Activation Energy Impacts on Hydromagnetic Convective Heat Transfer Flow of Nanofluid Past a Surface of Vertical Wavy with Variable Properties

Amitosh Tiwari
Post Graduate Students of Mathematics, Central University, Andhra Pradesh, Anantapuramu-515001, A.P., India

Amit Ranjan
Post Graduate Students of Mathematics, Central University, Andhra Pradesh, Anantapuramu-515001, A.P., India

Subhransu Mania
Post Graduate Students of Mathematics, Central University, Andhra Pradesh, Anantapuramu-515001, A.P., India

ABSTRACT
An attempt has been made to analyse effect of activation energy on hydromagnetic nanofluid past a vertical-wavy-surface with variable properties in the presence of temperature gradient dependent heat sources with Darcy model. By means of the Rungre-Kutta fourth order with shooting technique, the vertical wavy wall and the governing equations for flow, heat, and mass transfer are transformed to a plane geometry case. The analysis has been carried out for different parametric values of the activation energy, variable viscosity, variable thermal conductivity, radiation, and amplitude of the wavy surface and exhibited graphically. It is found that higher the activation energy/ temperature difference parameter (δ), larger the velocities. The temperature diminishes with increasing values of Brownian motion (Nb) and accelerates with increasing values of thermophoresis(Nt). The nano-concentration (C) upsurges with Nb and depreciates with Nt in the boundary layer.

Keywords
Activation energy, thermal conductivity, energy and heat sources, Variable viscosity.

1. INTRODUCTION
Over the past two decades, a major area of research activity has been the investigation of mass and heat transfer from a stems wall within a porous medium. Rees and Pop [16] investigated free convection along a vertical wavy channel embedded in a Darcy porous media wall with a constant surface temperature or heat flux (Cheng [2]). The impact of wall waviness on friction and pressure drop of the generated coquette flow has been studied by Vajravelu and Nayfeh [21], Vajravelu and Sastry [22], and Vajravelu and Debnath [20]. Goren[5] investigated free convection thermal transfer inside an incompressible viscous fluid maintained with both long vertical wavy walls in the presence of a steady heat source. Deshikachar et al [3] and Sreeramachandra Murthy [19], Madhavi and Prasada Rao[12] extended this problem to the case of wavy walls with chemical reaction, soret, and dufour effects.

Most research team have only looked at the effect of steady viscosity and thermal conductivity on the boundary layer formed by a vertical wavy surface. However, it is known that fluid viscosity changes with temperature; for example, the absolute viscosity of evaporation by 240% when the temperature rises from 100 degrees Celsius to 500 degrees Celsius. Ling and Dybbs [10] have theoretically investigated a actual motivating flow in a porous medium with variable properties over a vertical corrugated surface. Ranganatha Reddy et al [15] have analysed a novel approach for convective heat and mass transfer flow past a vertical wavy wall with variable viscosity thermal conductivity, thermal radiation and chemical reaction.

The minimal quantity of energy which is essential to initiate a chemical response is known as energy of activation. Scientist S. Arrhenius from Swedish country gave the term energy of activation. The activation energy in nanofluid is to explore the influence of energy of activation on fluid flow through different surfaces with other influencing effects. Recently, Satya Narayana and Ramakrishna [17] & Nagasasikala [14] have discussed the effect of Brownian motion and thermophoresis, activation energy on hydromagnetic convective heat transfer flow of nanofluid in a vertical channel. The effect of thermal radiation on the heat transfer flow of Nanofluid with Brownian motion and thermophoresis has been discussed by Devasena [4]. Keeping these applications in view the problem with activation energy have been analysed by several authors(Khan et al. [7, 8], Mabood et al. [11], Ijaz and Ayub [6]).

In this paper, an attempt has been made to investigate effect of activation energy, variable viscosity and heat sources on natural convective heat and mass transfer flow over a vertical wavy surface. The Darcy model is used to analysed the flow of liquids in a porous medium. The results obtained are compared with results Bejan and Khair [1] and excellent arrangement was stated in the deficiency of activation energy, dissipation, heat source.

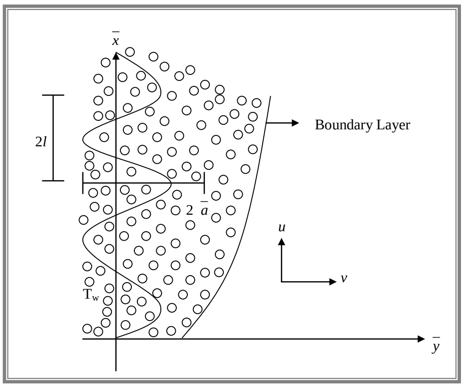


Fig. 1 : Physical Configuration and Co-ordinate System

2. PROBLAMATIC ANALYSIS
A natural convective flow of steady, incompressible heat and mass transfer above a vertically wavy surface within a porous medium has been considered. The fluid and the uniformly porous medium are in local thermal equilibrium. The porous fluid-saturated medium is defined by the Darcy law. The profile of the wave is given by

$$y=\bar{\sigma}(\bar{x})=\bar{a}Sin\left(\frac{\pi\bar{x}}{l}\right) \quad (1)$$

in which l = length effective of the wave-like and $\bar{a}$ is its amplitude The temperature(T) of the wave-like surface is kept constant at T_w, which is significantly high than the T of the surrounding fluid, T_∞. According to Boussinesq and Rosseland approximations, the air flow in the presence of a heat source with a temperature gradient is controlled by

