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Impact of activation energy on Non-Darcy Hydromagnetic convective Heat and Mass transfer flow Ethylene Glycol based Copper (Cu) Nanofluid in Vertical channel with Asymmetric slip, Newtonian cooling and Heat sources

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Abstract: *We explore the combined influence of activation energy, thermal radiation, dissipation, irregular heat sources on non-darcy hydromagnetic, convective heat and mass transfer flow of Eg based Cu nanofluid through a porous medium confined in a vertical channel with asymmetric slips and convective boundary conditions. After evaluating the governing equations numerically, we find that increase in asymmetric slips (αo, $\alpha 1$) results in enhancement in velocity, temperature and nanoconcentration in the flow region. An upsurge in Biot numbers (Bio, Bi1) augments velocity(u), temperature(θ) and nano-concentration(C) in the flow region. Stress, Nusselt and Sherwood numbers enhance with increase in Bio and depreciate with higher values of Bi1.*

Keywords: *Newtonian cooling, asymmetric slip, activation energy, Heat and Mass transfer, Eg based Cu nanofluid, vertical channel, thermal radiation, dissipation, irregular heat sources.*

1. INTRODUCTION :

The increasing cost of energy has led technologists to examine measures which could considerably reduce the usage of the natural source energy. Thermal insulations will continue to find increased use as engineers seek to reduce cost. The study of combined heat and mass transfer problems has great importance in extending theory of separation processes and in the chemical and hydrometallurgical industries. Heat transfer phenomena in addition to mass transfer have received great attention by modern researchers for their enormous application in chemical industries, reservoir engineering, and other processes. In view of these applications several researchers (Muthukumaraswamy and Ganesan [30], Bhattacharyya [9], Rao and Shivaiah[35, Anghel et al [6],Muralidhar [28]) have studied and reported the significance of chemical reaction.

Due to the rapid progress in thermal engineered systems and heat exchangers, enhancement of rate of heating or cooling has always been in demands for heating/cooling industrial processes. Poor heat transfer properties of traditional coolants have been an indispensable challenge for the scientists and engineers in heat transfer media and limit their applications. Nanoparticles are made from different materials, such as oxide ceramics (Al_2o_3, Cuo), metal nitrides (AlN, SiN), carbide ceramics (SiC, TiC), metals (Cu, Ag, Au), carbons (e.g., diamond, graphite, carbon nanotubes, fullerene) and functionalized nanoparticles. Several authors have been studied (Choi and Eastman [12,13,14,] Das et.al.[15] were probably the first to employ a mixture of nanoparticles and base fluid that such fluids were designated as *nano-fluids*.

Non – Darcy effects on natural convection in porous media have received a great deal of attention in recent years because of the experiments conducted with several combinations of solids and fluids covering wide ranges of governing parameters which indicate that the experimental data for systems other than glass water at low Rayleigh numbers, do not agree with theoretical predictions based on the Darcy flow model. This divergence in the heat transfer results has been reviewed in detail in Cheng [11], Raju et al. [34] among others using a regular perturbation technique.

Thermal radiation is a process by which energy is emitted by a heated surface in all directions in the form of electromagnetic radiation and travels in a combination of magnetic and electric waves. Mondal et al. [27] other authors (Umamaheswar et al. [39], Vedavathi et. al. [40]) have studied the effect of ethylene glycol based copper (eg-cu) nanofluid in porous vertical channel with asymmetric slip, radiation on heat transfer problems. The study of asymmetric slip and thermal radiation on free convection flow has various practical applications such as high-speed flights, re-entry of space vehicle and power generation plants.

The presence of heat generation or absorption can be used in semiconductor wafers and electronic chips. Alam and Ahammad [4], Kumar et al. [22], Sreenivasa Reddy and Malleswari[37] have applied Nachtsheim-Swigert shooting iteration technique with sixth-order Runge-Kutta integration scheme to study the effects of variable chemical reaction of water ethylene glycol based titania (TiO2) nanofluid in a vertical channe and variable electric conductivity on free convective heat and mass transfer flow along an inclined stretching sheet.

Natural convection inside channels has been a subject of extended research during the last decades due to its applications in engineering such as electronic cooling systems, nuclear reactors and heat exchangers. Gill and Casal [19] have made an analysis on the influence of electrically conducting the case of fully developed mixed convection between horizontal parallel plates with a linear axial temperature distribution. The problem of fully developed mixed convection between vertical plates with and without heat sources was solved by Ostrach [32]. Cebeci et al., [10], Datta and Jana [16] and Barletta et.al. [7, 8].

Merkin [26] was the first to consider a somewhat different but practically relevant driving mechanism for the natural convection boundary layer flow near a vertical surface in which it was assumed that the flow was setup by the Newtonian heating and Madhusudhana Rao and Vishwanatha Reddy [24] has studied Soret and Dufour effects on Hydro-Magnetic heat and mass transfer over a vertical plate in a porous medium with a convective surface boundary condition and chemical reaction.

The no-slip boundary condition (the assumption that a liquid adheres to a solid boundary) is frequently utilized in flow problems of viscous fluids. The slip flows under different flow configurations have been studied by many researchers(Adetayo et al [3], Falade John [18] and Muthu and Berhane Tesfahun [29]).

In chemistry and physics, activation energy refers to the minimal amount of energy required for compounds to undergo a chemical reaction. The activation energy (Ea) of a reaction is expressed in joules per mole (J/mol), kilojoules per mole (kJ/mol), or kilocalories per mole. Activation energy may be thought of as the amount of the potential barrier. Svante Arrhenius[38], a Swedish physicist, first used the phrase "activation energy" in 1889. Abu-Nada et al. [1,2], Amitosh Tiwari et al [5], Kathyani and Subramanyam [20], Satya Narayana and Ramakrishna [36], Nagasasikala [31], Devasena [17], Lalramngaihzuali and Prasada Rao [23] Kiran Kumar et al. [21] extended and investigate the natural convection of nanofluid in a concentric annulus with varying viscosity and thermal conductivity, heat transfer flow of Ethylene Glycol based SWCNT and MWCNT nanofluids.

In this paper, an attempt has been made to investigate the MHD non-darcy convective heat and mass transfer flow of Ethylene based Cu nanofluid in a vertical channel with asymmetric slip and convective boundary conditions in the presence of non-uniform heat heat sources. The non-linear, coupled equations governing the flow, heat and mass transfer have been executed by using Galerkine Finite element method with quadratic interpolation functions. The velocity, temperature & nanoconcentration, Stress, Nusselt and Sherwood numbers have exhibited through graphs and tables.

