International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

Jeffrey Fluid Behaviour on Oscillatory Couette Flow past Two Horizontal Parallel Plates in Presence of MHD and Radiative Heat Transfer

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Abstract— The aim of this study carry out on an unsteady MHD at no cost convective oscillatory Couette flow of a well-known non-Newtonian Jeffrey fluid of an optically thin fluid bounded by two horizontal porous parallel walls in a channel embedded in porous medium in the presence of thermal radiation and angle of inclination. Design and Method is the flow is governed by a coupled non-linear system of partial differential equations which are solved numerically by using finite difference method. Results are the impacts of various physical parameters on the flow quantities viz. velocity and temperature reports, skin-friction and rate of heat transfer coefficients are studied numerically. The results are discussed with the help of graphs and tables. Conclusion is the finite difference results are compared favourably with already established results in literatures.

Index Term: MHD, Couette flow, Jeffrey Fluid, Finite difference method

I. INTRODUCTION

In fluid dynamics, Couette flow refers to the laminar flow of a viscous incompressible fluid in the space between two parallel plates, one of which is moving and the other remains fixed. Couette flow occurs in fluid machinery involving moving parts and is especially important for hydrodynamic lubrication. Couette flow has been used as the fundamental method for the measurement of viscosity and as a means of estimating the drag force in many wall driven applications [1]. Israel-Cookey et al. discussed oscillator magneto hydrodynamic Couette run of a radiating viscous liquid in a porous intermediate with episodic partition heat. This proposed paper is to inspect impacts of temperature vitality and thick dissemination on free convective Couette flow of a gooey, incompressible, electrically directing Jeffrey fluid over a vertical plate within the sight of attractive field and edge of tendency.

The overseeing conditions are first changed into a lot of standardized conditions and after that comprehended diagnostically by utilizing finite difference and a general arrangement is acquired. The comments for neighbourhood skin grating, Nusselt and Sherwood numbers against different physical parameters are assessed numerically and exhibited through tables.

II. ARTHEMATICAL STUDY

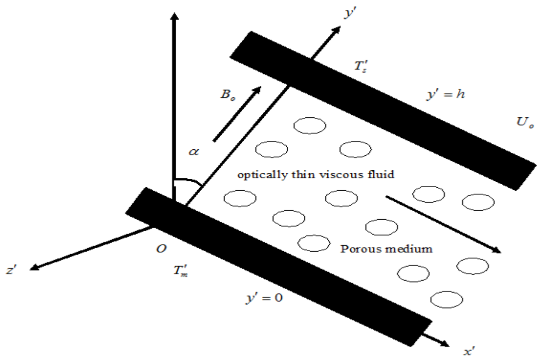

Fig. 1. material pattern and coordinates scheme

1. A Cartesian organize framework is considered as pursued: the $x'-$ axis pivot is along the plate, the $y'-$ axis is opposite to it.
2. The plates are situated at $y'=0$ and $y'=h$.
3. The two plates are thought to be electrically non-directing and kept at two steady temperatures: T'_m for the lower plate and T'_s for the upper plate with $T'_s > T'_m$
4. A steady weight inclination is connected toward the path and the upper plate is moving with a consistent speed U_o while the lower plate is kept stationary.
5. A uniform attractive field B_o is connected the positive $y'-$ way. By expecting a little attractive Reynolds number the instigated attractive field is disregarded.
6. Since the plates are infinite in the x' and $z'-$ direction, the physical factors are invariant in these ways. It is expected that there is no connected voltage which suggests the nonattendance of an electric field.
7. The Cauchy stress tensor, $\bar{S}$, of a Jeffrey's non-Newtonian fluid accepts the structure as pursues:

$$S=\frac{\mu}{1+\lambda}\left(\dot{\gamma}+\lambda_1\ddot{\gamma}\right) \quad (1)$$

Manuscript published on 30 September 2019.
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8. The shear rate and gradient of shear rate are further defined in terms of velocity vector, $\overline{V}$, as follows:

$$\text{where } \dot{\gamma} = \nabla\overline{V} + \left(\nabla\overline{V}\right)^T$$

$$\text{and } \ddot{\gamma} = \frac{d}{dt}\left(\dot{\gamma}\right) + \left(\overline{V}.\nabla\right)\dot{\gamma}$$

