Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html

ISSN: 2289-7879

Advanced Research in Fluid Mechanics and Thermal Sciences

Effects of Dissipation and Radiation on Heat Transfer Flow of a Convective Rotating Cuo-Water Nano-fluid in a Vertical Channel

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ARTICLE INFO

Article history:
Received 24 June 2018
Received in revised form 23 July 2018
Accepted 1 September 2018
Available online 12 October 2018

Keywords:
Viscous dissipation, nanofluid, heat transfer, vertical channel

ABSTRACT

In this paper, we systematically investigate the operative of radiation and dissipaton on steady convective heat transfer flow of a nanofluid in a vertical channel. Analytical closed form solutions are obtained for both the energy and momentum equations. The impact of various parameters on nanofluid velocity, temperature and concentration fields are shown graphically and tables and analyzed in detail. We found the significance of various parameters on the nanofluid velocity and temperature distributions.

1. Introduction

The vertical channel is a most frequently encountered configuration in thermal engineering equipment, for example, collectors of solar energy, cooling devices of electronic and micro-electronic equipment's etc. The influence of electrically conducting the case of fully developed mixed convection between horizontal parallel plates with a linear axial temperature distribution was solved by Gill and Casal [2]. Lavanya [1] discussed effect of radiation on free convection heat and mass transfer flow through porous medium in a vertical channel with heat absorption/generation and chemical reaction.

Nanotechnology has been broadly used in several industrial applications. It aims at manipulating the structure of the matter at the molecular level with the goal for innovation in virtually every industry and public endeavour including biological sciences, physical sciences electronics cooling, transportation, the environment and national security.

The study of heat transfer in the presence of nanofluids is of great practical importance to engineers and scientists because of there universal occurrence in many branches of science and engineering. The ongoing research ever since then has extended to utilization of nanofluids in

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microelectronics, Defense and ships, and boiler flue gas temperature reduction [3]. The nanofluids are more stable and have acceptable viscosity and better wetting, spreading, and dispersion properties on a solid surface [4,5]. Despite vast amount of literature on the flow of nanofluid using a model proposed by Buongiorno [6] and few others [7,8], we will consider a different model which proposed by Abu-Nada Das [9]. This model is being applied by many rescent studies, like Norifiah *et al*., [10] on various flow fields.

The study of flow heat transfer and MHD Many authors have studied the flow and heat transfer in a rotating system with various geometrical situations [11-13]. Lavanya [14] studied unsteady MHD convective laminar flow between two vertical porous plates with mass transfer.

Thermal radiation is plays a very important role overall surface heat transfer in situations where convective heat transfer coefficients are small. The Newtonian approach may be sufficient to understand the flow of classical fluids through microchannel under various assumptions [18-19] Satyanarayana *et al*., have studied the effect of radiation on the convective heat transfer flow of a rotating nanofluid past a porous vertical plate with oscillatory velocity. Rahman and sultana investigated the thermal radiation interaction of the boundary layer flow of micro polar fluid past a heated vertical porous plate embedded in a porous medium with variable suction as well as heat flux in the plate. Recently, Sunitha [16] has discussed the convective heat transfer flow of Cuo-water nanofluid in a vertical channel in the presence of heat sources.

In this paper we carry the systematic enquiry of the effect of dissipation on steady convective heat transfer flow of rotating Cuo-water nanofluid in a vertical channel. Analytical closed form solutions are obtained for both the momentum and the energy equations. Graphs are used to illustrate the significance of key parameters on the nanofluid velocity and temperature distributions.