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (2)$$

$$u=-\frac{k}{\mu_f}\frac{\partial p}{\partial x}+\frac{kg(1-C_\infty)\beta(T-T_\infty)-(\rho_p-\rho_{f\infty})kg(C-C_\infty)}{\mu_f}-\frac{k\sigma\mu_e^2H_0^2}{\mu_f}u \quad (3)$$

$$v=-\frac{k}{\mu_f}\frac{\partial p}{\partial y} \quad (4)$$

$$\begin{aligned}&\bar{u}\frac{\partial T}{\partial \bar{y}}+\bar{v}\frac{\partial T}{\partial \bar{y}}=\frac{\partial}{\partial \bar{x}}(\alpha\frac{\partial T}{\partial \bar{x}})+\frac{\partial}{\partial \bar{y}}(\alpha\frac{\partial T}{\partial \bar{y}})+\frac{1}{C_p}(Q_H\frac{\partial T}{\partial \bar{y}})+\\&+\frac{16\sigma^\bullet T_\infty^3}{3\beta_R C_p}(\frac{\partial^2 T}{\partial \bar{x}^2}+\frac{\partial^2 T}{\partial \bar{y}^2})+\frac{\tau}{\rho C_p}[D_B(\frac{\partial T}{\partial \bar{x}}\frac{\partial C}{\partial \bar{y}}+\frac{\partial T}{\partial \bar{y}}\frac{\partial C}{\partial \bar{x}})+\\&+\frac{D_T}{C_pT_\infty^2}(\frac{\partial T}{\partial \bar{x}})^2+(\frac{\partial T}{\partial \bar{y}})^2]\end{aligned} \quad (5)$$

$$\begin{aligned}&u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=\frac{D_B}{Cp}(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2})-\frac{k_c^{'}}{C_p}(C-C_o)\\&(\frac{T}{T_0})^n Exp(-\frac{E_n}{KT})+\frac{D_T}{T_\infty}(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2})\end{aligned} \quad (6)$$

The relevant boundary conditions are

$$\begin{aligned}&\bar{u}=0,\bar{v}=0,T=T_w\ ,C=C_w\ \ at\ \ \bar{y}=\bar{\sigma}(\bar{x})=\bar{a}\ Sin(\frac{\pi\bar{x}}{l})\\&\bar{u}=0,T\to T_\infty\ ,C\to C_\infty\ \ as\ \ \bar{y}\to\infty\end{aligned} \quad (7)$$

$\bar{u}\ \&\ \bar{v},T,C,\rho,\mu,k\sigma,\mu_eH_0D_B,kc,\beta_0,\alpha,q_r,g,Q_H,K$
are velocities, temperature Concentration, density of the fluid, dynamic viscosity, porous medium, electrical conductivity, magnetic permeability, magnetic field, molecular diffusivity, chemical reaction, thermal expansion, thermal conductivity, radiative heat flux gravity acceleration, strength of temperature dependent heat source and Stefan-Boltzmann coefficient.

Following Lai and Kulacki [9] and Seddeek and Salem [18] viscosity variation(μ) and fluid thermal conductivity α are taken as

$$\frac{1}{\mu}=\frac{1}{\mu_\infty}(1+\delta(T-T_\infty)\ \text{or}\ \frac{1}{\mu}=b(T-T_\infty))$$

$$\theta_r=\frac{T_r-T_\infty}{T_w-T_\infty}=-\frac{1}{\delta(T_w-T_\infty)}b=\frac{\delta}{\mu_\infty}\text{and}\,T\ =T_\infty-\frac{1}{\delta}$$

$\alpha=\alpha_0(1+\beta\theta),\beta=E(T\ -T_\infty)$ (thermal conductivity parameter) (8)

On introducing non dimensional variables

$$x=\frac{\bar{x}}{l},y=\frac{\bar{y}}{l},a=\frac{\bar{a}}{l},\sigma=\frac{\bar{\sigma}}{l},\psi^*=\frac{\bar{\psi}}{l}=\theta=\frac{T-T_\infty}{T_w-T_\infty},\quad C=\frac{C'-C_\infty}{C_w-C_\infty} \quad (9)$$

the governing equations reduced to

$$\begin{aligned}&(\frac{1}{\theta-\theta_r})(\frac{\partial\theta}{\partial y}\frac{\partial\psi^\bullet}{\partial y}-\frac{\partial\theta}{\partial x}\frac{\partial\psi^\bullet}{\partial x})-Ra(1-\frac{\theta}{\theta_r})\\&(\frac{\partial\theta}{\partial y}-Nr\frac{\partial C}{\partial y})-M^2(1-\frac{\theta}{\theta_r})\frac{\partial^2\psi^\bullet}{\partial y^2}\end{aligned} \quad (10)$$

$$\begin{aligned}&\frac{\partial\theta}{\partial x}\frac{\partial\psi^\bullet}{\partial y}-\frac{\partial\theta}{\partial y}\frac{\partial\psi^\bullet}{\partial x}=\beta((\frac{\partial\theta}{\partial x})^2+(\frac{\partial\theta}{\partial y})^2)+\\&(1+\beta\theta+\frac{4Rd}{3})(\frac{\partial^2\theta}{\partial y^2}+\frac{\partial^2\theta}{\partial x^2})+Q\frac{\partial\theta}{\partial y}+Nb\frac{\partial\theta}{\partial y}\frac{\partial C}{\partial y}+Nt(\frac{\partial\theta}{\partial y})^2\end{aligned} \quad (11)$$

$$\begin{aligned}&Le(\frac{\partial C}{\partial x}\frac{\partial\psi^\bullet}{\partial y}-\frac{\partial C}{\partial y}\frac{\partial\psi^\bullet}{\partial x})=(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2})-\\&-Le\gamma(C)(1+n\delta\theta)\exp(-\frac{E_1}{1+\delta\theta})+(\frac{Nt}{Nb})(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2})\end{aligned} \quad (12)$$

Where $Ra=\frac{\beta_T g(T_w-T_\infty)l}{\alpha_0\nu}$ is the Darcy-Rayleigh number $\nu=\frac{\mu_\infty}{\rho}$ is the kinematic viscosity of the fluid $Rd=\frac{\sigma^\bullet T_\infty^3}{k_f\beta_R}$ is the Radiation parameter, $M^2=\frac{\sigma\mu_e^2H_0^2l^2}{\mu}$, is the magnetic parameter, $Le=\frac{\nu}{D_B}$ is the Lewis number $\gamma=\frac{kcl^2}{D_B}$ is the chemical reaction parameter, $k_c^{'}=kcx^{-1}$, $Nr=\frac{(\rho_p-\rho_{f\infty})(C_w-C_\infty)}{\rho_{f\infty}\beta_T(T_w-T_\infty)(1-C_\infty)}$ is the buoyancy ratio , $E_1=\frac{E_n}{KT_0}$ Activation energy constant,,

$Q=\frac{Q_H l}{C_p}$ is the heat source parameter, $\theta_w=\frac{T_w}{T_\infty}$,,and $\delta=(\theta-1)$ is temperature difference parameter.