(2) & (3)

A. Momentum Equation

$$\rho\frac{\partial u'}{\partial t'} = \rho\frac{dU'}{dt'} + \left(\frac{\mu}{1+\lambda}\right)\frac{\partial^2 u'}{\partial y'^2} + \rho g\beta\left(T' - T'_s\right)\left(\cos\alpha\right) - \left(\frac{1}{K'} + \sigma B_o^2\right)\left(u' - U'\right) \quad (4)$$

B. Energy Equation

$$\rho C_p\frac{\partial T'}{\partial t'} = \kappa\frac{\partial^2 T'}{\partial y'^2} + \mu\left(\frac{\partial u'}{\partial y'}\right)^2 - \frac{\partial q_r}{\partial y'} + \sigma B_o^2 u'^2 \quad (5)$$

C. Conditions of Boundary

$$\left.\begin{aligned} &u' = U_o\left(1 + \varepsilon e^{i\omega' t'}\right),\ T' = T'_m + \varepsilon\left(T'_m - T'_s\right)e^{i\omega' t'}\ at\ y' = 0 \\ &u' = 0,\ T' = T'_s\ \ at\ y' = h \end{aligned}\right\} \quad (6)$$

Assumed temperatures are T'_m & T'_s are enough to induce radiative heat transfer.

S radiative heat flux q_r as

$$\frac{\partial q_r}{\partial y'} = 4\varphi^2\left(T' - T'_s\right) \quad (7)$$

(7) In (5), rewrite equations are

$$\omega\frac{\partial u}{\partial t} = \omega\frac{\partial U}{\partial t} + \left(\frac{1}{1+\lambda}\right)\frac{\partial^2 u}{\partial y^2} + (Gr)(\cos\alpha)\theta - \left(\chi^2 + M^2\right)(u - U) \quad (8)$$

$$\omega(\Pr)\frac{\partial\theta}{\partial t} = \frac{\partial^2\theta}{\partial y^2} + (\Pr)(Ec)\left(\frac{\partial u}{\partial y}\right)^2 - F^2\theta + \left(M^2\right)(\Pr)(Ec)u^2 \quad (9)$$

Where $U = 1 + \varepsilon e^{it}$ and the corresponding Border States are

$$u = 1 + \varepsilon e^{it},\ \theta = 1 + \varepsilon e^{it}\ at\ \ y = 0\ \ \&\ u \to 0,\ \theta \to 0\ at\ \ y = 1 \quad (10)$$

Dimensionless parameters & variables for above equations are

$$\left.\begin{aligned} &y = \frac{y'}{h},\ u = \frac{u'}{U_o},\ U = \frac{U'}{U_o},\ t = \frac{\omega\nu t'}{h^2},\ \theta = \frac{T' - T'_s}{T'_m - T'_s}, \\ &Gr = \frac{g\beta h^2\left(T'_m - T'_s\right)}{\nu U_o},\ \chi^2 = \frac{h^2}{K'\rho\nu},\ M^2 = \frac{\sigma B_o^2 h^2}{\nu\rho}, \\ &F^2 = \frac{4\varphi^2 h^2}{\kappa},\ \Pr = \frac{\rho\nu C_p}{\kappa},\ Ec = \frac{U_o^2}{C_p\left(T'_m - T'_s\right)},\ \omega = \frac{\omega' h^2}{\nu} \end{aligned}\right\} \quad (11)$$

For pragmatic engineering applications and the structure of chemical engineering frameworks, amounts of intrigue incorporate the accompanying skin-friction and pace of heat transfer coefficients valuable to process. The skin-friction or the shear worry at the moving plate of the direct in non-dimensional structure is given by

$$\tau = \left(\frac{1}{1+\lambda}\right)\frac{\tau_w}{\rho u_w^2},\ \tau_w = \left[\nu\frac{\partial u}{\partial y}\right]_{y'=0} = \left(\frac{1}{1+\lambda}\right)\rho U_o^2 u'(0) = \left(\frac{1}{1+\lambda}\right)\left[\frac{\partial u}{\partial y}\right]_{y=0} \quad (12)$$