2. Methodology

We have considered the steady, three dimensional flow of a nanofluid consisting of a base fluid and small nanoparticles in a vertical porous channel with dissipation and thermal radiation. Table 1 shows the thermo properties of nanoparticles and water. A uniform magnetic field of strength Ho is applied normal to the plate. It is assumed that there is no applied voltage which implies the absence of an electric field. The flow is assumed to be in the x-direction which is taken along the plane in an upward direction and z-axis is normal to the plate. The radiation heat flux in the x-direction is considered negligible in comparison with that in the z-direction. As the flow is fully developed, the flow variables are functions of z and t only. Under the above mentioned assumptions, the governing equations of momentum and thermal energy respectively, can be taken in dimensional form for this investigation as

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

$$w\frac{\partial u}{\partial z} - 2\Omega v = \frac{1}{\rho_{nf}}\left(\mu_{nf}\frac{\partial^2 u}{\partial z^2} + (\rho\beta_{nf})g(T - T_\infty) - (\sigma\mu_e^2 H_o^2)u\right. \tag{2}$$

$$w\frac{\partial v}{\partial z} + 2\Omega u = \frac{1}{\rho_{nf}}\left(\mu_{nf}\frac{\partial^2 v}{\partial z^2} - (\sigma\mu_e^2 H_o^2)v\right) \tag{3}$$

$$w\frac{\partial T}{\partial z} = k_{nf}\frac{\partial^2 T}{\partial z^2} - \frac{1}{(\rho C_P)_{nf}}\frac{\partial(q_r)}{\partial z} + 2\mu_{nf}(u^2 + v^2) \tag{4}$$

Where the appropriate boundary conditions are

$$u(\pm L) = 0, v(\pm L) = 0,$$
$$T(-L) = T_1, T(+L) = T_2$$

The physical properties of the nanofluids are mentioned as follows

$$\mu_{nf} = \mu_f/(1-\varphi)^{2.5}\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}}\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s$$
$$(\rho C_p)_{nf} = (1-\varphi)(\rho C_P)_f + \varphi(\rho C_P)_s(\rho\beta)_{nf} = (1-\varphi)(\rho\beta)_f + \varphi(\rho\beta)_s$$
$$k_{nf} = \frac{k_f(k_s + 2k_f - 2\varphi(k_f - k_s)}{(k_s + 2k_f + 2\varphi(k_f - k_s)}$$

Table 1
Thermo properties of nanoparticles and water [17]

Properties of particles	H_20	Cu	Al_2O_3
C_p (J/kg K)	4178	384	764
ρ (kg/m^3)	987.0	8932	3971
K (W/m K)	0.612	401	41
β X 10^{-5} (1/K)	20	1.68	0.84

Equations (2) to (4) in the ordinary non-dimensional form are

$$-S\frac{\partial u}{\partial \eta} - 2Rv = \frac{1}{A_1A_3}\frac{\partial^2 u}{\partial \eta^2} + \frac{A_4}{A_3}G\theta - \frac{M^2}{A_3}u \tag{5}$$

$$-S\frac{\partial v}{\partial \eta} + 2Ru + \frac{1}{A_1A_3}\frac{\partial^2 v}{\partial \eta^2} - \frac{M^2}{A_3}v \tag{6}$$

$$-S\frac{\partial \theta}{\partial \eta} = \frac{1}{P_r}(\frac{A_2}{A_5}(1 + \frac{4F}{3})\frac{\partial^2 \theta}{\partial \eta^2} + 2A_1Ec(u^2 + v^2) \tag{7}$$

where

$$A_1 = (1-\varphi)^{2.5}A_2 = \frac{k_{nf}}{k_f} + \frac{4F}{3}, A_3 = 1 - \varphi + \varphi(\frac{\rho_s}{\rho_f})$$
$$A_4 = 1 - \varphi + \varphi((\frac{(\rho\beta)_s}{(\rho\beta)_f}), A_5 = 1 - \varphi + \varphi\frac{(\rho C_P)_s}{(\rho C_P)_f}$$

