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Research paper

Cross Diffusion Impacts on Chemically Reactive Unsteady Mass and Energy Transport Over Elongated Surface through Penetrable Medium

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Abstract

The analysis of Dufour and Soret impacts on chemically reactive unsteady stream with molecules and energy transport in the thin fluid layer over an elongated surface rooted in a penetrable transporting agency with thermal suction/injection is scrutinized. The mathematically formulated PDEs are changed into ODEs with the application of similarity transforms. The converted ODEs are determined by Runge-Kutta method linked shooting process. Numerically computed data are graphically manifested to illustrate the domination of various parametric values. Numerical inspections are made over for local skin drag, rate of energy and solute transport.

Keywords: *Chemical reaction; Dufour and Soret impacts; Heat generation; Unsteady.*

1. Introduction

The unsteady behavior of the laminar stream in the thin fluid layer over an elongated surface rooted in a penetrable medium is a typical type of flow which has prominent realistic applications. This category of significant fluid stream phenomena has enchanted many researchers all over the world due to its wide usage in engineering and technology. In particular it may be noticed that multitude of manufacturing operations include the cooling of elongated sheets by trailing across a passive flow and achievement of the product with expected excellence is based on the rate of warming at the elongated surface. In recent years many investigations have been scrutinized on mass and heat transfer with various physical characteristics by the experts of fluid dynamics.

Sivasankaran et al. [1] studied the hydromagnetic chemically reactive, stagnation-point stream with mixed convection in a penetrable transporting agency. They found that the diminishing chemically reactive parametric values boost the stream speed. Ferdows et al. [2] analyzed the problem of natural convective stream in an inclined surface with permeability. It was concluded that increasing porosity parameter decreases the stream velocity. Hakeem et al. [3] scanned the sectional slip response against MHD stream across permeable expanding film with varying heat source/sink and wall molecules transport. They obtained that stream speed is diminished by magneto parametric values. Bhuvaneswari et al. [4] scrutinized the natural convective flow with heat emission over an inclined surface in a penetrable transporting agency. They concluded stream speed is boosted by the porosity parameter. Ganga et al. [5] reviewed the MHD stream of Boungiorno model nanofluid past a vertical plate. They reported that flow velocity is accelerated by Prandtl number. Nayak et al. [6] scanned the Dufour and Soret influences on chemically reactive unsteady stream past an expanding sheet. It was observed that the incremented values of Soret parameters enhance the skin drag magnitude. Hakeem et al. [7] reviewed the domination of thermal emission in a Walter liquid B fluid above developable film among elastic deformation. Rathish kumar et al. [8] surveyed the naturally convective stream in a Non-Darcy penetrable transporting agency with Dufour and Soret responses. It was explored that Soret parameter raises the heat fluxes. Ram Reddy et al. [9] investigated the mixed convection stream in nanofluid with Soret impact under heat transporting boundary restrictions. Pal et al. [10] explored the Dufour and Soret and influences on hydromagnetic non-Darcian chemically reactive energy and molecule transport stream pattern past a non-linear developable covering. They observed that Soret parameter enhances skin-drag magnitude.

The impacts of Dufour and Soret MHD mixed convective stream and energy emission interaction along a permeable covering in a penetrable agency was examined by Chamkha and Ben-Nakhi [11]. Tsai et al. [12] inspected the matter and energy transport on Hiemenz flow onto developable surface through a permeable agency in the existence of Dufour and Soret. Anwar Beg et al. [13] reviewed Dufour and Soret dominance about hydromagnetic naturally convective energy and molecule transport from a developable surface in a saturated penetrable transporting agency. Mansour et al. [14] made an examination on MHD naturally convective mass and heat transport over a vertically elongated covering in a penetrable medium with Dufour and Soret responses. It was concluded that the stream speed is decelerated for lower Soret number. Matter and energy transport in a stream of chemically reactive elongated film past a penetrable agency with Dufour and Soret influences are surveyed by multiple investigators [15] to [21]. The analysis of chemically reacting unsteady stream with matter and energy transport in the occurrence of suction or injection through an elongated surface rooted in a penetrable transporting agency exists in many engineering process which has yielded global fascination by the experts. In this present paper we propose to investigate the domination of cross diffusion on chemically reactive unsteady flow over an elongated surface with matter and energy transport in a permeable agency.