The rate of heat transfer at the moving hot plate of the channel in non-dimensional form

$$Nu_o = -x'\frac{\left(\frac{\partial T'}{\partial y'}\right)_{y'=0}}{T'_m - T'_s} \Rightarrow Nu_o\,\mathrm{Re}_x^{-1} = -\left(\frac{\partial\theta}{\partial y}\right)_{y=0} \quad (13)$$

Heat transfer rate on the stationary plate is

$$Nu_1 = -x'\frac{\left(\frac{\partial T'}{\partial y'}\right)_{y'=h}}{T'_m - T'_s} \Rightarrow Nu_1\,\mathrm{Re}_x^{-1} = -\left(\frac{\partial\theta}{\partial y}\right)_{y=1} \quad (14)$$

III. FINITE DIFFERENCE SCHEME

$$\omega\left(\frac{u_i^{j+1} - u_i^j}{\Delta t}\right) = \omega\frac{\partial U}{\partial t} + \left(\frac{1}{1+\lambda}\right)\left(\frac{u_{i+1}^j - 2u_i^j + u_{i-1}^j}{(\Delta y)^2}\right) + (Gr)(\cos\alpha)\left(\theta_i^j\right) - \left(\chi^2 + M^2\right)\left(u_i^j - U\right) \quad (15)$$

$$\omega(\Pr)\left(\frac{\theta_i^{j+1} - \theta_i^j}{\Delta t}\right) = \left(\frac{\theta_{i+1}^j - 2\theta_i^j + \theta_{i-1}^j}{(\Delta y)^2}\right) - F^2\theta_i^j + (Ec)(\Pr)\left[\left(\frac{u_{i+1}^j - u_i^j}{\Delta y}\right)^2\right] + \left(M^2\right)(Ec)(\Pr)\left(u_i^j\right)^2 \quad (16)$$

Where the indices i and j refer to y and t respectively. The initial and boundary conditions (10) yield.

$$u_i^0 = 0,\ \theta_i^0 = 0\ \ for\ all\ i,\ u_i^j = U,\ \theta_i^j = U\ at\ i = 0\ \&\ u_1^j \to 0,\ \theta_1^j \to 0 \quad (17)$$

A. Validation of Code

Table-1: present skin-friction (τ) results with the skin-friction (τ*) results of Israel-Cookey et al. comparison [6] for variations of Grashof number for Magnetic field & heat transfer parameter

M	$Gr = 2.0$		$Gr = 5.0$	
	τ	τ^*	τ	τ^*
0.5	0.42785612	0.427979	0.36651489	0.366666
1.0	0.34152449	0.341348	0.42080164	0.420780
1.5	0.22583394	0.225900	0.49013047	0.490254
2.0	0.10751318	0.107657	0.55691427	0.556827
2.5	0.00403614	0.004081	0.60726491	0.608813

Tables 1, 2, 3 and 4 when pertinent parameters $\lambda = \alpha = 0$. Present results are compared by finite difference method is good conformity through solutions by Israel-Cookey et al

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International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

Table-2: present skin-friction (τ), skin-friction (τ*), Israel-Cookey et al. [6] results comparison for Grashof number for heat transfer and Porosity parameter

χ	$Gr = 2.0$		$Gr = 5.0$	
	τ	τ^*	τ	τ^*
0.1	0.10982348	0.109924	0.05548015	0.555610
0.2	0.10931785	0.109344	0.55589612	0.555922
0.3	0.10763148	0.107634	0.55617831	0.556839
0.4	0.10479318	0.104814	0.55601843	0.558350
0.5	0.10089497	0.100915	0.56124893	0.560430
0.6	0.09581247	0.095982	0.56315294	0.563050
0.7	0.90047215	0.090070	0.56623849	0.566171
0.8	0.08324561	0.083244	0.56920148	0.569750
0.9	0.07558316	0.075576	0.56823473	0.573735
1.0	0.06155872	0.061472	0.57903156	0.578072

Table-3: present skin-friction (τ), skin-friction (τ*), Israel-Cookey et al. [6] results comparison of Grashof number for Thermal radiation & heat transfer parameter