We have to find the solution of Equation (1) as W = $-w_0$.
In this paper, we introduce radiation heat term considering the Rosseland approximation as follow

$$q_r = -\frac{4\sigma^{\bullet}}{3\beta_R}\frac{\partial T'^4}{\partial z} \tag{8}$$

$$T'^4 \cong 4TT_\infty^3 - 3T_\infty^4 \tag{9}$$

$$\frac{\partial q_R}{\partial z} = -\frac{16\sigma^{\bullet}T_\infty^3}{3\beta_R}\frac{\partial^2 T}{\partial z^2}$$

where

$$A_1 = (1-\varphi)^{2.5} A_2 = \frac{k_{nf}}{k_f} + \frac{4F}{3}, A_3 = 1-\varphi+\varphi(\frac{\rho_s}{\rho_f})$$

$$A_4 = 1-\varphi+\varphi((\frac{(\rho\beta)_s}{(\rho\beta)_f}), A_5 = 1-\varphi+\varphi\frac{(\rho C_P)_s}{(\rho C_P)_f}$$

The boundary conditions (5) reduce to $u(\pm1) = 0, v(\pm1) = 0, \theta(-1) = 0, \theta(+1) = 1.$

3. Method of Solution

The coupled non-linear coupled Equations (5) to (7) have been solved by considering Fourth order Runge-Kutta Shooting method. The physical quantities of interest are skin friction and Nusselt number which are, represented as

$$C_f = \frac{\tau_w}{\rho_f U_o^2} \tag{10}$$

$$Nu = \frac{xq_w}{k_f(T_w - T_\infty)} \tag{11}$$

where τ_w and q_w are the wall heat flux and the wall shear from the plate respectively, which are given by

$$\tau_w = \mu_{nf}(\frac{\partial u}{\partial z})_{z=0} and q_w = -k_{nf}(\frac{\partial T}{\partial z})_{z=0}$$

In view of Equation (11) we obtained the following

$$Nu = -\frac{k_{nf}}{k_f}\theta'(\pm1) = -A_2\theta'(\pm1)$$

4. Discussion of Numerical Results

In the present paper, we discussed the combined influence of dissipation and thermal radiation on convective heat and mass transfer flow of a Cuo-water nanofluid in a vertical channel. The coupled equation governing the flow and heat transfer are analytically solved and exhibited in graphs (2-9) for different variations of the parameters G,M,R,S F, Ec, ϕ and Pr.

Figure 1a and 1b shows the primary and secondary velocity components with reference to Grashof number (G). Figure 2a and 2b represents the image of velocity component with the change in magnetic parameter. From Figure 3a and 3b the velocity of nanofluid profiles for different values of rotational parameter R. Figure 4a and 4b depicts velocity with Suction parameter. we observed that velocity enhances with increase in Suction parameter. Figure 5a and 5b shows the behaviour of the primary and secondary velocities with Eckert parameter (Ec). Figure 6a and 6b exhibit the effect of thermal radiation. It can be noticed that an increase in thermal radiation results in a decrease in T. Figure 7a and 7b shows When the volume of the nanoparticle of a fluid enhances, the thermal conductivity and the thermal boundary layer thickness increase. Figure 8b shows that the with ϕ. Figure 8a, 8b depicts the variation with respect to Eckert number.

Table 2 exhibits the behavior of local skin friction component τ_x and Nusselt number Nu at the plates η=±1. It is found that an increase in the Hartmann number M reduces τ_x at η=-1 and increases it at η==1while an enhance in the rotation parameter R decreases τ_x at both the walls. Also τ_x reduces with increase in the suction parameter S and the radiation parameter F at η=±1. The variation of the skin friction component τx with Ec shows that it decreases with Ec at left wall η=-1 and enhances at the right wall η=+1.An increase in the nanoparticle volume fraction ϕ reduces τ_x for Cu-water nanofluid Lesser the thermal diffusivity smaller the skin friction component at η=±1.

The local Nusselt number (Nu) at η=+1 is found to reduce with enhance in S or Q or ϕ or F or Prandtl number Pr while at η=-1,it enhances with enhance in F or Q >0 or S or ϕ or Pr and decreases with Q<0 in Cuo-water nanofluid .