2 Mathematical configurations

An unsteady, 2D laminar stream of a viscous electrically conducting fluid with incompressibility owing to an elongated surface rooted in a heat producing penetrable transporting agency. Moreover, the responses of Soret and Dufour are surveyed. The fluid characteristics are estimated as unchanged. It is believed that the first-order equivalent chemical responses occur in the stream. Using the Boussinesq approximation, PDE for the stream, energy and the concentration dispensation are drafted in traditional symbols in this fashion

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\beta_T\,(T-T_\infty)+g\beta_C(C-C_\infty) -\frac{\nu}{k_1}u-\frac{\sigma B_0{}^2}{\rho}u \quad (2)$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{D_e k_T}{c_S c_P}\frac{\partial^2 C}{\partial y^2}+Q(T-T_\infty) \quad (3)$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-k_c(C-C_\infty)+\frac{D_e k_T}{T_m}\frac{\partial^2 T}{\partial y^2} \quad (4)$$

In a stream, velocity factors u and v are forth x and y directions in order. The flow is believed to be in *x*-direction. A magneto vector range of consistent strength B_0 is activated in crosswise to the stream. At t = 0, the sheet is spontaneously elongated with the non-uniform speed U_w (x, t). U_∞ is the free stream speed. T_∞ and C_∞ are the free stream temperature and concentration. t represents time, μ is the coefficient of viscosity, ν is the kinematic viscosity, σ is the electrical conductivity, ρ is the density, θ is the dimensionless temperature, φ is Dimensionless concentration, A is an unsteadiness parameter, C is concentration, c_P is the specific heat, c_s is the concentration susceptibility, D is the coefficient of mass diffusivity, D_e coefficient of effective mass diffusivity, Du is the Dufour parameter, f is the dimensionless stream function, f' is the dimensionless speed, g is the acceleration due to gravity, K is the permeability parameter, k_1 is the permeability of porous medium, k_c is the rate of chemical reaction, k_T is the thermal diffusion ratio, m_w is the Mass flux, p is the pressure, q_w is the local wall heat flux, t is the time, T_m is the fluid mean temperature, T_w is the wall temperature, β_C is the coefficient concentration expansion, β_T is the coefficient of thermal expansion.

The boundary conditions are drafted as

$u = U_W$, $v = V_W$, $C = C_W$, $T = T_W$, at $y = 0$

$u = 0$, $C = C_\infty$, $T = T_\infty$, as $y\to\infty$ (5)

Where

$$U_w(x,t)=\frac{ax}{1-ct}\;,T_w(x,t)=T_\infty+\frac{bx}{1-ct}\,,$$

$$C_w(x,t)=C_\infty+\frac{bx}{1-ct} \quad (6)$$

where a, b, c are no variables with ct < 1. V_W is the suction/injection parameter, $V_W < 0$ (suction) and $V_W > 0$ (injection). We instigate similarity transforms as below.

$$\psi=\sqrt{\frac{a\nu}{(1-ct)}}xf(\eta)\,,T=T_\infty+\left(T_W-T_\infty\right)\theta(\eta) \quad (7)$$

$$C=C_\infty+\left(C_W-C_\infty\right)\varphi(\eta)$$

where ψ is the stream function drafted in traditional notation as $u=\frac{\partial\psi}{\partial y}$ and $v=-\frac{\partial\psi}{\partial x}$. Using the above transforms equations (2) - (4) reduced to

$$f'''(\eta)+R_{iT}[\theta+N\phi]-[f'(\eta)]^2+f(\eta)f''(\eta)-A[f'(\eta)+\frac{1}{2}\eta f''(\eta)] -M\,f'(\eta)=0 \quad (8)$$

$$\frac{1}{\Pr}\theta''(\eta)+Df\phi''(\eta)-A[\frac{1}{2}\eta\theta'(\eta)+\theta(\eta)]-f'(\eta)\theta(\eta)+\theta'(\eta)f(\eta)=0 \quad (9)$$

$$\frac{1}{Sc}\phi''(\eta)-\gamma\varphi(\eta)-f'(\eta)\phi(\eta)+f(\eta)\phi'(\eta)-A[\frac{1}{2}\eta\phi'(\eta)+\phi(\eta)] +Sr\theta''(\eta)=0 \quad (10)$$

