion
F' – non-dimensional radial velocity
G – non-dimensional tangential velocity
k^* – coefficient of mean absorption
M – magnetic parameter
Nb – Brownian moion coefficient
Nt – thermophoresis coefficient
Pr – Prandtl number
p – pressure
r – radial direction
T_w – temperature of disk plane
T_∞ – free stream temperature
t – time
u – Radial velocity factor
v – axial velocity factor
w – tangential velocity factor
z – axial direction

Greek symbols

η – non-dimensional element
θ – non-dimensional heat
ϵ – temperature dependent vicinity prameter
κ – thermal conductivity
μ_∞ – magnetic porosity
ν – kinematic viscosity
ρ – density
$(\rho c)_f$ – heat capability of fluid
$(\rho c)_p$ – nanoparticles heat capability
φ – lateral direction
ϕ – non-dimensional density
Ω – angular speed of the circular lamina
μ_∞ – uniform fluid thickness

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