The transformed boundary conditions are

$$\begin{aligned}&\psi^\bullet=0,\theta=1\ ,\phi=1\ \ at\ \ \ y=aSin(x)\\&\frac{\partial\psi^\bullet}{\partial y}\to 0,\theta\to 0\,,\phi\to\infty\ \ as\ \ y\to\infty\end{aligned} \quad (13)$$

On introducing transformations

$$x=\zeta,\bar{\eta}=\frac{y-aSin(x)}{\zeta^{1/2}Ra^{-1/2}},\psi^*=Ra^{1/2}\psi$$

and similarity variables

$$\eta=\frac{\bar{\eta}}{(1+a^2Cos^2(\zeta))},\psi\ \ =\zeta^{1/2}f(\eta),\theta=\theta(\eta)$$

the governing eqs. reduce to

$$\begin{aligned}&f''+(\frac{1}{\theta-\theta_r})\theta'f'-\frac{M^2}{(1+a^2Cos^2\xi)}(1-\frac{\theta}{\theta_r})\\&f''=Ra(1-\frac{\theta}{\theta_r})(\theta'-Nr\,C')\end{aligned} \quad (14)$$

$$\beta(\theta')^2 + \left(1 + \beta\theta + \frac{4Rd}{3}\right)\theta'' + \frac{1}{2} f\theta' + Q\theta' + Nb(\theta')(C') + Nt(\theta')^2 \qquad (15)$$

$$C'' + Le\frac{1}{2} fC' - Le\gamma Ra^{-1}(1 + a^2Cos^2(\xi)) (C)(1 + n\delta\theta)\exp\left(-\frac{E1}{1+\delta\theta}\right) + \left(\frac{Nt}{Nb}\right)\theta'' \qquad (16)$$

where prime denotes differentiation with respect to η.
The corresponding boundary conditions are

$$f = 0 \ \theta=1 \ \ C=1 \text{ at } \eta = 0 \qquad (17)$$
$$f' \to 0 \ \theta\to 0 \ \ C \to 0 \text{ as } \eta \to \infty$$

The primary findings of practical importance across many implementations are the surface heat transfer coefficient and mass transfer coefficient. The Cf(skin friction), Nusselt and Sherwood (Nu&Sh) number are given by

$$C_f = \frac{f''(0)(1 + a^2Cos^2(\xi))Ra^{1/2}}{(1\grave{}+M^2 + a^2Cos^2(\xi))},\ Nu_\zeta = -\frac{\phi'(0)Ra_\xi^{1/2}}{\sqrt{1 + a^2Cos^2(\xi)}}$$

$$Sh_\xi = -\frac{\phi'(0)Ra_\xi^{1/2}}{\sqrt{1 + a^2Cos^2(\xi)}}$$

3. COMPARISON

In order to evaluate the accuracy of the current numerical method, the results are compared with those of ***Bejan and Khair***[1] in the absence of activation energy(E1), variable viscosity(θr), thermal conductivity(β), radiation(Rd), The comparison in the above case is found to be in good agreement as shown in table.1.

Table.1. Comparison of the rate of heat and mass transfer with the good findings gotten by ***Bejan and Khair***[1] for E1=0,δ=0, β=0,a=0,Rd=0,Q=0and $\theta_r \to \infty$

Parameters		$Nu_\xi\ Ra^{-1/2}$	$Sh_\xi\ Ra^{-1/2}$	$Nu_\xi\ Ra^{-1/2}$	$Sh_\xi\ Ra^{-1/2}$
Le	Nr	Bejan and Khair[1]	Bejan and Khair[1]	**Present results**	**Present results**
1	3	0.888	0.888	**0.8883**	**0.8883**
2	3	0.810	1.286	**0.8126**	**1.2814**
6	1	0.541	1.685	**0.5414**	**1.6888**
6	2	0.618	2.009	**0.6186**	**2.0086**

4. RESULTS AND DISCUSSION

The variation of the non-dimensional velocities(*u, w*), temperature(θ) and nanoconcentration(ϕ) profiles with η for different values of Brownian motion parameter (Nb), thermophoresis parameter(Nt) temperature dependent viscosity parameter(θr), thermal conductivity parameter(β), radiation parameter(Rd), heat source parameters(Q), Buoyancy ratio(Nr), activation energy parameter(E1), temperature difference parameter(δ), wavy surface(*a)* amplitude and stream wise coordinate (ξ) are presented in figs.2a-7d.

Figs.2a-2d depict the variation of velocity, temperature and concentration with buoyancy ratio(Nr) and thermal radiation parameter(Rd). Over the thermal molecular buoyancy force dominates the velocities accelerate, temperature and concentration decay in the area (0,4.0). This may be attributed to the fact upgrade values of Nr lead to a progress in the depth of momentum, decay in thermal and solutal boundary layers. Also velocities, temperature upsurge and nanoconcentration diminishes with higher values of thermal radiation parameter (Rd).