The dimensionless boundary conditions (5) becomes

$$\begin{array}{llll} f(0)=f_w & f'(0)=1 & \theta(0)=1 & \varphi(0)=1 \\ f'(\eta)=0 & \theta(\eta)=0 & \varphi(\eta)=0\;\; as & \eta\to\infty \end{array} \quad (11)$$

with $f_w > 0$ (suction), $f_w < 0$ (injection).

where $Gr_T=g\beta_T(T_W-T_\infty)x^3/\nu^2$ is thermal Grashof number, $Gr_C=g\beta_C(C_W-C_\infty)x^3/\nu^2$ is solutal Grashof number, $Ri_T=\frac{Gr_T}{\mathrm{Re}^2}$ is thermal Richardson number, $Ri_C=\frac{Gr_C}{\mathrm{Re}^2}$ is solutal Richardson number, $N=\frac{Ri_C}{Ri_T}$ is buoyancy ratio,

$Ha^2=\frac{\sigma B_0{}^2x^2}{\rho\nu}$ is Hartmann number, $M=K+\frac{Ha^2}{\mathrm{Re}}$ is porous magnetic parameter, $Sc=\frac{\nu}{D}$ is Schmidt number, $A=\frac{c}{a}$ is unsteadiness parameter, $\Pr=\frac{\mu c_p}{k}$ is Prandtl number,

$\mathrm{Re}=\frac{U_w x}{\nu}$ is the local Reynolds number,

$Df = \dfrac{Dek_T(C_W - C_\infty)}{c_s c_p \nu\,(T_W - T_\infty)}$ is Dufour number,

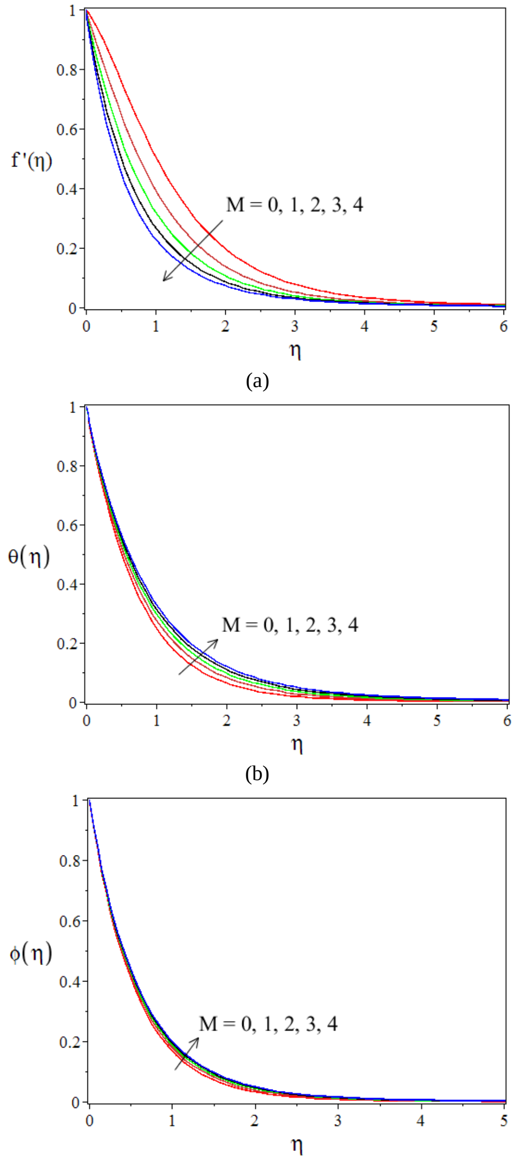
$Sr = \dfrac{Dek_T(T_W - T_\infty)}{c_s c_p \nu\,(C_W - C_\infty)}$ is Soret number, $\gamma = \dfrac{k_c(1-ct)}{a}$ is chemical reaction parameter.