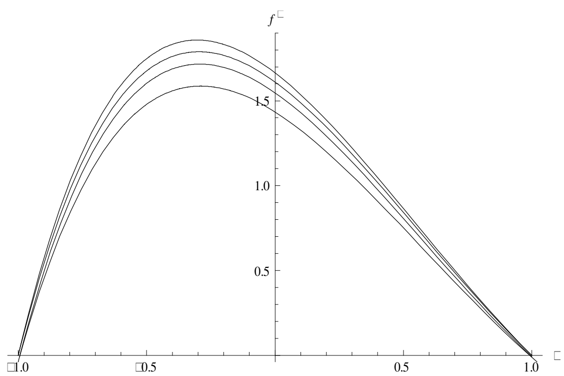

Fig. 1a. Variation of Primary velocity f ‘with G M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, s=0.2

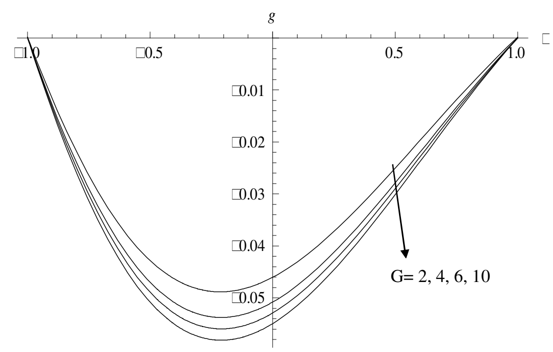

Fig. 1b. Variation of Secondary velocity (g) with G M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, s=0.2