Figs.3a-3d represent u ,w,θ and C with thermal conductivity parameter(β) and viscosity parameter(θr). Figs.3a-3b, the u (primary velocity), concentration reduce and secondary velocity(w), temperature experience enhancement with higher values of thermal conductivity parameter. The indicates that thermal boundary layer grows and solutal boundary layer decays with increasing values of β. An upsurges in θr diminishes the depth of the energy, thermal and solutal boundary layer .

Figs.4a-4d illustrate the influence of the temperature gradient dependent heat generating/ absorption source(Q>0 or Q<0) in the boundary layer on velocities, temperature and concentration. It is evident that the primary velocity(u) enhances with heat generating source(Q>0)and reduces with heat absorption(Q<0) in a narrow region adjacent to the wall while far away from the wall, a reversed effect is noticed. The secondary velocity(w)reduces with strength of heat gradient generation and enhances with heat absorption source(fig.4b).The temperature and nanoconcentration decelerates with increasing values of heat source while they reduce with rising values of heat absorbing source in the boundary layer.

The Brownian motion & thermophoresis parameter (Nb)&(Nt) on flow variables view in figs.5a-5d.The primary velocity(u) upsurges with Nb and reduces with Nt in a narrow region adjacent to the wall, while far away from the wall an opposite effect in its behaviour fig.5a.The secondary velocity(w) and temperature(θ) reduce with increasing values of Nb and accelarate with increasing values of thermophoresis (Figs.5b-5c).The nanoconcentration (C) upsurges with Nb and depreciates with increasing Nt in the boundary layer.

Figs.6a-6d illustrate the influence of activation energy(E1) and temperature difference parameter(δ).Higher the activation energy/temperature difference parameter(δ) larger the velocity with E1 and smaller with δ in the flow region(0,0.5) and an opposite behaviour is noticed with them far away from the boundary(fig.6a).The secondary velocity enhance with E1 and reduces with δ in the entire flow region(figs.6b&6d).). The thermal boundary layer becomes thinner with higher values of E1 and δ.This indicates that thickness of the momentum boundary layer, solutal layer grow while they decay with E1&δ. The thermal boundary layer thickness becomes thinner with higher values of E1 and δ fig.6b&6d. The bare minimum of energy needed to stimulate the atoms or molecules involved in a chemical reaction is known as the activation energy. In a chemical reaction, there should be a sizable quantity of atoms for whom the activation energy is below or equal to computational energy. A better coolant in many industrial applications may be thought of as activation energy.

Figs.7a-7d represent u,w,θ and C with surface '*a*' (wavy amplitude) and 'ξ' (coordinates of stream wise). The primary velocity, nanoconcentration rise, while secondary velocity, temperature decay values rising of surface amplitude of the wave(a).An increase in stream wise coordinate (ξ) leads to a reduction in both velocities, θ and upsurge in ϕ at η=0 (fig.7a-7d).

The skin frictions (Cfx, Cfz) η=0 are in table.2 for different variations. The magnitude of the Cf coefficients enhances with increase in Nr. Higher the viscosity parameter(θr) or higher thermal radiation(Rd) or thermal conductivity(β) smaller the Cfx, Cfz at the wall. Higher the strength of the temperature gradient dependent generating heat source larger the magnitude of Cfx, Cfz at the wall. Cfx, Cfz enhance at the wall in degenerating γ case while they experience reduction in generating γ case. Higher the amplitude of the wavy surface '*a*'/stream wise coordinate(ξ) smaller the Cfx at the wall while Cfz diminishes with 'a' and upsurges with 'ξ' at η=0.The skin friction coefficients decay with E1(activation energy) and grow with θ difference parameter(δ) at η=0.The skin friction coefficients enhance with rise in Brownian motion parameter(Nb) and enhance with thermophoresis parameter(Nt) at the wall at η=0.

The Nu (rate of heat transfer) from table.2. The rate of heat transfer at the wall upsurge with upgrade in buoyancy ratio(Nr). The Nu reduces with upsurge in viscosity parameter(θr)/thermal conductivity parameter(β)/ thermal radiation parameter(Rd). The Nu with heat source parameters(Q) illustrations that Nu upgrades with upsurges in temperature gradient heat generating source while an opposite effect is observed with heat absorbing source. Nu upsurges with E1 and reduces with temperature difference parameter(δ) at the wall. An increase in Nb or Nt or Le or n leads to a reduction in the Nu at η=0. The Nu with wavy surface amplitude (*a*) and ξ(stream wise coordinate) displays that Nu upsurges with upgrade in '*ξ*' and 'a' at the wall.

The Sh (rate of mass transfer) in table.2. The Sh at the wall grows with upgrade in buoyancy ratio(Nr)/thermal conductivity(β) and reduces with viscosity parameter(θr). The variation of Sh with temperature gradient heat source parameters(Q) shows that the Sh at the wall(η=0) decays with upsurge in the strength of the temperature gradient heat generating source and increases with heat absorbing source (Q<0). Nu grows with rising values of Brownian motion parameter(Nb) and decays with thermophoresis parameter(Nt) at η=0. An increase in amplitude(a)/stream wise coordinate(ξ), reduces the Sh at η=0. The Sh at the wall enhances in degenerating chemical reaction case and reduces in generating case. The sh at η=0 reduces with activation energy parameter(E1) and enhances with temperature difference parameter(δ) at η=0.