The dimensionless skin drag or skin drag coefficient at the wall can be formulated as $Cf_x = \dfrac{\tau_w}{\rho(u_w)^2/2}$, where $\tau_w = -\mu\left(\dfrac{\partial u}{\partial y}\right)_{y=0}$ and is reduced as $\dfrac{1}{2}Cf_x\sqrt{\mathrm{Re}} = -f''(0)$ and Nusselt number is derived as $Nu_x = \dfrac{xq_w}{k(T_W - T_\infty)}$ where $q_w = -k\left(\dfrac{\partial T}{\partial y}\right)_{y=0}$, $Nu_x = -\theta'(0)\sqrt{\mathrm{Re}}$. The local Sherwood number is derived as $Sh_x = \dfrac{xm_w}{\rho D(C_W - C_\infty)}$ where $m_W = -\rho D(\dfrac{\partial c}{\partial y})$ at y=0 utilizing above result we obtain $Sh_x = -\varphi'(0)\sqrt{\mathrm{Re}}$. The mathematically formulated PDEs are changed into self -similar ODEs and the solution is obtained by Runge-Kutta integration linked shooting scheme.

3. Results and review

In favour of physical insight of the problem, the parametric analysis has been made for various values on speed, energy and concentration sketches. This review studies Dufour and Soret impacts on unsteady molecule and energy transport over an elongated surface with heat generation/absorption in a penetrable agency with chemical reaction.

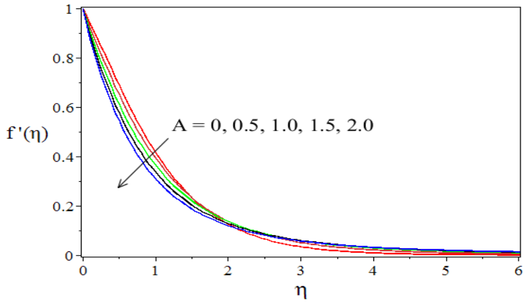
The velocity sketches for distinct M are exposed in Fig. 1(a). It is vividly deducted that velocity is diminished on enhancing porous magnetic parameter M with A = 0.5, f_w= 0.5, s = 1, Cr = 1.0, Df = 0.2, Sr = 0.2. Fig. 1(b) demonstrates the effects of M over the temperature sketch. It is clear from the graph that the temperature is accelerated by M. The physical phenomenon of the sketch is that the existence of the porosity magnetic field affects the stream temperature. It is depicted through the Fig. 1(c) that concentration boundary layer is boosted due to the improving values of M with A = 0.5, f_w = 0.5, Cr = 1.0, Df = 0.2, Sr = 0.2. The stream speed sketch for distinct unsteady parameter A is established in Fig. 2(a). It is viewed that unsteady parameter initially increases then decreases the stream speed. The influence of unsteadiness over a temperature is shown in Fig. 2(b). It is noted from the portrait rising values of A initially accelerate and then decelerate the dimensionless temperature with M = 1.0, f_w = 0.5, Cr = 1.0, Df = 0.2, Sr = 0.2.The effect of unsteady parameter over a concentration profiles is noted in Fig. 2(c). It is deducted that the increase of unsteadiness parameter initially raises then diminishes concentration boundary layer. Figures 3(a)-3(c) display the effect of suction parameters over the speed, energy and concentration sketches. Enhancing values of f_w lead to decrease speed, energy and concentration in the thin layer. Figures 4(a) and 4(b) exhibit the response of chemically reactive parameter over the speed and the concentration profiles respectively. One can see from the portraits that chemical reaction parameter decreases stream speed and concentration profiles. The impact of diffusion of matter triggered by temperature gradient is observed through Figures 5(a)-5(c). Enhancing diffusion of matter improves both the speed and the concentration and it decelerated the energy profile. The influence of Dufour parameter is disclosed in Figures 6(a)-6(c). It is noticed that enhancing values of Dufour numbers lead to raise the stream speed and the stream energy but it decreases the concentration boundary layer.



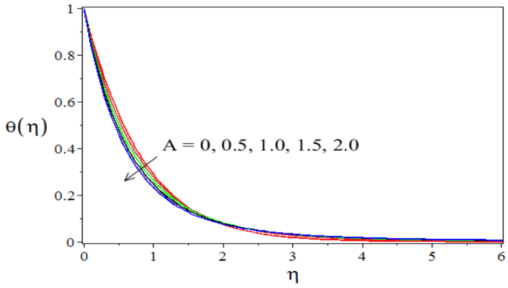
(c)

Fig.1: Effects of M on (a) velocity, (b) temperature, (c) concentration with A = 0.5, fw = 0.5, Cr = 1.0, Df = 0.2, Sr = 0.2.