2. FORMULATION OF THE PROBLEM:

Consider the steady flow of a viscous electrically conducting fluid through a porous channel of distance 2L apart. The fluid consisting of a Ethylene Glycol base fluid and small nanoparticles of Copper in a vertical porous channel with thermal radiation. 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. The fluid is assumed to be gray, absorbing emitting but not scattering medium. The radiation heat flux in the x-direction is considered negligible in comparison with that in the z-direction. Due to the fully developed assumption, the flow variables are functions of y only. Figure. 1 shows that the problem under consideration and the co-ordinate system.

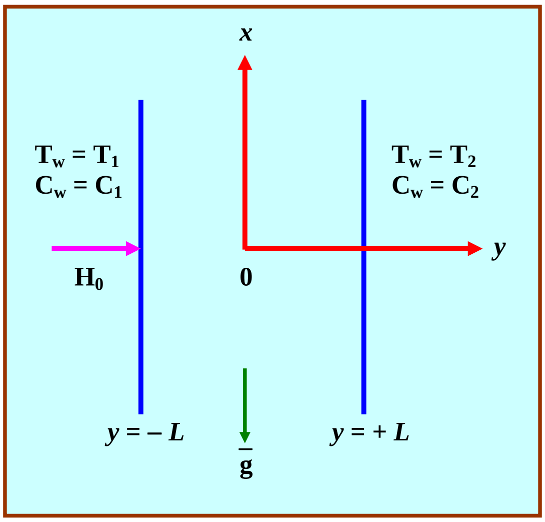

Fig.1. Schematic diagram of the problem under consideration

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Under the above mentioned assumptions, the equation of momentum and thermal energy respectively under Rosseland approximation can be written in dimensional form as :

$$\frac{\partial v}{\partial y} = 0 \tag{2.1}$$

$$-\rho_{nf} v_o \frac{\partial u}{\partial y} = -\frac{\partial P}{\partial y} + \mu_{nf}[\frac{\partial^2 u}{\partial y^2}] + (\rho\beta_T)_{nf} g(T - T_o) -$$
$$-\sigma_{nf}\mu_e^2 \mathrm{H}_o^2(u) - (\frac{\mu_{nf}}{k_p})u - (\frac{C_b}{\sqrt{k_p}})\mathrm{u}^2 \tag{2.2}$$

$$-v_o \frac{\partial T}{\partial y} = \frac{k_{nf}}{(\rho C_p)_{nf}} \frac{\partial^2 T}{\partial y^2} - \frac{1}{(\rho C_p)_{nf}} \frac{\partial (q_R)}{\partial y} + \frac{1}{(\rho C_p)_{nf}}(A_{11}^{'}(T_f - T_o)u + B_{11}^{'}(T - T_o))$$
$$+2\mu_{nf}[(\frac{\partial u}{\partial y})^2 + (\frac{\partial w}{\partial y})^2] + \sigma_{nf}\mu_e^2 H_o^2(u^2) + \mathrm{Q}_1^{'}(C - C_o) \tag{2.3}$$

$$-v_o \frac{\partial C}{\partial y} = D_B \frac{\partial^2 C}{\partial y^2} + D_T \frac{\partial^2 T}{\partial y^2} - kc(C - C_o)(\frac{T}{T_o})^n Exp(-\frac{E_a}{KT})$$

The boundary conditions are:

$$u(-L) = \alpha_o^{'} \frac{\partial u}{\partial y} \quad , -k_{nf} \frac{\partial T}{\partial y} = \gamma_o (T - T_o), C = C_o \; on \;\; y = -L$$
$$u(+L) = -\alpha_1^{'} \frac{\partial u}{\partial y} \; , -k_{nf} \frac{\partial T}{\partial y} = \gamma_1 (T - T_f), C = C_f \;\; on \;\; y = +L \tag{2.4}$$

where $(\alpha_o^{'}, \alpha_1^{'})$ are the Navier slip coefficients at the walls, μ_f is the viscosity of the base fluid, u is the axial velocity, P is the fluid pressure, ρ_f is the density of the nanoparticle, v_o is the channel porosity due to suction and injection, Cp is the specific heat at constant pressure,(T,C)are the nanofluid temperature, concentration and kf is the thermal conductivity of the material respectively, (T_o,T_1), (C_o,C_1) are referenced fluid temperatures, Concentration and $\gamma_{o,1}$ measures the Newtonian cooling rate at the walls. D_B is the molecular diffusivity, D_T is the μ_{nf} is the effective dynamic viscosity, ρ_{nf} is the effective density of the nanofluid,, σ_{nf} is the effective electrical conductivity of the nanofluid, k_f , k_{nf} are the thermal conductivity of the base fluid and nanoparticles respectively. $(\rho C_p)_{nf}$ is the effective heat capacitance of the nanofluid, $(\rho\beta)_{nf}$ is the effective thermal expansion of the nanofluid. which are given by.

$$\mu_{nf}=\mu_f/(1-\varphi)^{2.5} \qquad \alpha_{nf}=\frac{k_{nf}}{(\rho C_p)_{nf}} \qquad \rho_{nf}=(1-\varphi)\rho_f+\varphi\rho_s$$
$$(\rho C_p)_{nf}=(1-\varphi)(\rho C_P)_f+\varphi(\rho C_P)_s \qquad (\rho\beta)_{nf}=(1-\varphi)(\rho\beta)_f+\varphi(\rho\beta)_s \tag{2.5}$$
$$k_{nf}=\frac{k_f(k_s+2k_f-2\varphi(k_f-k_s)}{(k_s+2k_f+2\varphi(k_f-k_s)},\sigma_{nf}=(\sigma_f+\frac{3(\sigma_f-\sigma_s)\phi}{(\sigma_s+2\sigma_f)}),$$

where the subscripts nf, f and s represent the thermo physical properties of the nanofluid, base fluid and the nanosolid particles respectively and ϕ is the solid volume fraction of the nanoparticles. The thermo physical properties of the nanofluid are given in Table 1.

The thermo physical properties of the nanofluids are given in Table 1 (See ***Ozotop and Abu-Nada*** [33]).