F	$Gr = 2.0$		$Gr = 5.0$	
	τ	τ^*	τ	τ^*
0.5	0.02056814	0.0205725	0.77654201	0.774538
1.0	0.04233692	0.0423447	0.71930455	0.720108
1.5	0.07290154	0.0731078	0.63812451	0.643200
2.0	0.10755982	0.1076570	0.54932688	0.556827
2.5	0.14230482	0.1421260	0.46920158	0.470655
3.0	0.17469301	0.1743390	0.39830152	0.390121
3.5	0.20350164	0.2034090	0.32015478	0.317447
4.0	0.22891542	0.2291960	0.26018423	0.252980

Table-4: Comparison of the present Nusselt number (Nuo) results with the Nusselt number (Nu*) results of Israel-Cookey et al. [6] for variations of Thermal radiation parameter

F	Nu_0	Nu^*
0.5	1.10019534	1.10024
1.0	1.31922468	1.32751
1.5	1.66543842	1.66653
2.0	2.06853146	2.07957
2.5	2.52064128	2.53619

IV. RESULT AND DISCUSSION

Results are discussed using various the Grashof number for heat transfer (Gr), Magnetic field parameter (M^2), Porosity parameter (χ^2), Jeffrey fluid parameter (λ), Thermal radiation parameter (F^2), Time (t), Frequency of Oscillation parameter (ω), Prandtl number (Pr), Inclination angle parameter (α) and Eckert number (Ec). All the numerical values are plotted in below mentioned figures. Fig. 2 shows that proportionality between thermal Grashof number and velocity. When Grashof number increases Velocity increased because of buoyancy force of gravitational to improve the fluid velocity.

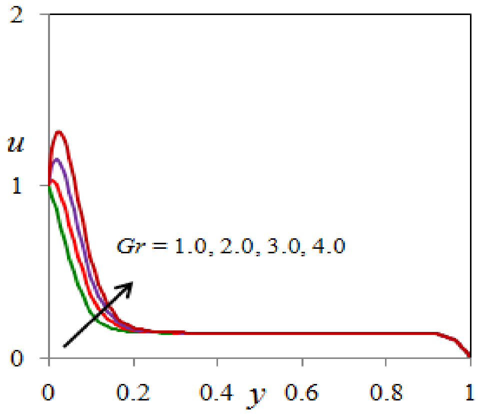

Fig. 2. Gr Velocity impact repors

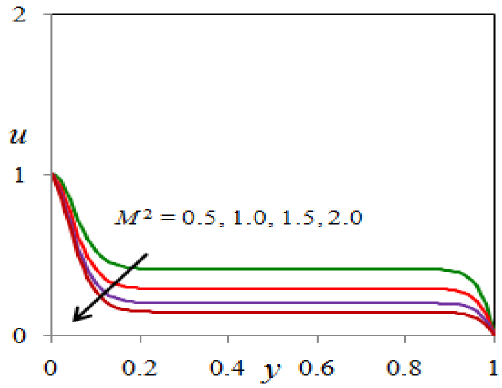

Fig. 3. M 2 impact on Velocity reports

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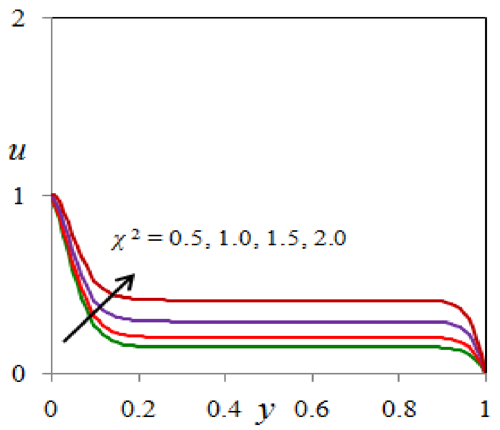