The parametric investigation has been performed to study the characteristics of skin drag, Nusselt number and Sherwood.Table1 summarizes the response of unsteadiness parameter, suction/injection parameter, chemically reactive parameter, penetrable magneto parameter, Dufour & Soret impacts and Richardson, skin drag, Sherwood number, and Nusselt number. One can detect that due to the rise in the porosity magnetic parameter, the magnitude of skin-drag is increased and both Sherwood and Nusselt numbers are decreased. We infer from the data that the enhancing values of A (unsteadiness parameter) are to accelerate the local skin drag magnitude, rate of both heat transfer and chemical reaction. It is displayed in the table that the skin drag magnitude and local Nusselt number are increased when f_w is raised. It is observed that local skin drag magnitude and Sherwood number are accelerated by the enhancing values of Cr and also the heat transport rate is decelerated. It is detected that enhancing Soret values decelerate both the local skin drag magnitude and solute transfer rate but it accelerates energy transfer rate. One can observe that enhancing values of Dufour number diminish the local skin-drag magnitude and local Nusselt number, consequently it accelerates the local Sherwood number with f_w = 0.5, Cr = 1.0, Sr = 0.2, A = 0.5, M = 1.0.



(a)



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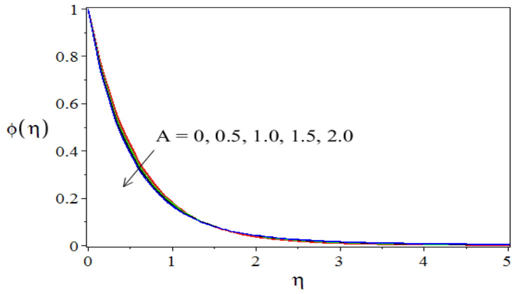

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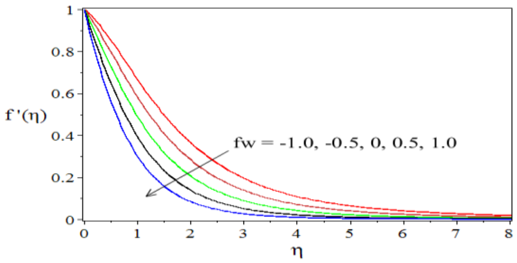
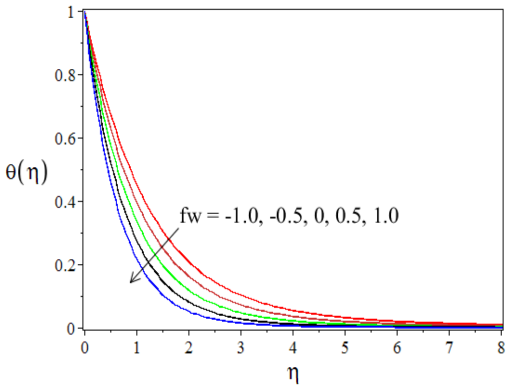
Fig.2: Domination A on (a) Velocity, (b) temperature, (c) concentration with M = 1.0, fw = 0.5, Cr = 1.0, Df = 0.2, Sr = 0.2



(a)



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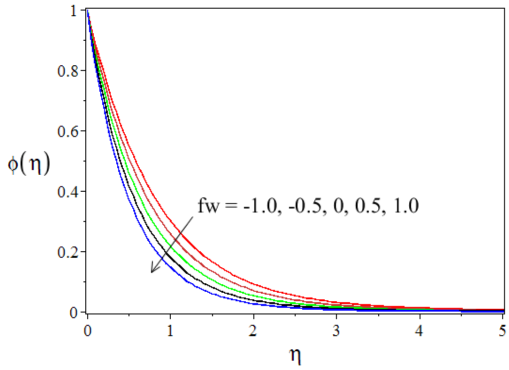


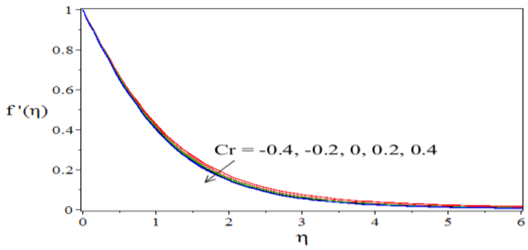
(c)

Fig.3: Impacts of f_w on (a) stream speed, (b) temperature, (c) concentration with A = 0.5, M = 1.0, Cr = 1.0,Df = 0.2, Sr = 0.2.