Table – 1 : Physical Properties of nanofluids

Physical properties	Fluid phase (Ethylene Glycol)	**Cu nanofluid**
C_p(j/kg K)	2430	**385**
ρ(kg m^3)	1115	**8933**
k(W/m K)	0.253	**401**
β$x10^{-5}$ 1/k)	5.7	1.67
σ	**10.7**	**5.96**

By using Rosseland approximation for radiative heat flux, qr is simplified as

$$q_r=-\frac{4\sigma^{\bullet}}{3\beta_R}\frac{\partial T'^4}{\partial y} \tag{2.6}$$

where $\sigma^{\bullet}$ =5.6607x10^{-8} $Wm^{-2}K^{-4}$ is the Stefan –Boltzman constant and β_R is the Rosseland mean absorption coefficient. In the case of nanofluid ,herein (optically thick)the thermal radiation travels only a short distance before being scattered or absorbed .If the temperature differences within the fluid flow are sufficiently small, T'^4 may be expressed as a linear combination of temperature .This is done by expanding T'^4 in a Taylor series about top wall temperature Ti as follows:

$$T'^4 \cong T_o^4+3T_o^3(T-T_o)+6T_o^2(T-T_o)^2+----- \tag{2.7}$$

Neglecting higher order terms in the above equation beyond the first order in $(T-T_o)$,we get

$$T'^4\cong 4T_o^3T-3T_o^4 \tag{2.8}$$

In view of the equations(2.6) and (2.8),equation(2.2) becomes

$$-v_o\frac{\partial T}{\partial y}=\frac{k_{nf}}{(\rho C_p)_{nf}}\frac{\partial^2 T}{\partial y^2}+\frac{1}{(\rho C_p)_{nf}}\frac{16\sigma^* T_o^3}{3\beta_R}\frac{\partial^2 T}{\partial y^2}+\frac{1}{(\rho C_p)_{nf}}(A_{11}'(T_f-T_o)u+B_{11}'(T-T_o))$$
$$+2\mu_{nf}[(\frac{\partial u}{\partial y})^2+(\frac{\partial w}{\partial y})^2]+\sigma_{nf}\mu_e^2H_o^2(u^2)+Q_1'(C-C_o) \tag{2.9}$$

We consider the solution of equation (2.1) as:

$$v=-v_0 \tag{2.10}$$

Introducing the following dimensionless variables:

$$y'=\frac{y}{L},\ u'=\frac{u}{U},\ p'=\frac{p}{\rho_f U^2},\ \theta=\frac{T-T_0}{T_f-T_0},C=\frac{C-C_0}{C_f-C_0} \tag{2.11}$$

we obtain the following ordinary differential equations with appropriate boundary conditions

$$(\frac{\partial^2 u}{\partial y^2})+[1+A_2S\frac{\partial u}{\partial y}A_1A_3G(\theta)-A_6M^2(u)-\Delta(u^2)]=0 \tag{2.12}$$

$$(A_5+\frac{4Rd}{3})\frac{\partial^2\theta}{\partial y^2}+(A_4S\Pr)\frac{\partial\theta}{\partial y}+A_{11}u+B_{11}\theta+Ec\Pr[\frac{\partial u}{\partial y})^2+A_6M^2(u^2)]=0$$

$$\frac{\partial^2 C}{\partial y^2}+(A_4SSc)\frac{\partial C}{\partial y}+ScSr(\frac{\partial^2 C}{\partial y^2})-\gamma C(1+n\delta\theta)\mathrm{E}xp(-\frac{E_1}{1+\delta\theta})=0 \tag{2.13}$$

The transformed boundary conditions (2.3) reduce to

$$u(-1)=\alpha_0\frac{\partial u}{\partial y}(-1), u(+1)=-\alpha_1\frac{\partial u}{\partial y}(+1),$$

$$\frac{\partial\theta}{\partial y}(-1)=(\frac{Bi_o}{A_5})\theta(-1), \frac{\partial\theta}{\partial y}(+1)=-(\frac{Bi_1}{A_5})\theta(+1)$$

where u is the dimensionless fluid velocity is the dimensionless fluid temperature,$\alpha_{0,1}$ are the dimensionless slip parameters at the walls and S is the fluid suction/injection parameter due to channel porosity,$Bi_{0,1}$ are the Biot numbers.

$$G=\frac{\beta g(T_f-T_o)L^2}{\mu_f U}\ \text{(Grashof number)},\ S=\frac{v_0 L}{U}\ \text{(Suction parameter)}$$

$$M=\frac{\sigma\mu_e^2 H_0^2 L^2}{\rho_f U\mu_f}\ \text{(Magnetic parameter)},\ \Delta=\frac{C_b UL}{\sqrt{k_p}}\ \text{(Forchheimer parameter)}$$

$$A_{11}=\frac{A_{11}^{'}L^2}{\rho_f C_p}\ \text{(Space dependent heat source)},\ B_{11}=\frac{B_{11}^{'}L^2}{\rho_f C_p}\ \text{(Temperature dependent heat source)},\ Rd=\frac{4\sigma^{\bullet}T_\infty^3}{\beta_R k_f}$$

(Radiation parameter), $\Pr=\frac{\mu_f C_p}{k_f}$ (Prandtl number),

$$Ec=\frac{U^2}{C_p(T_f-T_o)}\ \text{(Eckert parameter)},\ Sc=\frac{v_f}{D_B}\ \text{is the Schmidt number},\ Sr=\frac{D_T(C_f-C_o)}{T_m(T_f-T_0)}\ \text{is the Soret parameter,}$$

$$\theta_w=\frac{T_f}{T_0}, \delta=\theta_w-1\ \text{is the temperature difference ratio},\ E_1=\frac{E_a}{KT_0}\ \text{is the Activation energy parameter}$$

$$A_1=(1-\varphi)^{2.5},\ A_2=1-\varphi+\varphi(\frac{\rho_s}{\rho_f}),\ A_3=1-\varphi+\varphi((\frac{(\rho\beta)_s}{(\rho\beta)_f}), A_4=1-\varphi+\varphi\frac{(\rho C_P)_s}{(\rho C_P)_f}$$

$$A_5=\frac{k_{nf}}{k_f}, A_6=(1+\frac{3(1-\sigma)\phi}{(\sigma+2)}), \sigma=\frac{\sigma_s}{\sigma_f}$$

The limiting case $\alpha_{0,1}\to\infty$ corresponds to the perfect lubricated plate surface.

3. FINITE ELEMENT ANALYSIS :

The finite element analysis with quadratic polynomial approximation functions is carried out along the axial distance across the vertical channel. The behavior of the velocity, temperature and concentration profiles has been discussed computationally for different variations in governing parameters. The Galerkin method has been adopted in the variational formulation in each element to obtain the global coupled matrices for the velocity, temperature and concentration in course of the finite element analysis.

Choose an arbitrary element e_k and let u^k, θ^k and C^k be the values of u, θ and C in the element e_k. We define the error residuals as

$$E_u^k=\frac{d}{dy}\left(\frac{du^k}{dy}\right)+A_1A_3G(\theta^k)+Su^k+A_1-A_1A_6M^2(u^k)-\Delta(u^k)^2 \quad (3.1)$$

$$E^k{}_\theta=\frac{A_5}{\Pr}\frac{d}{dy}\left(\frac{d\theta^k}{dy}\right)-S\theta^k A_4u^k+A_{11}u^k+B_{11}\theta^k+Ec[(\frac{du^k}{dy})^2]+ \quad (3.2)$$
$$+\mathrm{EcM}^2\mathrm{A}_6(u^k)^2$$

$$E^k{}_C=\frac{d}{dy}\left(\frac{dC^k}{dy}\right)-SSc(u^k)+ScSr\frac{d}{dy}\left(\frac{d\theta^k}{dy}\right)-\gamma Sc(C^k)(1+n\delta\theta^k)Exp(-\frac{E_1}{1+\delta\theta^k}) \quad (3.3)$$

where u^k, θ^k,C^k are values of u, θ and C in the arbitrary element e_k. These are expressed as linear combinations in terms of respective local nodal values.

$$u^k = u_1^k\psi_1^k + u_2^k\psi_1^k + u_3^k\psi_3^k \,,\theta^k = \theta_1^k\psi_1^k + \theta_2^k\psi_2^k + \theta_3^k\psi_3^k \,, C^k = C_1^k\psi_1^k + C_2^k\psi_2^k + C_3^k\psi_3^k \quad (3,3)$$

where ψ_1^k , ψ_2^k --------- etc are Lagrange's quadratic polynomials.