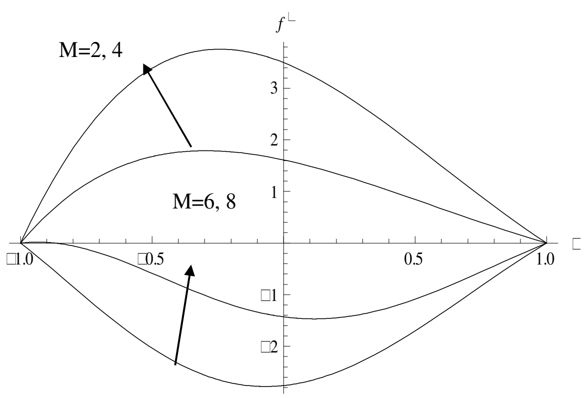

Fig. 2a. Variation of f’ with M G=10, R=0.5, F=0.5, Ec=0.01, Pr=6.2, s=0.2

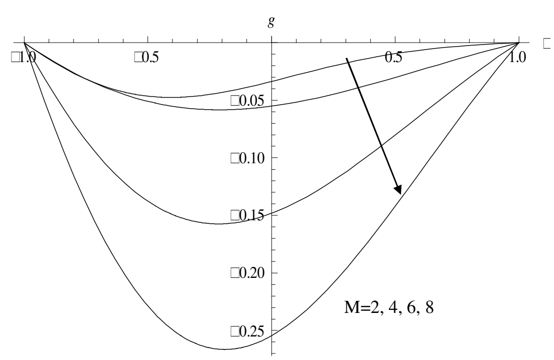

Fig. 2b. Variation of g with G=10, R=0.5, F=0.5, Ec=0.01, Pr=6.2, s=0.2

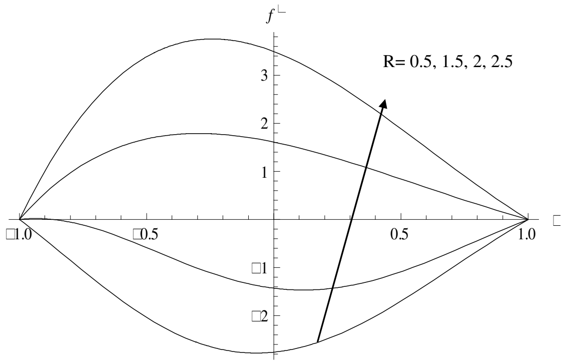

Fig. 3a. Variation of f’ with R M=2, G=10, F=0.5, Ec=0.01, Pr=6.2, s=0.2

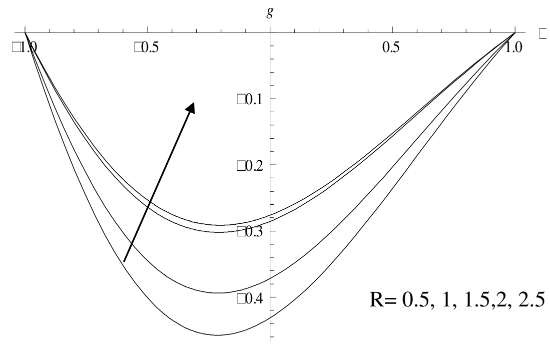

Fig. 3b. Variation of g with R M=2, G=10, F=0.5, Ec=0.01, Pr=6.2, s=0.2

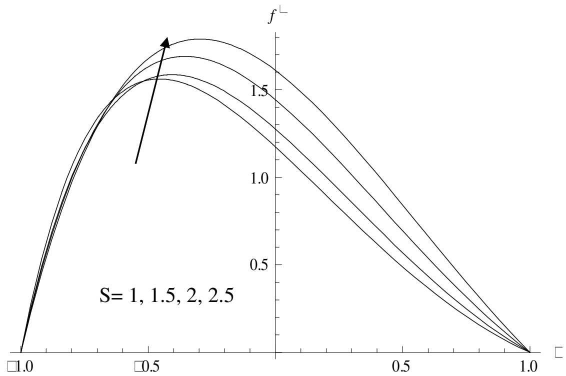

Fig. 4a. Variation of f’ with S M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, G=10

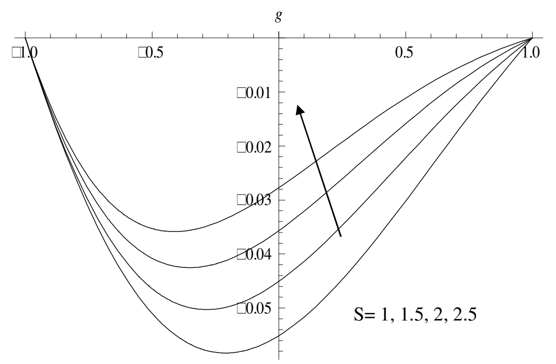

Fig. 4b. Variation of g with M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, G=10

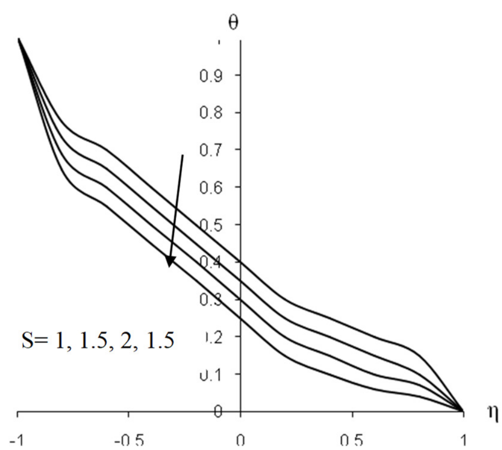

Fig. 4c. Variation of Temperature (θ) with S M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, G=10