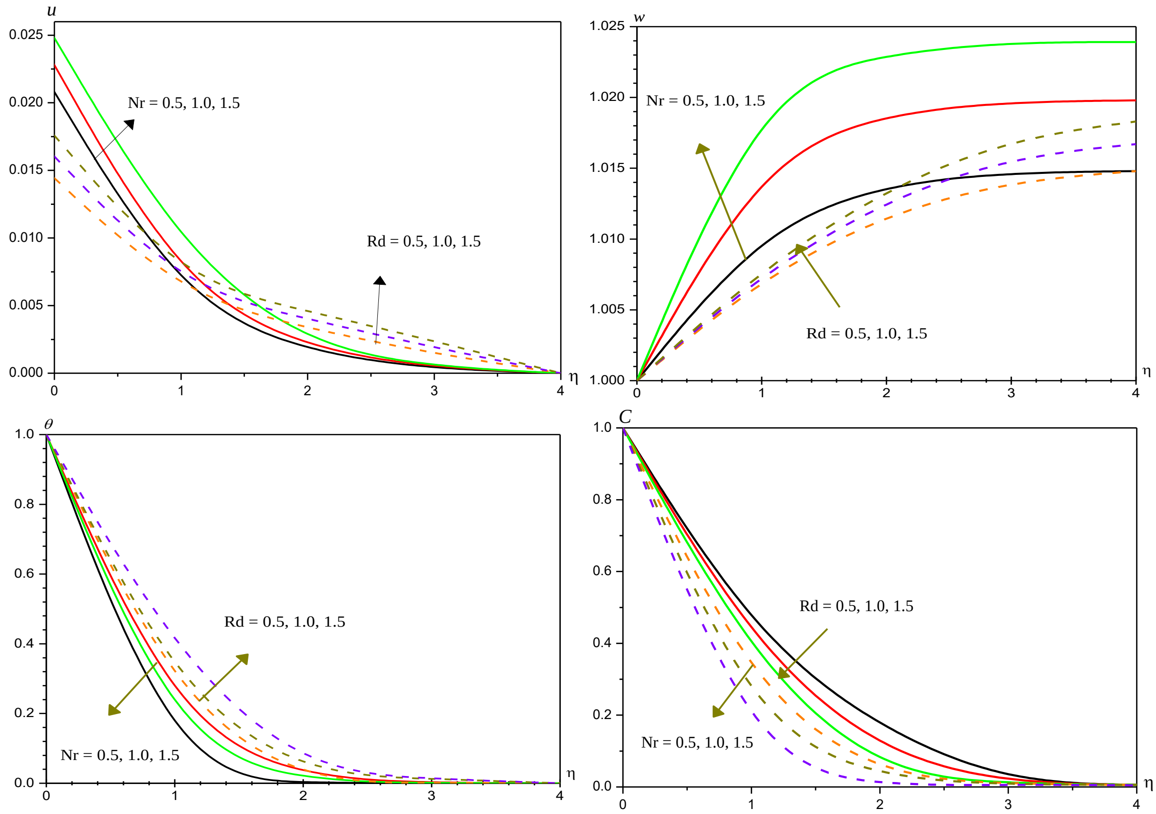
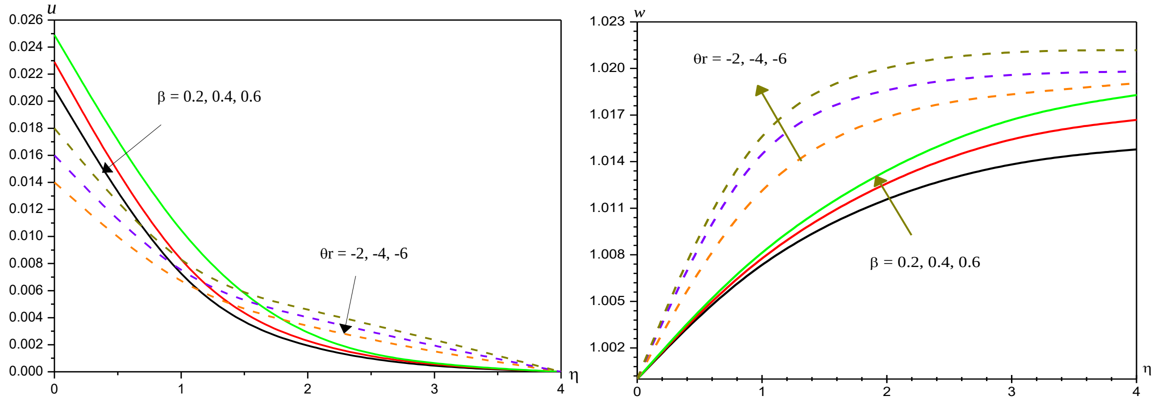


Fig.2 : Variation of [a]axial velocity(u), [b]secondary velocity(w), [c]temperature (θ), [d]nanoconcentration(C) with Nr and Rd θr=-2, Nb=0.1,Nt=0.1,Q=0.5,E1=0.1,δ=0.2, β =0.2



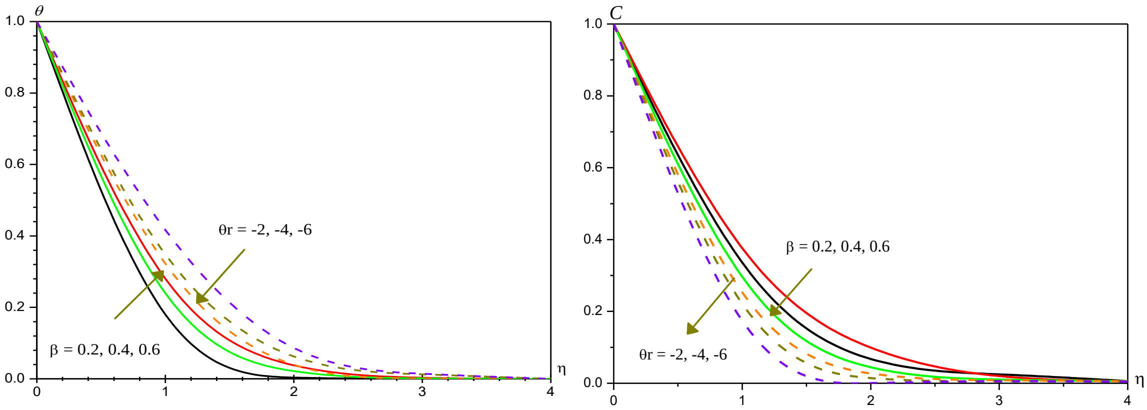


Fig.3 : Variation of [a]axial velocity(u), [b]secondary velocity(w), [c]temperature (θ), [d]nanoconcentration(C) with β and θr Nr=0.5,Rd=0.5, Nb=0.1,Nt=0.1,Q=0.5,E1=0.1,δ=0.2