Galarkin's method is used to convert the partial differential Equations (3.1) – (3.2) into matrix form of equations which results into 3x3 local stiffness matrices. All these local matrices are assembled in a global matrix by substituting the global nodal values and using inter element continuity and equilibrium conditions. The resulting global matrices have been solved by iterative procedure until the convergence i.e $|u_{i+1}-u_i|<10^{-6}$ is obtained.

4. COMPARISON:

In the absence of convection(G=0), heat sources(A11=0=B11), Activation energy(E1=0), δ=0 the results are in good agreement with ***Falade John*** [18]

Para-meter	***Falade John*** [22]				**Present results**			
	τ(-1)	τ(+1)	Nu(-1)	Nu(+1)	**τ(-1)**	**τ(+1)**	**Nu(-1)**	**Nu(+1)**
M	1.07612	0.93072	0.264868	0.678584	**1.07613**	**0.93075**	**0.264853**	**0.678586**
	1.06352	0.91948	0.264384	0.677301	**1.06356**	**0.91953**	**0.264369**	**0.677306**
	1.03616	0.89501	0.263057	0.673813	**1.03606**	**0.89511**	**0.263086**	**0.673821**
S	1.07611	0.93072	0.264870	0.678586	**1.07613**	**0.93071**	**0.264872**	**0.678591**
	1.14285	0.87496	0.261245	0.677394	**1.14288**	**0.87503**	**0.261227**	**0.677398**
	1.20148	0.81987	0.255948	0.661667	**1.20153**	**0.81999**	**0.255913**	**0.661662**
Ec	-----------	-----------	0.332844	0.858343	-----------	-----------	**0.332873**	**0.858347**
			0.399164	1.010345			**0.399132**	**1.010336**
			0.448915	1.011167			**0.448947**	**1.011156**
Pr	-----------	-----------	0.026506	0.067915	-----------	-----------	**0.026514**	**0.067911**
			0.069255	0.177434			**0.069259**	**0.177433**
			0.119911	0.286912			**0.119901**	**0.286911**
αo	1.07613	0.93073	0.264871	0.678585	**1.07616**	**0.93075**	**0.264873**	**0.678588**
	0.97714	1.01155	0.311924	0.807821	**0.97709**	**1.01153**	**0.311929**	**0.807820**
	0.89847	1.07582	0.349923	0.912144	**0.89839**	**1.07587**	**0.349911**	**0.912146**
α1`	1.12742	0.88861	0.265258	0.752469	**1.12747**	**0.88881**	**0.265258**	**0.752467**
	1.20334	0.82628	0.340627	0.862844	**1.20332**	**0.82635**	**0.340625**	**0.862848**
	1..26932	0.77213	0.380441	0.959778	**1.26920**	**0.77212**	**0.380487**	**0.959781**
Bio	-----------	-----------	0.264866	0.678584	-----------	-----------	**0.264861**	**0.678580**
			0.541767	0.955267			**0.541774**	**0.955270**
			1.016422	2.205502			**1.016416**	**2.205513**
Bi1	----------	----------	0.118607	0.532444	----------	----------	**0.118601**	**0.532448**
			0.045989	0.459881			**0.045986**	**0.459887**
			0.015638	0.429554			**0.015636**	**0.429560**

5. RESULTS AND DISCUSSION:

In this analysis an attempt has been made to investigate the effect of thermal radiation, non-uniform heat source, asymmetric slip on the convective heat and mass transfer flow of Eg based nanofluid in vertical channel with Newtonian cooling. The velocity(u), temperature(θ) and nanoconcentration(C) have been discussed for different parametric variations.

The *u* augments with higher values of Grashof number(G)/ Eckert Number(Ec)/Slip parameters(αo,α1)/ Convective parameter(Bi_1)/Prandtl Number(Pr) and depreciates with rising values of M/K/Δ/A11/B11/Rd/Bi_0 in the entire flow region(figs.2a,31,5a,9a). From figs 4a, we notice reduces in *u* in the region (1,0) and enhances in (0,1) with increase in suction parameter(S)/nano particle volume fraction.

The non-dimensional temperature(θ) enhances with rising values of G/M/Ec/αo/α1/Pr /Sc/δ/Q1/*n* (figs.2b,6b,7b,9b,10b,12b,13b) and depreciates with K/Δ/S/ϕ/A11/B11/Rd/Bi_1/Sr (Figs.3b,6b,8b,10b). Increase in δ/E1, upraises θ in the flow region(-1,0) and reduces in (0,1) (figs.11b, 12b).

The nanoconcentration(C) upraises with increasing values of G/S/Ec/α_0/Pr/δ/Q1/*n*/E1/ and depreciates with M/K/Δ/ϕ/A11/B11/α_1/Bi_0/Bi_1 (Figs.2c-5c, 7c, 8c). From figs. 10c and 11c, we find that C reduces in the flow region (-1,0) and enhances in the flow region (0,1) with larger values of Sc and γ. Higher the thermo diffusion effect (Sr) larger C in the region (-1,0) and smaller in (0,1) (figs.10c).

Increase in G/ϕ/Ec/Bi_0/Pr upsurge τ at $\eta=\pm1$. It reduces at $\eta=\pm1$ with rising value sof M/K/Δ/A11/B11/Rd/Bi_1. An increase in slip parameters (αo,$\alpha 1$) reduces τ at $\eta = -1$ and enhances at $\eta = +1$.

The rate of heat transfer(Nu) experiences augmentation with higher values of G/M/ Ec/ α_0/ Bi_0/Pr/Sc/E1/δ/Q1 and depreciates with increase in K/Δ/S/ϕ/A11/B11/Rd/Bi_1/Sr. Nu reduces at $\eta = -1$ and enhances at $\eta = +1$ with larger values of slip parameter α_0 and chemical reaction parameters (γ).

The rate of mass transfer(Sh) enhances at $\eta = \pm 1$ with higher values of A11/Rd/Sc and reduces with G/Pr. Sh enhances at $\eta = -1$ and reduces and $\eta = +1$ with rising values of M/K/Δ/S/B11/Ec/Bi_1 with opposite effect is noticed with ϕ /αo/$\alpha 1$/Bi_0/E1/δ/A1Q1.