Fig. 4. χ 2 impact on Velocity reports

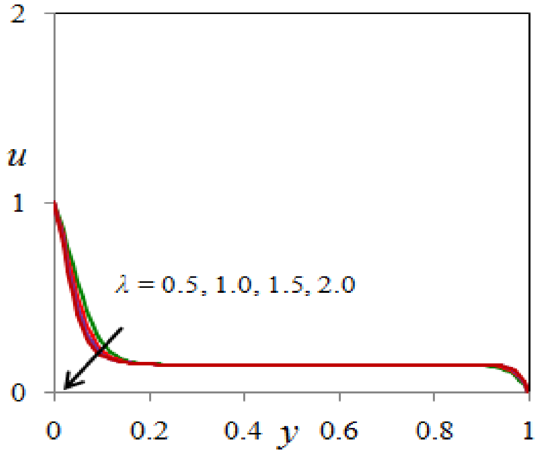

Fig. 5. Impact of λ on Velocity reports

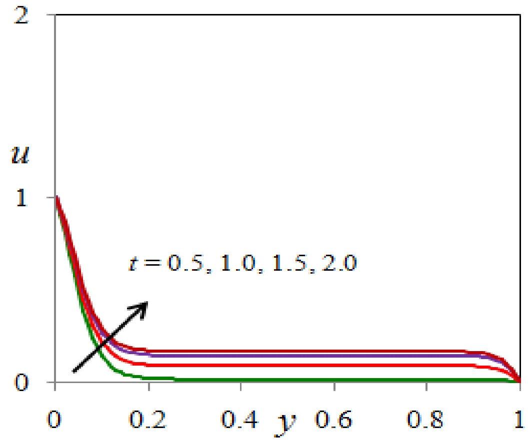

Fig. 6. Impact of t on Velocity reports

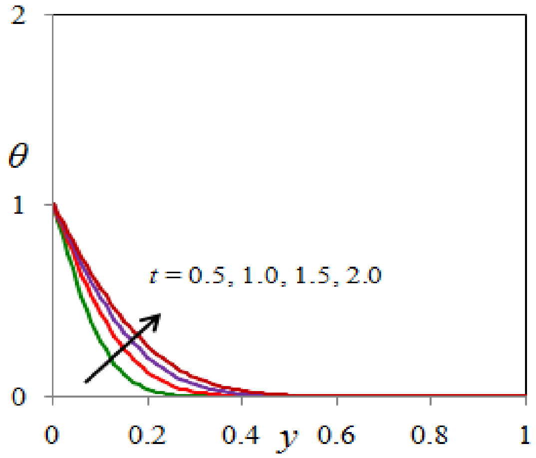

Fig. 7. Impact of t on temperature reports

Results are discussed using various the Grashof number for heat transfer (Gr), Magnetic field parameter (M 2), Porosity parameter (χ 2), Jeffrey fluid parameter (λ), Thermal radiation parameter (F 2), Time (t), Frequency of Oscillation parameter (ω), Prandtl number (Pr), Inclination angle parameter (α) and Eckert number (Ec). All the numerical values are plotted in below mentioned figures. Fig. 2 shows that proportionality between thermal Grashof number and velocity. When Grashof number increases Velocity increased because of buoyancy force of gravitational to improve the fluid velocity. Fig. 3 shows that velocity is getting reduced due to as Lorentz force and finally fluid velocity reduced. In Figure 4 we demonstrate the permeability impact. The velocity is increased due to dimensionless porous medium χ^2 becomes smaller. In figure Figure 5 shows that impact of Jeffrey fluid and velocity. As Jeffrey fluid values increases velocity decreases. Figure 6 and 7 shows that the impact time on velocity & temperature. Velocity and time increases when time increases. As is evident from the Figure 8 and 9 demonstrate that velocity and temperature parameter decreases with oscillating frequency increases. Figure 10 and 11 demonstrate that velocity and temperature values for different Prandtl number. Increasing the Prandtl number decreasing velocity and temperature.