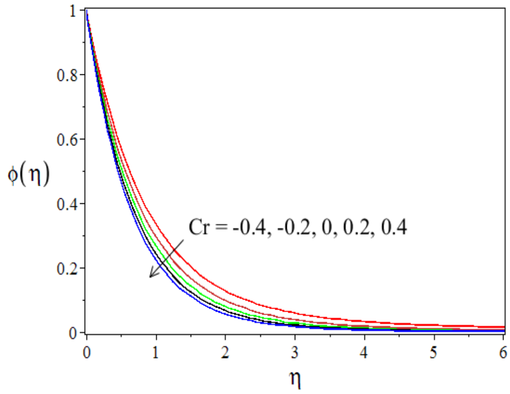
4. Conclusions

In this review we have studied Dufourt and Soret impacts on unsteady mass and energy transport over an elongated surface with heat suction/injection rooted in a penetrable medium under chemical reaction dominance.

- The stream speed rises with the enhancing values of Dufour and Soret values. It is decelerated for higher values of penetrable magneto parameter, suction/injection and chemical reaction.
- Unsteadiness values initially boost and then diminish the speed, energy and concentration sketches.
- The raising values of porous magnetic parameter and Dufour lead to improve the stream energy and in turn the temperature is decelerated whenever suction/injection, Soret values are increased.
- The concentration of the fluid rises due to the rising values of porous magnetic and Soret values and is reduced by the rising values of suction/injection, chemical reaction and Dufour.
- Soret values decelerate local skin-drag magnitude and the rate of concentration dispensation. The effect of Soret parameter is favour to local Nusselt number.
- The magnitude of skin-drag and the rate of energy transport are diminished due to the enhancing values of Dufour number. Sherwood number is increased by Dufour parameter.

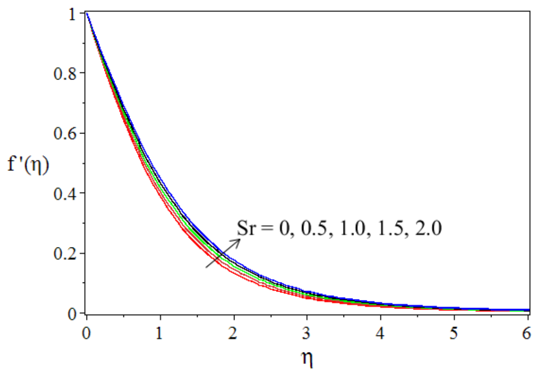


(a)

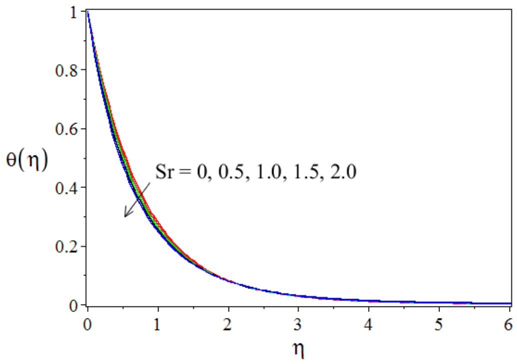


(b)

Fig.4: Influences of Cr with A=0.5, M =1.0, fw =0.5, Df =0.2, Sr=0.2.