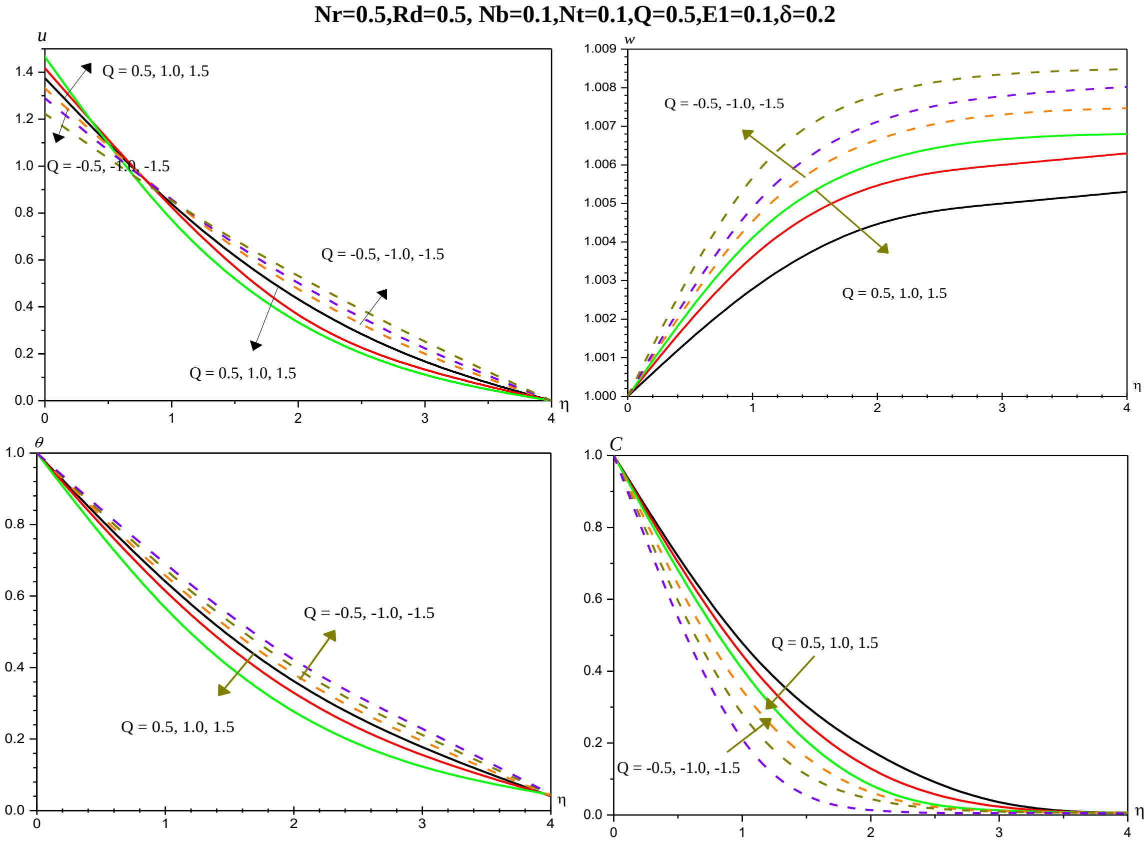
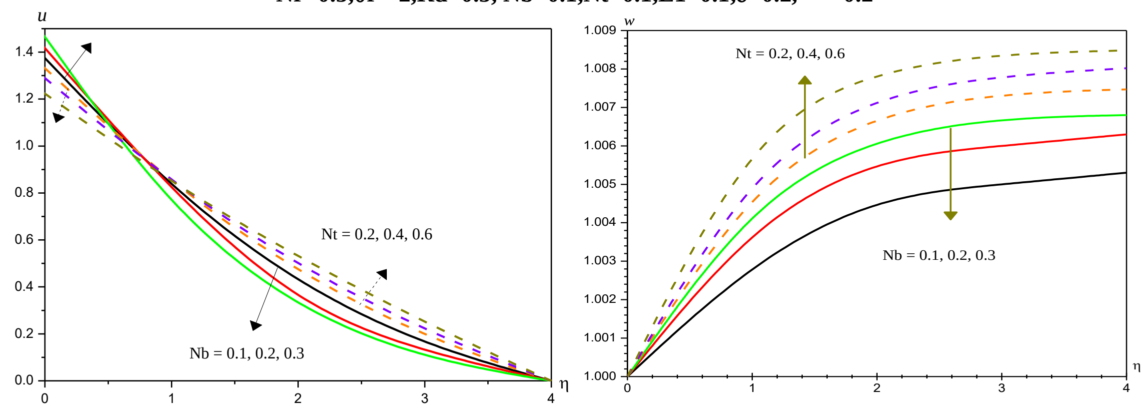


Fig.4 : Variation of [a]axial velocity(u), [b]secondary velocity(w), [c]temperature (θ), [d]nanoconcentration(C) with Q Nr=0.5,θr=-2,Rd=0.5, Nb=0.1,Nt=0.1,E1=0.1,δ=0.2, β =0.2