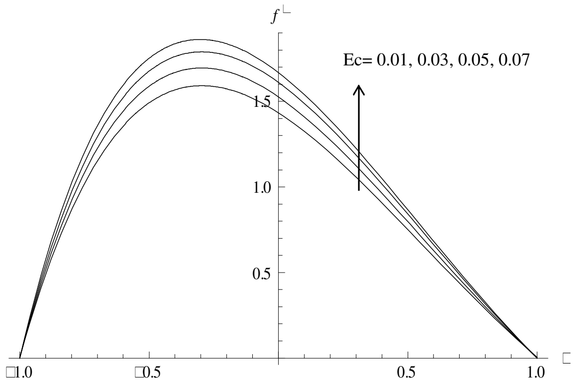

Fig. 5a. Variation of f' with Ec G=10, M=2, R=0.5, s=0.2, F=0.5, ϕ=0.1, Pr=6.2

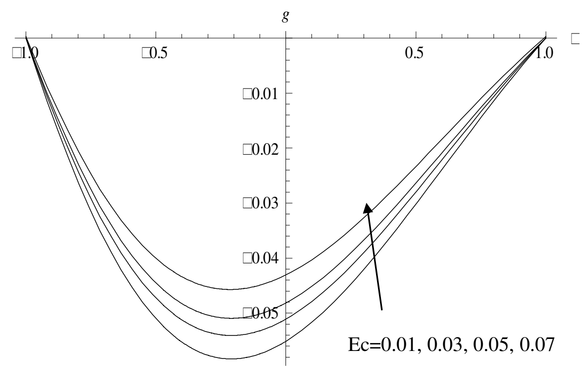

Fig. 5b. Variation of g with Ec M=2, R=0.5, F=0.5, G=10, Pr=6.2, s=0.2

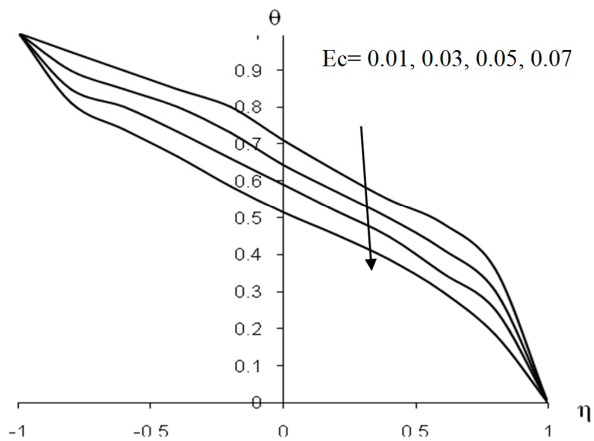

Fig. 5c. Variation of θ with Ec M=2, R=0.5, F=0.5, G=10, Pr=6.2, s=0.2

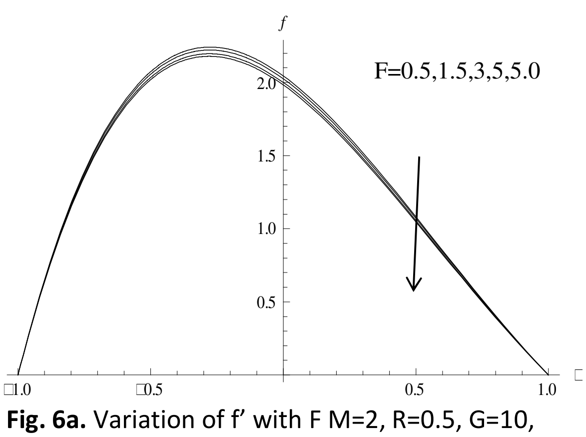

Fig. 6a. Variation of f' with F M=2, R=0.5, G=10, Ec=0.01, Pr=6.2, s=0.2

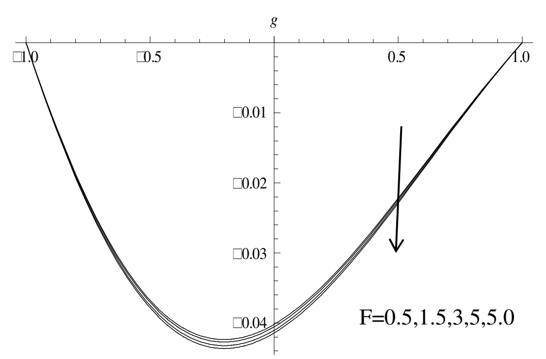

Fig. 6b. Variation of g with F M=2, R=0.5, G=10, Ec=0.01, Pr=6.2, s=0.2