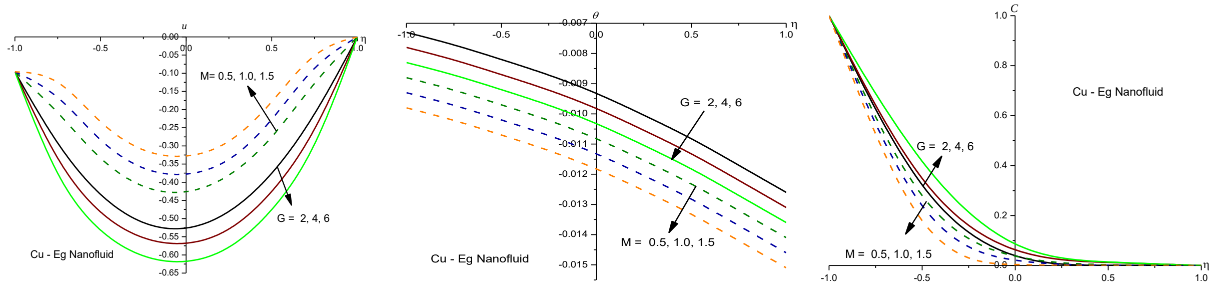

Fig.2. : Variation of [a] Velocity, [b] Temperature(θ), [c] Nano-Concentration(C) with G & M (Cu-Eg Nanofluid)
Δ=0.2, K=0.2, ϕ=0.05, S =0.1, A11=0.1, B11=0.2, Rd=0.5, Ec=0.05, $\alpha 1$=0.2, α_0=0.1, B_0=2, B_1=3, Pr=0.71, Sr=0.5, Sc=0.24, γ=0.5, E1=0.2, δ=0.01, Q1=0.25, n = 0.2

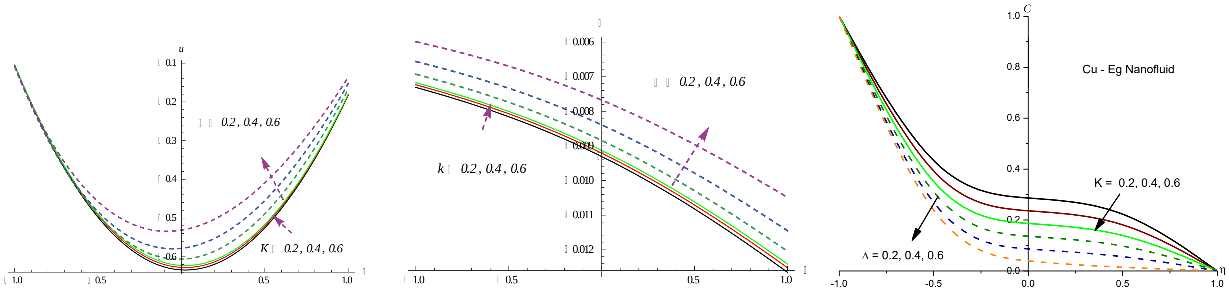

Fig.3. : Variation of [a] Velocity, [b] Temperature(θ), [c] Nano-Concentration(C) with Δ & K (Cu-Eg Nanofluid)
G=2, M=0.5, ϕ=0.05,S =0.1, A11=0.1, B11=0.2, Rd=0.5, Ec=0.05, $\alpha 1$=0.2, α_0=0.1, B_0=2, B_1=3, Pr=0.71, Sr=0.5, Sc=0.24, γ=0.5, E1=0.2, δ=0.01, Q1=0.25, n = 0.2

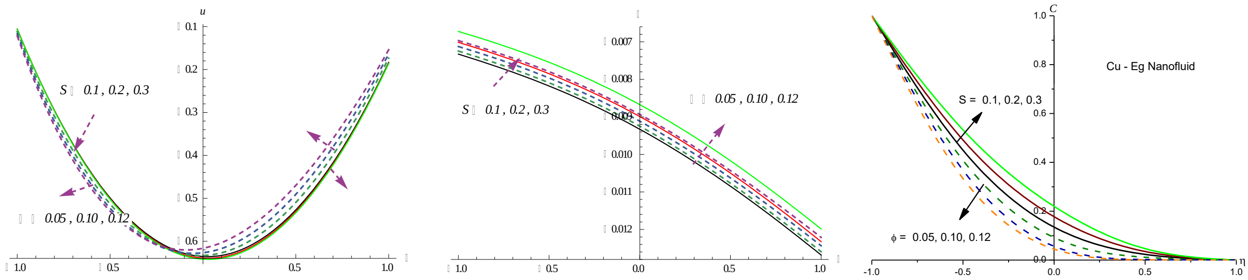

Fig.4. : Variation of [a] Velocity, [b] Temperature(θ), [c] Nano-Concentration(C) with S & ϕ (Cu-Eg Nanofluid)
G=2, M=0.5, Δ=0.2, K=0.2, A11=0.1, B11=0.2, Rd=0.5, Ec=0.05, $\alpha 1$=0.2, α_0=0.1, B_0=2, B_1=3, Pr=0.71, Sr=0.5, Sc=0.24, γ=0.5, E1=0.2, δ=0.01, Q1=0.25, n = 0.2

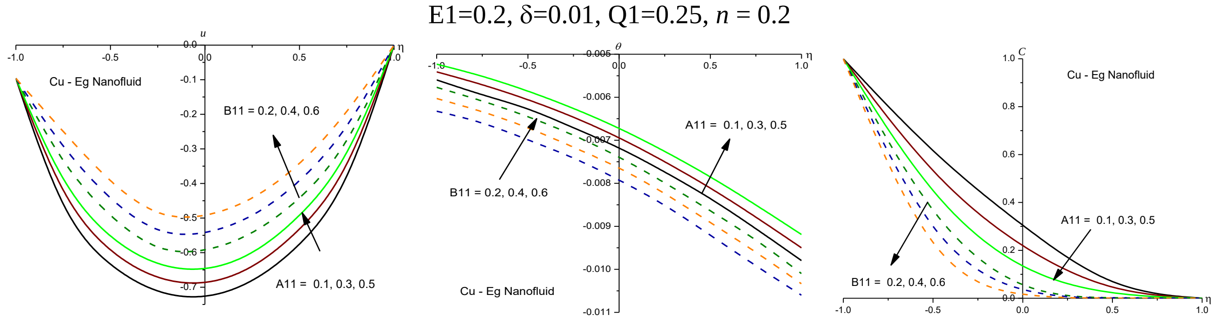

Fig.5. : Variation of [a] Velocity, [b] Temperature(θ), [c] Nano-Concentration(C) with A11 & B11 (Cu-Eg Nanofluid)
G=2, M=0.5, Δ=0.2, K=0.2, ϕ=0.05,S =0.1, Rd=0.5, Ec=0.05, $\alpha 1$=0.2, α_0=0.1, B_0=2, B_1=3, Pr=0.71, Sr=0.5, Sc=0.24, γ=0.5, E1=0.2, δ=0.01, Q1=0.25, n = 0.2