(a)



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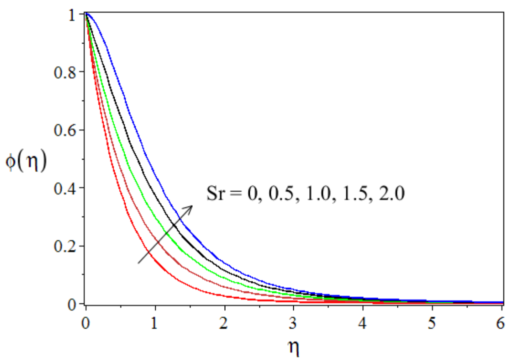
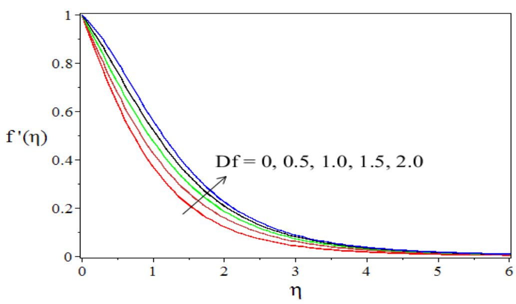
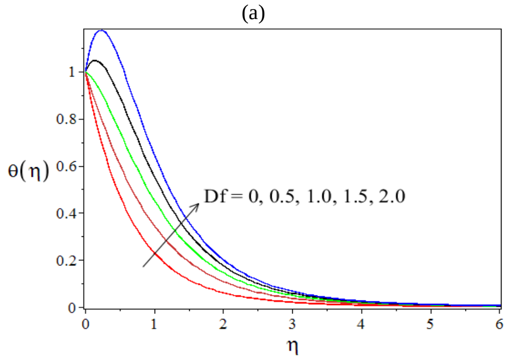


(c)

Fig.5: Domination of Sr with A =0.5, M = 1.0, fw =0.5, Cr =1.0, Df =0.2



(a)



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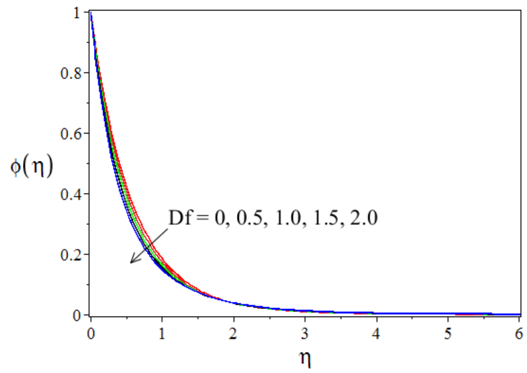

(c)

Fig. 6: Domination of Df with A =0.5, M =1.0, fw =0.5, Cr =1.0, Sr=0.2.

Table.1: (Values of $-f''(0)$, $-\theta'(0)$, $-\varphi'(0)$ with Pr=1, Sc=1, Ri=2, N=.5, M=1).

A	fw	Cr	Sr	Df	$-f''(0)$	$-\theta'(0)$	$-\varphi'(0)$
0.5	0.5	1.0	0.2	0.2	0.28138	1.32837	1.78502
					0.73286	1.27107	1.75389
					1.10009	1.22672	1.73039
					1.41396	1.19089	1.71164
					1.69053	1.16111	1.69614
0	0.5	1.0	0.2	0.2	0.54143	1.14246	1.66979
0.5					0.73286	1.27107	1.75389
1.0					0.91694	1.39549	1.83672
1.5					1.08820	1.51321	1.91897
2.0					1.24610	1.62400	2.00025
0.5	-1.0	1.0	0.2	0.2	0.17740	0.76381	1.16578
	-0.5				0.30667	0.89942	1.33789
	0				0.48858	1.06679	1.53413
	0.5				0.73286	1.27107	1.75390
	1.0				1.04358	1.51488	1.99653
0.5	0.5	-0.4	0.2	0.2	0.67185	1.39105	1.12667
		-0.2			0.68678	1.36815	1.24559
		0			0.69790	1.34846	1.34846
		0.2			0.70699	1.33070	1.44139
		0.4			0.71474	1.31435	1.52706
0.5	0.5	1.0	0	0.2	0.74447	1.24629	1.88347
			0.5		0.71495	1.31125	1.54311
			1.0		0.68374	1.38804	1.13875
			1.5		0.65059	1.48116	0.64713
			2.0		0.61518	1.59792	0.03087
0.5	0.5	1.0	0.2	0	0.78223	1.50343	1.71046
				0.5	0.65935	0.89495	1.82368
				1.0	0.53674	0.17795	1.95576
				1.5	0.41200	-0.68871	2.11492
				2.0	0.28293	-1.77069	2.31405

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