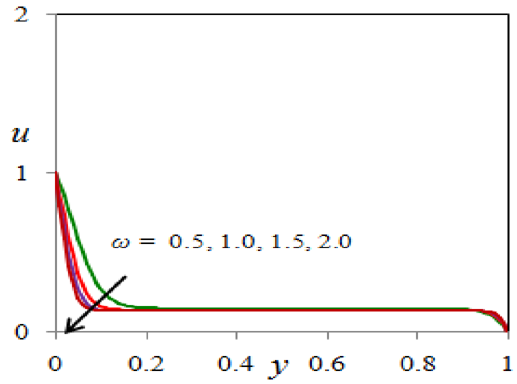

Fig. 8. ω impact on Velocity

Figure 12 and 13 shows the Eckert number on temperature and velocity. High viscous causes increase in velocity and temperature. Figure 14 and 15 show the impact of thermal radiation and temperature and velocity. Velocity Increasing due to increase radiation and temperature decreases due to incease in radiation.

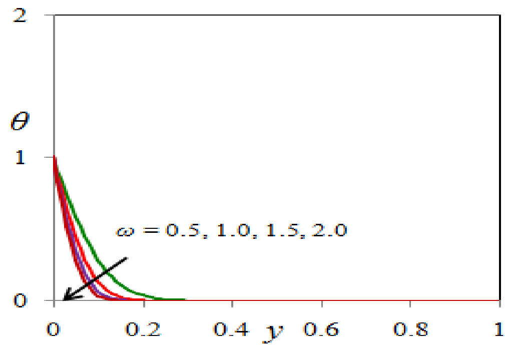

Fig. 9. ω impact on temperature

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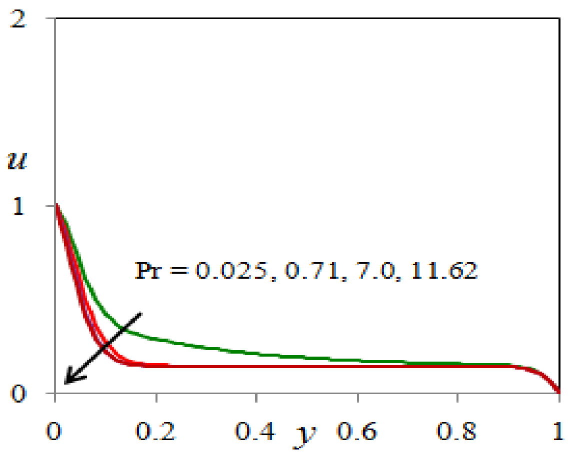