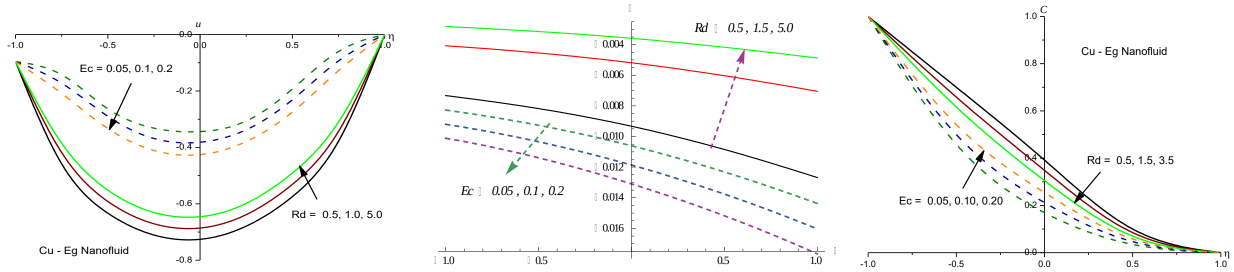

Fig.6. : Variation of [a] Velocity, [b] Temperature(θ), [c] Nano-Concentration(C) with Rd & Ec (Cu-Eg Nanofluid)
G=2, M=0.5, Δ=0.2, K=0.2, ϕ=0.05, S =0.1, A11=0.1, B11=0.2, α1=0.2, α_0=0.1, B_0=2, B_1=3, Pr=0.71, Sr=0.5, Sc=0.24, γ=0.5, E1=0.2, δ=0.01, Q1=0.25, *n* = 0.2

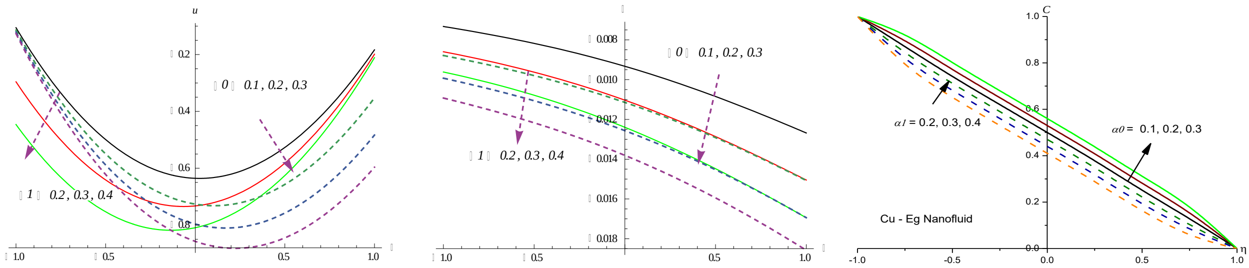

Fig.7. : Variation of [a] Velocity, [b] Temperature(θ), [c] Nano-Concentration(C) with α1 & α_0 (Cu-Eg Nanofluid)
G=2, M=0.5, Δ=0.2, K=0.2, ϕ=0.05, S =0.1, A11=0.1, B11=0.2, Rd=0.5, Ec=0.05, B_0=2, B_1=3, Pr=0.71, Sr=0.5, Sc=0.24, γ=0.5, E1=0.2, δ=0.01, Q1=0.25, *n* = 0.2

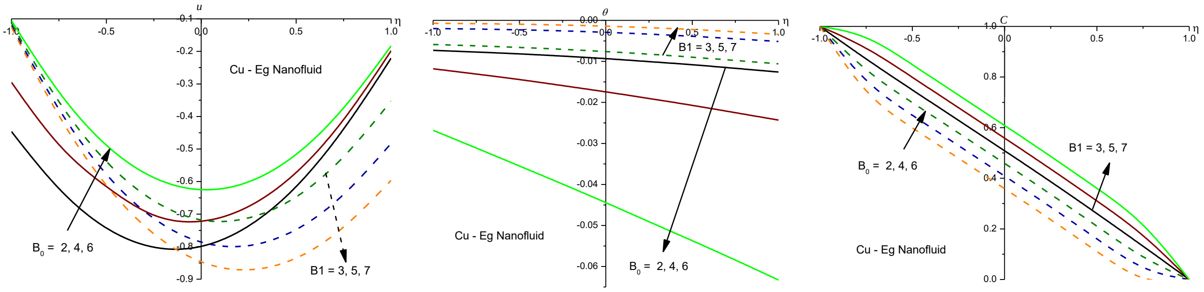

Fig.8. : Variation of [a] Velocity, [b] Temperature(θ), [c] Nano-Concentration(C) with Bi_0 & Bi_1 (Cu-Eg Nanofluid)
G=2, M=0.5, Δ=0.2, K=0.2, ϕ=0.05,S =0.1, A11=0.1, B11=0.2, Rd=0.5, Ec=0.05, α1=0.2, α_0=0.1, Pr=0.71, Sr=0.5, Sc=0.24, γ=0.5, E1=0.2, δ=0.01, Q1=0.25, *n* = 0.2

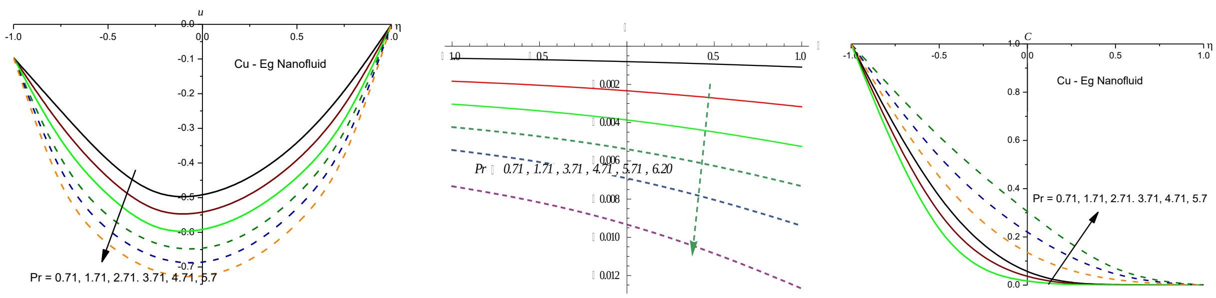

Fig.9. : Variation of [a] Velocity, [b] Temperature(θ), [c] Nano-Concentration(C) with Pr (Cu-Eg Nanofluid)
G=2, M=0.5, Δ=0.2, K=0.2, ϕ=0.05, S =0.1, A11=0.1, B11=0.2, Rd=0.5, Ec=0.05, α1=0.2, α_0=0.1, B_0=2, B_1=3, Sr=0.5, Sc=0.24, γ=0.5, E1=0.2, δ=0.01, Q1=0.25, *n* = 0.2