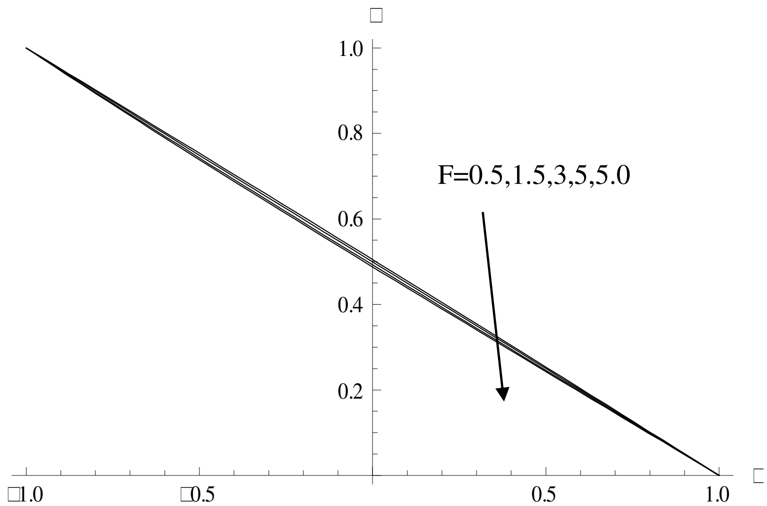

Fig. 6c. Variation of θ with F M=2, R=0.5, G=10, Ec=0.01, Pr=6.2, s=0.2

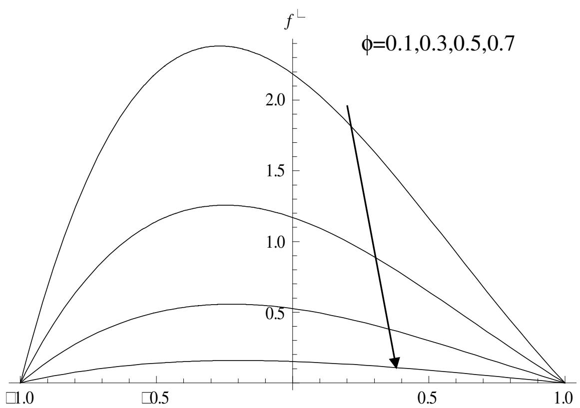

Fig. 7a. Variation of f ‘with ϕ M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, s=0.2

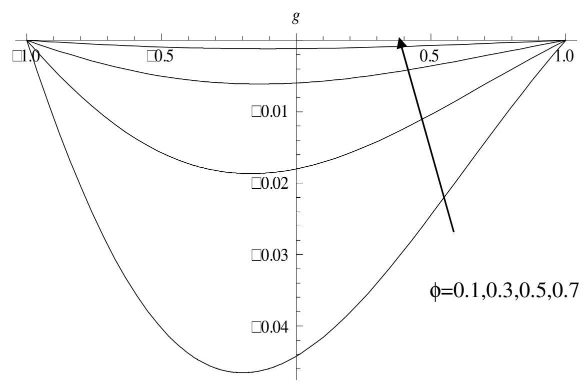

Fig. 7b. Variation of g with ϕ M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, s=0.2

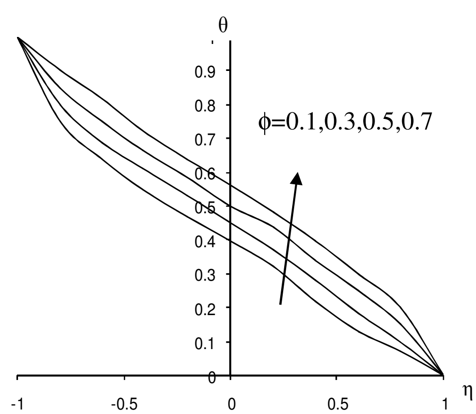

Fig. 7c. Variation of θ with ϕ M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, s=0.2