Fig. 10. Pr impact on velocity

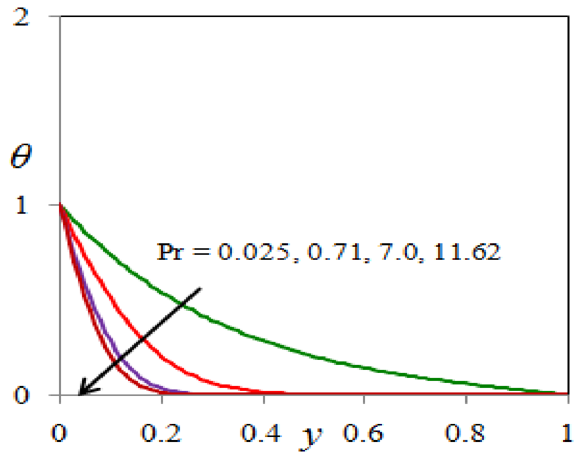

Fig. 11. Pr impact on temperature

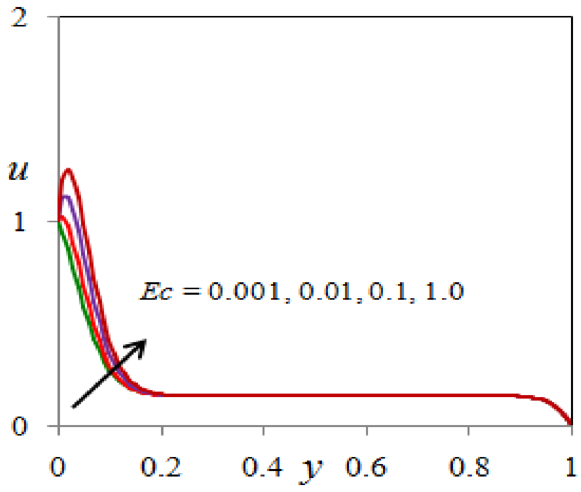

Fig. 12. Ec impact on Velocity

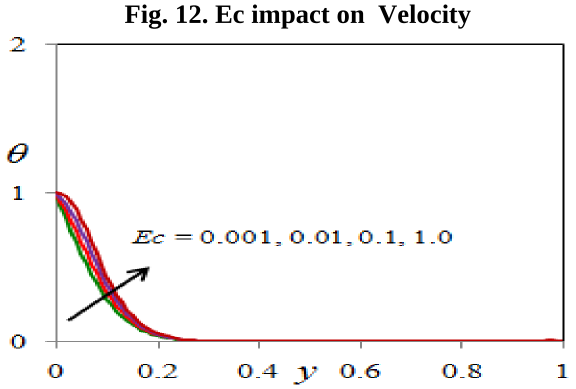

Fig. 13. Ec impact on temperature

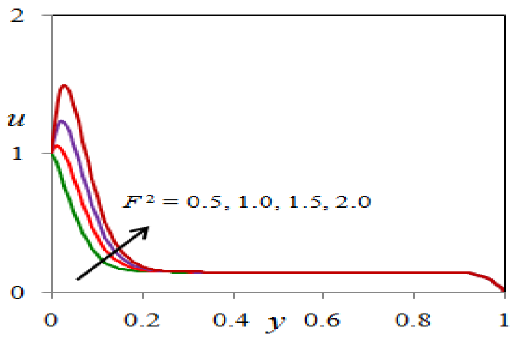

Fig. 14. F 2 impact on Velocity

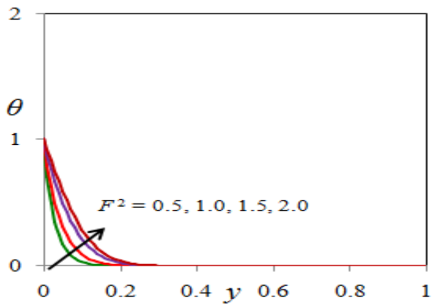

Fig. 15. F 2 impact on temperature

In table 2 describe that Porosity parameter impact on skin-friction coefficient. From this table numerical values of skin-friction coefficient linearly high due to Porosity parameter. Values of skin-friction and heat transfer rate coefficients increase as radiation of Thermal values increased at tables 3 and 4. Table 4 shows skin-friction coefficient with different parameters and time increasing values and Eckert number increases and increasing Jeffrey fluid parameter, Frequency of oscillations parameter, Prandtl number and Angle of inclination parameter reduced skin-friction coefficient in table.

Table-5. Heat transfer rate coefficient different value of Pr, *Ec*, *t* and *ω* at *Gr* = 5.0, χ^2 = 0.5, M^2 = 0.5, *λ* = 0.5, *α* = 30º and F^2 = 0.5

Pr	*Ec*	*t*	*ω*	*α*	*λ*	*τ*
0.71	0.001	1.0	0.5	30º	0.5	0.3685241641
7.00	0.001	1.0	0.5	30º	0.5	0.3301562478
0.71	1.000	1.0	0.5	30º	0.5	0.3761530489
0.71	0.001	2.0	0.5	30º	0.5	0.3831990482
0.71	0.001	1.0	1.0	30º	0.5	0.3480692273
0.71	0.001	1.0	0.5	45º	0.5	0.3216350951
0.71	0.001	1.0	0.5	30º	1.0	0.3591446037

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Pr	*Ec*	*t*	ω	*Nu*
0.71	0.001	1.0	0.5	1.1206354824
7.00	0.001	1.0	0.5	1.1060553954
0.71	1.000	1.0	0.5	1.1329577051
0.71	0.001	2.0	0.5	1.1422031957
0.71	0.001	1.0	1.0	1.1144985016

V. CONCLUSION AND FUTURE WORK

In this proposed system Grashof number impacted to heat transfer which is to restrain velocity impacted skin-friction coefficient improvement. Velocity decreases due to increasing magnetic field values. Result found that temperature decreases due to increase in prandtl number, thermal radiation increases due to surface stress increases. Frequency of oscillation parameter reduces due to heat transfer rate coefficient values, Wall temperature increases through increasing Eckert number, due to increase in radiation parameter temperature increases. High accuracy of numerical results compared with results of Israel-Cookey et al and found good agreement.

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