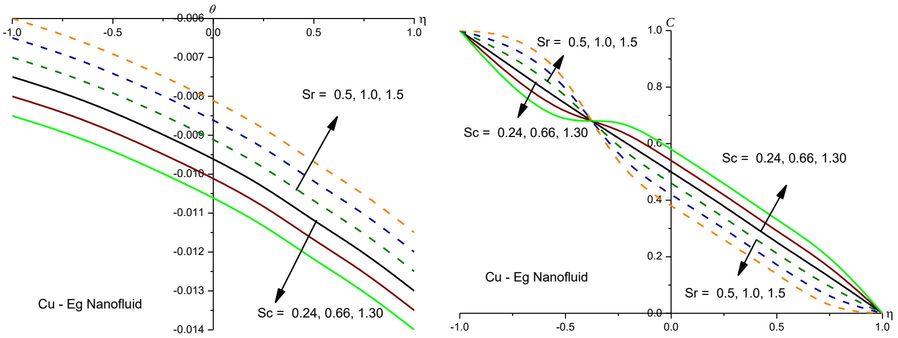

Fig.10. : Variation of [a] Temperature(θ), [b] Nano-Concentration(C) with Sc & Sr (Cu-Eg Nanofluid)
γ=0.5, E1=0.2, δ=0.01, Q1=0.25, *n* = 0.2

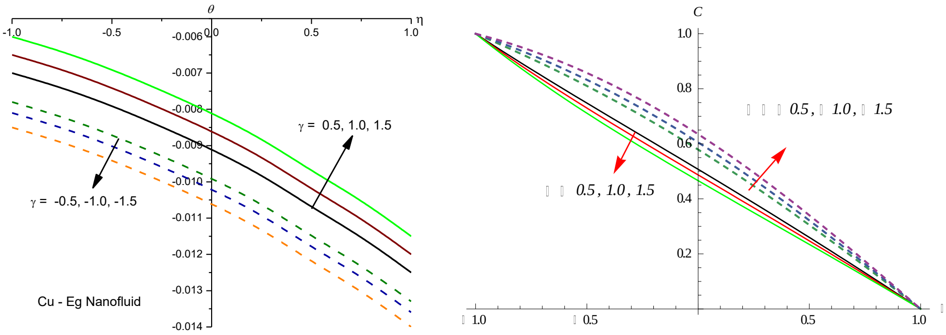

Fig.11. : Variation of [a] Temperature(θ), [b] Nano-Concentration(C) with γ (Cu-Eg Nanofluid)
Sr=0.5, Sc=0.24, E1=0.2, δ=0.01, Q1=0.25, *n* = 0.2

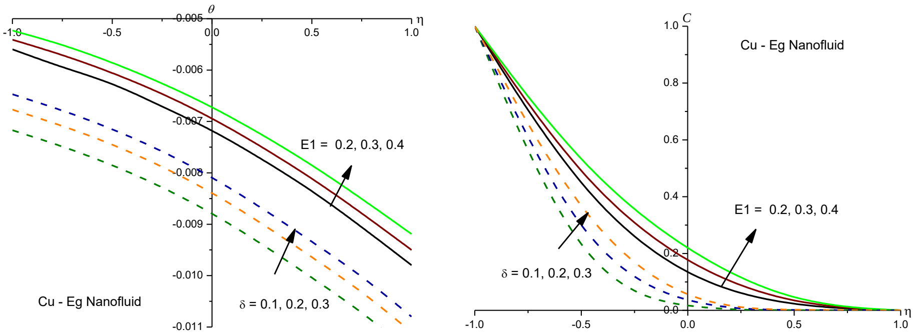

Fig.12. : Variation of [a] Temperature(θ), [b] Nano-Concentration(C) with E1 & δ (Cu-Eg Nanofluid)
Sr=0.5, Sc=0.24, γ=0.5, Q1=0.25, *n* = 0.2

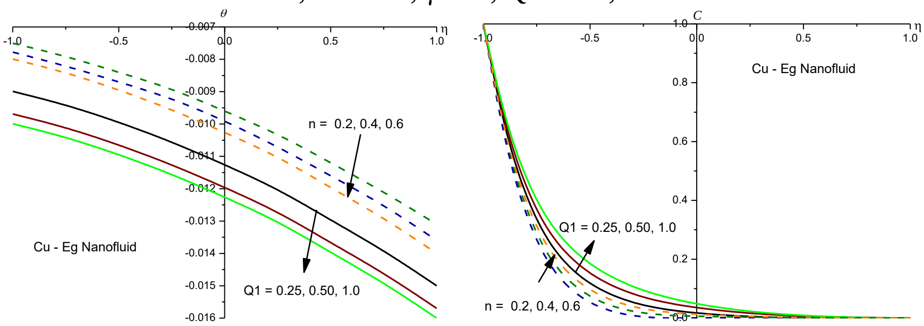

Fig.13. : Variation of [a] Temperature(θ), [b] Nano-Concentration(C)with Q1 & *n* (Cu-Eg Nanofluid)
Sr=0.5, Sc=0.24, γ=0.5, E1=0.2, δ=0.01

Table 3. : Skin friction (τ), Nusselt number (Nu) and Sherwood number(Sh) at η=(±1)

Parameter	τ(-1)	τ (+1)	Nu(-1)	Nu(+1)	Sh(-1)	Sh(+1)
G	-1.05516	0.916841	0.00149873	0.00389046	0.530123	0.533643
	-1.05706	0.918789	0.00150187	0.00389859	0.52994	0.53384
	-1.05897	0.920746	0.00150503	0.00390675	0.529756	0.534039
M	-1.04585	0.908481	0.00150116	0.00389655	0.531063	0.532668

Table 3. : Skin friction (τ), Nusselt number (Nu) and Sherwood number(Sh) at η=(±1)