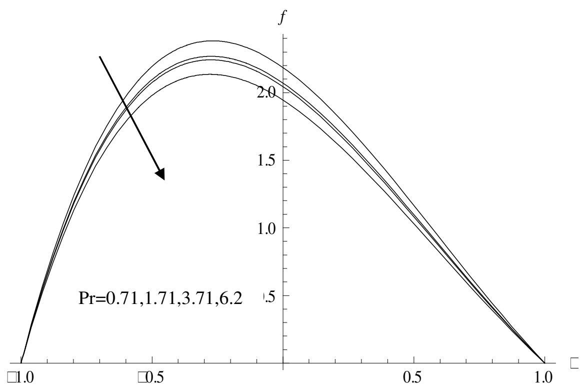

Fig. 8a. Change of f' with Pr M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, s=0.2

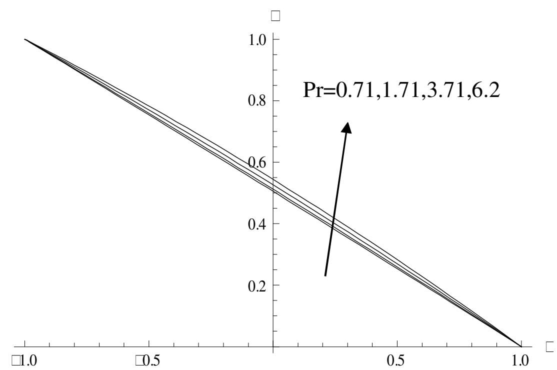

Fig. 8b. Variation of θ with Pr M=2, R=0.5, F=0.5, Ec=0.01, Pr=6.2, s=0.2

Table 2
Skin friction(τ), Nusselt Number(Nu at η=±

M	R	S	Ec	F	ϕ	Pr	τx(+1)	τx(-1)	Nu(+1)	Nu(-1)
2	0.5	0.2	0.01	0.5	0.05	6.2	-0.046315	0.67143	0.49466	0.51096
4	0.5	0.2	0.01	0.5	0.05	6.2	-0.054031	0.57668	--------	--------
6	0.5	0.2	0.01	0.5	0.05	6.2	-0.068279	0.57712	---------	-------
1	1.5	0.2	0.01	0.5	0.05	6.2	-0.040801	0.52665	----------	--------
1	2.0	0.2	0.01	0.5	0.05	6.2	-0.038121	0.50846	----------	--------
1	0.5	0.4	0.01	0.5	0.05	6.2	-0.039312	-0.07086	0.49352	0.51344
1	0.5	0.2	0.03	0.5	0.05	6.2	-0.558533	-0.63476	0.48924	0.51342
1	0.5	0.2	0.05	0.5	0.05	6.2	-0.597884	0.621601	0.398765	0.45678
1	0.5	0.2	0.07	0.5	0.05	6.2	-0.646466	0.598706	0.356743	0.43563
1	0.5	0.2	0.01	1.5	0.05	6.2	-0.046299	0.671287	0.49352	0.51489
1	0.5	0.2	0.01	5.0	0.05	6.2	-0.046183	0.670992	0.49271	0.51969
1	0.5	0.2	0.01	0.5	0.1	6.2	-0.013495	0.36641	0.49476	0.51117
1	0.5	0.2	0.01	0.5	0.3	6.2	-0.004588	0.13857	0.49466	0.51139
1	0.5	0.2	0.01	0.5	0.05	0.71	-0.046574	0.67189	0.49640	0.50665
1	0.5	0.2	0.01	0.5	0.05	2.00	-0.064654	0.67129	0.49485	0.50822

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