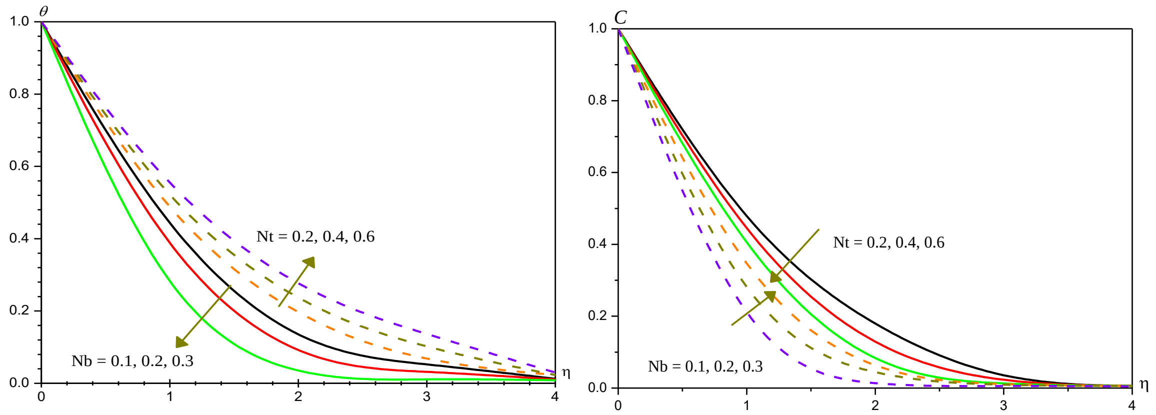


Fig.5 : Variation of [a]axial velocity(u), [b]secondary velocity(w), [c]temperature (θ), [d]nanoconcentration(C) with Nb and Nt

Nr=0.5,θr=-2,Rd=0.5,Q=0.5,E1=0.1,δ=0.2, β =0.2

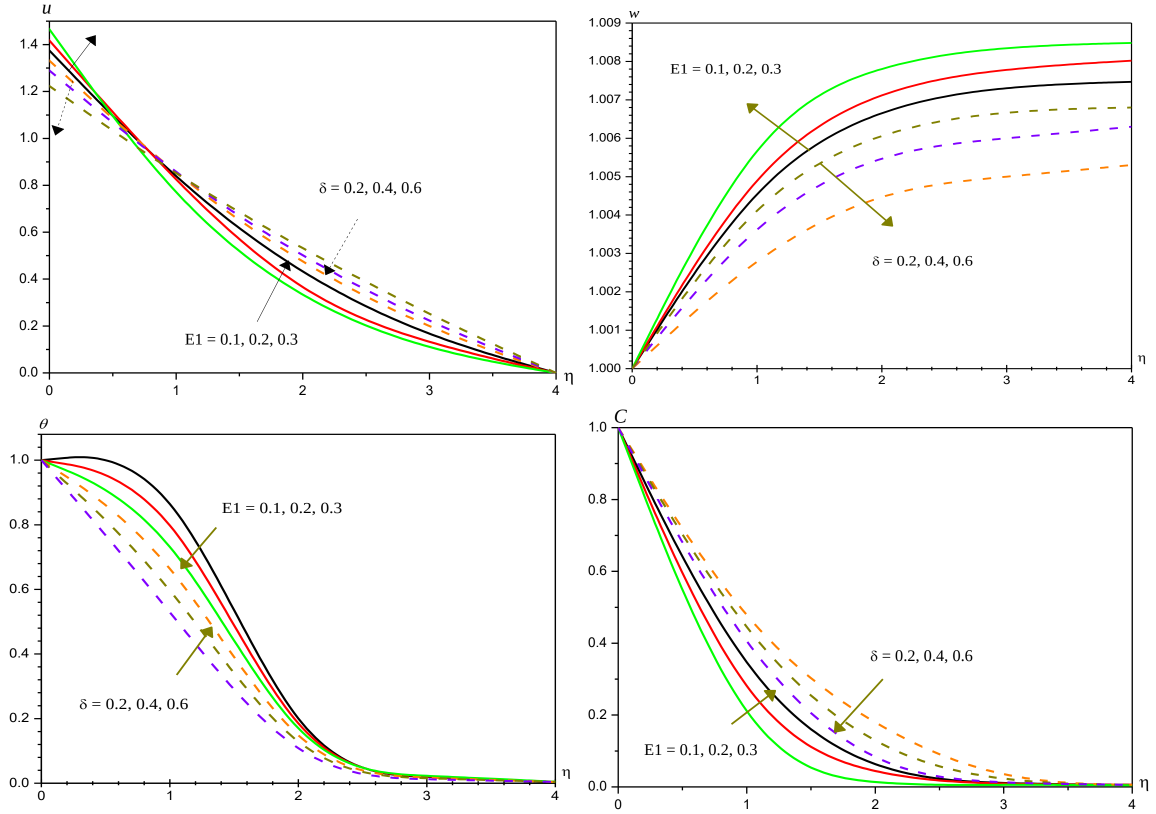
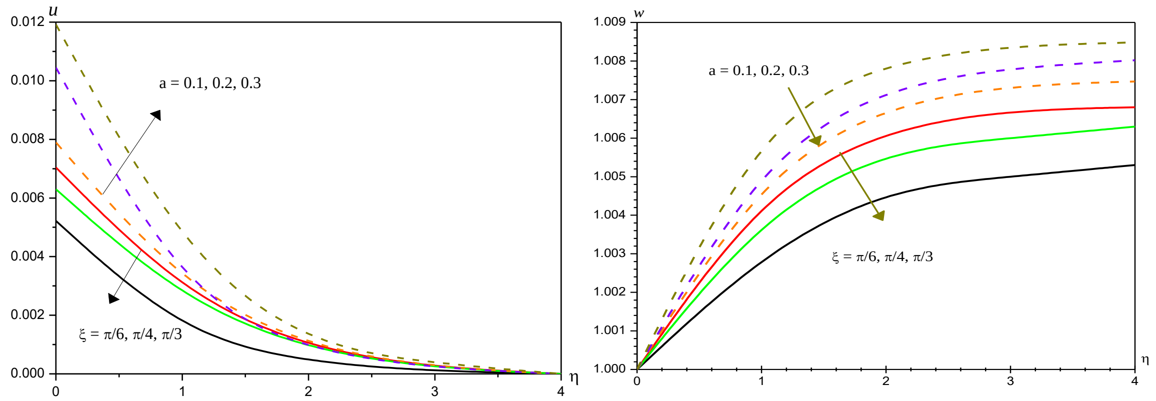