Parameter	τ(-1)	τ (+1)	Nu(-1)	Nu(+1)	Sh(-1)	Sh(+1)
	-1.03695	0.900482	0.00150317	0.00390154	0.531963	0.531736
	-1.01212	0.878174	0.0015071	0.00391115	0.53447	0.529137
K	-1.05516	0.916841	0.00149873	0.00389046	0.530123	0.533643
	-1.04585	0.908473	0.00148296	0.00384947	0.531064	0.532669
	-1.03853	0.901896	0.00147058	0.00381729	0.531803	0.531904
δ	-1.01816	0.883828	0.0014361	0.00372764	0.533871	0.529772
	-0.985011	0.854251	0.00138044	0.00358293	0.537225	0.526307
	-0.954715	0.827219	0.00132955	0.00345065	0.54029	0.523141
Rd	-1.05516	0.916841	0.00149873	0.00389046	0.530123	0.533643
	-1.05474	0.91641	0.000833053	0.00216243	0.530157	0.533652
	-1.05458	0.916243	0.000576345	0.00149605	0.53017	0.533656
Ec	-1.05529	0.916972	0.00169192	0.00440896	0.530119	0.533643
	-1.05533	0.91703	0.00188232	0.00491942	0.530122	0.533634
	-1.05553	0.917227	0.00206869	0.00541947	0.53011	0.533642
A11	-1.05516	0.916841	0.00149873	0.00389046	0.530123	0.533643
	-1.05513	0.91681	0.00145029	0.00376501	0.530126	0.5336453
	-1.0551	0.91678	0.00140417	0.00364554	0.530128	0.533648
B11	-1.05516	0.91684	0.00149757	0.00388751	0.530123	0.533643
	-1.05508	0.916769	0.00149663	0.00388512	0.530131	0.533635
	-1.05516	0.916839	0.00149517	0.0038814	0.530123	0.533643
ϕ	-1.05516	0.916841	0.00149873	0.00389046	0.530123	0.533643
	-1.05729	0.923974	0.00147105	0.00387719	0.529675	0.534263
	-1.0583	0.929669	0.00144332	0.00386014	0.529359	0.534733
S	-1.11507	0.867482	0.00148187	0.00386339	0.551085	0.510235
	-1.16841	0.818748	0.00145721	0.00381482	0.57226	0.488054
	-1.21722	0.769436	0.0014251	0.00374612	0.594632	0.466084
αo	-1.05516	0.916841	0.00149873	0.00389046	0.530123	0.533643
	-0.954491	0.994121	0.00175851	0.00461637	0.503099	0.54775
	-0.874987	1.05515	0.00196685	0.00519815	0.481756	0.558891
α1	-1.14059	0.839353	0.00179713	0.0046235	0.517058	0.558004
	-1.20662	0.779464	0.00203042	0.00519704	0.506959	0.576833
	-1.26386	0.727552	0.00223452	0.00569912	0.498205	0.593154
Bio	-1.05516	0.916841	0.00149873	0.00389046	0.530123	0.533643
	-1.05592	0.917702	0.00508467	0.00747363	0.529871	0.533839
	-1.05847	0.920572	0.0170431	0.0194229	0.52903	0.534492
Bi1	-1.05466	0.916361	0.000668313	0.0030611	0.530295	0.533527
	-1.05441	0.916121	0.000254299	0.00264761	0.53038	0.533469
	-1.0543	0.916021	8.09163E-05	0.00247445	0.530416	0.533444
Pr	-1.05429	0.915954	0.000129077	0.000335178	0.530193	0.533663
	-1.05445	0.916519	0.000374443	0.00288347	0.530151	0.53364
	-1.05516	0.916841	0.00149873	0.00389046	0.530123	0.533643
Sc	----	----	0.00154055	0.00402818	0.533861	0.52979
	----	----	0.00154255	0.00403272	0.602871	0.583568
	----	----	0.0015446	0.00403728	0.690587	0.642191
Sr	----	----	0.00154053	0.00402815	0.533992	0.529665
	----	----	0.00154052	0.00402812	0.534124	0.529539
	----	----	0.00154051	0.00402809	0.534255	0.529413
γ	----	----	0.00154055	0.00402818	0.533861	0.52979
	----	----	0.00153735	0.00401967	0.5903	0.503016
	----	----	0.00153406	0.00401093	0.649698	0.475815
	----	----	0.00155177	0.00405797	0.345429	0.62559

Table 3. : Skin friction (τ), Nusselt number (Nu) and Sherwood number(Sh) at η=(±1)

Parameter	τ(-1)	τ (+1)	Nu(-1)	Nu(+1)	Sh(-1)	Sh(+1)
	----	----	0.00155588	0.00406885	0.279683	0.661267
	----	----	0.00156051	0.00408109	0.207397	0.701787
Q1	----	----	0.00154055	0.00402818	0.533861	0.52979
	----	----	0.00159277	0.00417845	0.533857	0.5298
	----	----	0.00163455	0.00429867	0.533853	0.529807
E1	----	----	0.00154055	0.00402818	0.533861	0.52979
	----	----	0.00154187	0.0040317	0.510843	0.54097
	----	----	0.00154287	0.00403436	0.493628	0.549428
δ	----	----	0.00154056	0.00402822	0.533602	0.529935
	----	----	0.00154058	0.00402826	0.533366	0.530067
	----	----	0.00154059	0.0040283	0.533129	0.530199
n	----	----	0.00154053	0.00402815	0.534038	0.529692
	----	----	0.00154054	0.00402819	0.533997	0.529715
	----	----	0.00154054	0.00402821	0.533958	0.529737

6. CONCLUSIONS:

The effect of thermal radiation and dissipation on convective heat transfer flow of a Eg based Cu nanofluid in a vertical channel with asymmetric slips and convective boundary conditions in the presence of irregular heat sources. The non-linear, couples equations have been executed by using Finite element method with quadratic interpolation functions. The findings of the this analysis are:

1. Increase in G enhances the *u* and θ in the flow region. The τ and Nu at the both cylinders upsurge with rising values of G.
2. Higher the M smaller *u* and larger θ. The τ decays and Nu augments at the cylinders with higher values of M.
3. Lesser S larger the velocity in (-1,0.5)and smaller in the region(0,5,1.0). θ reduces with increases in K. τ enhances, Nu reduces at η= -1 while opposite effect is noticed at the right wall η=+1 with rising values of K.
4. *u* and θ enhances with Rd and depreciate with higher values of Ec in the flow region. τ and Nu decay with Rd and grows with Ec on the walls
5. Increase in A11,B11 decays the *u* and θ in the flow region. τ and Nu reduce with higher values of A11 on η=±1, while increase in B11 decays τ and grows the Nu on the walls.
6. Increase in ϕ enhances the *u* and θ. τ grows and Nu decays with increase in ϕ.
7. Lesser Δ, larger *u* and θ in the flow region. τ and Nu upsurge with higher values of Pr on η=±17). Higher the inertia and boundary effects smaller *u* and larger θ in the flow region. τ and Nu decays with increase in Δ on η=±1
8. Increase in αo,α1 results in an enhancement in *u* and θ in the flow region. Increase in αo reduces τ, enhances Nu on η=-1 while they grow on η=+1 with increase in αo. Increase in α1 enhances stress and Nu on η=-1 while on r=2, τ increase and Nu reduces on η=+1.
9. Increase in Biot numbers (Bio,Bi1) upsurge *u* and θ in the flow region. τ and Nu enhance with increase in Bio and depreciate with higher values of Bi1.

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