Fig.6 : Variation of [a]axial velocity(u), [b]secondary velocity(w), [c]temperature (θ), [d]nanoconcentration(C) with E1 and δ

Nr=0.5,θr=-2, Rd=0.5,Nb=0.1,Nt=0.1,Q=0.5, β =0.2



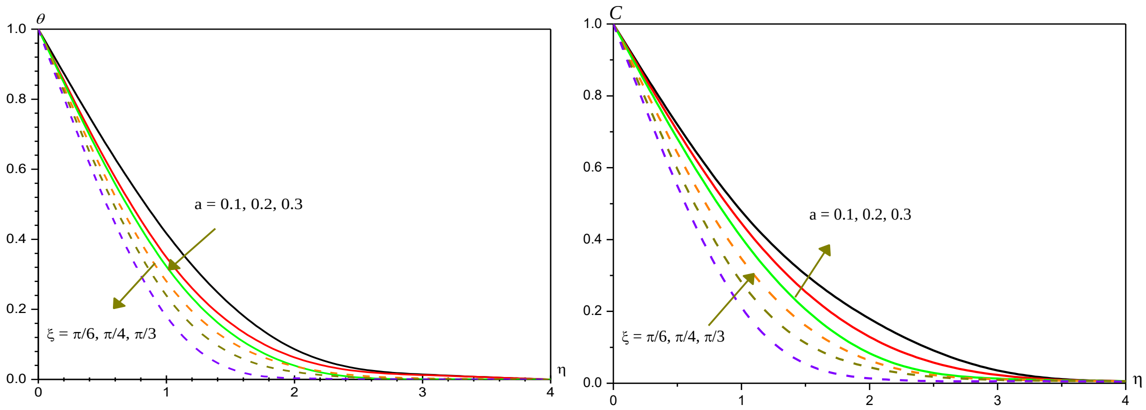


Fig.7 : Variation of [a] axial velocity(u), [b] secondary velocity(w), [c] Temperature(θ), [d] Nanoconcentration (C) with a & ξ β=0.5,θr=-2,Nr=0.5, Rd=0.5, Nb=0.2.Nt=0.2,Q=0.5, E1=0.1, δ=0.2

Table – 2: Skin Friction (τ_x, τ_z), Nusslet number (Nu) and Sherwood Number (Sh) at η = 0

Parameter		τx(0)	τz(0)	Nu(0)	Sh(0)		Parameter		τx(0)	τz(0)	Nu(0)	Sh(0)
Nr	0.5	-0.700481	1.40348	0.551003	0.322459		Nb	0.1	-0.700481	1.40348	0.551003	0.322459
	1	-0.822257	1.64805	0.568671	0.359753			0.2	-0.786314	1.42272	0.525894	0.427408
	1.5	-1.224723	1.89183	0.570565	0.686494			0.3	-0.811455	1.43254	0.501472	0.517861
Rd	0.5	-0.682757	1.39408	0.515157	0.352227		Nt	0.1	-0.550065	1.37676	0.548333	0.548333
	1.5	-0.670598	1.38652	0.490973	0.371902			0.2	-0.258115	1.32959	0.542074	0.542074
	5	-0.643886	1.36687	0.439023	0.413028			0.3	-0.108997	1.29319	0.535291	0.535291
β	0.2	-0.731056	1.40475	0.617523	0.261577		Q	0.5	-0.627556	1.38271	0.399013	0.454821
	0.4	-0.721365	1.40648	0.596324	0.281094			1.0	-0.651161	1.39098	0.447435	0.413348
	0.6	-0.772286	1.43407	0.568755	0.312307			1.5	-0.849645	1.43336	0.543651	0.314257
θr	-2	-0.755437	1.39778	0.548947	0.317197			-0.5	-0.540358	1.33795	0.227461	0.595615
	-4	-0.705778	1.38747	0.539515	0.319138			-1.0	-0.481557	1.29561	0.11856	0.679654
	-6	-0.699573	1.39362	0.550205	0.310729			-1.5	-0.404801	1.22819	-0.01574	0.777616
E1	0.1	-0.700481	1.40348	0.551003	0.322459		a	0.1	-0.038751	0.02091	0.893676	1.028835
	0.2	-0.690986	1.40234	0.551431	0.304023			0.2	-0.035865	0.02009	0.887975	1.011622
	0.3	-0.537073	1.39222	0.566158	0.289988			0.3	-0.030846	0.01664	0.892284	1.009514
δ	0.2	-0.707737	1.40382	0.550736	0.336393		ξ	π/6	-0.093577	0.0911	0.889725	1.027845
	0.3	-0.714296	1.40412	0.550496	0.348985			π/4	-0.093246	0.0912	0.890568	1.027844
	0.4	-0.720814	1.40442	0.550258	0.361501			π/3	-0.092917	0.09211	0.891426	1.027823

5. CONCLUSIONS

Utilizing the Runge-Kutta shooting method, the overall consequence of Brownian motion, thermophoresis, activation energy, and temperature on variables of flow are investigated. The effect of the physical parameters on the flow variables is presented graphically.

1. The buoyancy ratio(Nr)/thermal radiation(Rd)has an increasing influence on the velocities. The temperature and nanoconcentration reduce with increasing Nr.
2. Increasing viscosity leads to a decay in *u*, θ and ϕ while *w* upsurges.
3. Increase in thermal conductivity(β) upsurges temperature and diminishes nanoconcentration.
4. Velocities, nanoconcentration upsurge, temperature decays with activation energy (E1) while an opposite effect is noticed with temperature difference parameter(δ)
5. Brownian motion (Nb) reduces velocities, temperature while thermophoresis (Nt) enhances them in the flow region.
6. Increasing surface amplitude (a)/stream wise coordinate(ξ)reduces temperature and enhances nanoconcentration.

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