COMBINED EFFECTS OF STEADY VARIABLE VISCOSITY AND THERMAL CONDUCTIVITY ON ELECTRO-OSMOTIC AND MAGNETO-HYDRODYNAMIC FLOWS IN A REACTIVE FLUID

by

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ABSTRACT

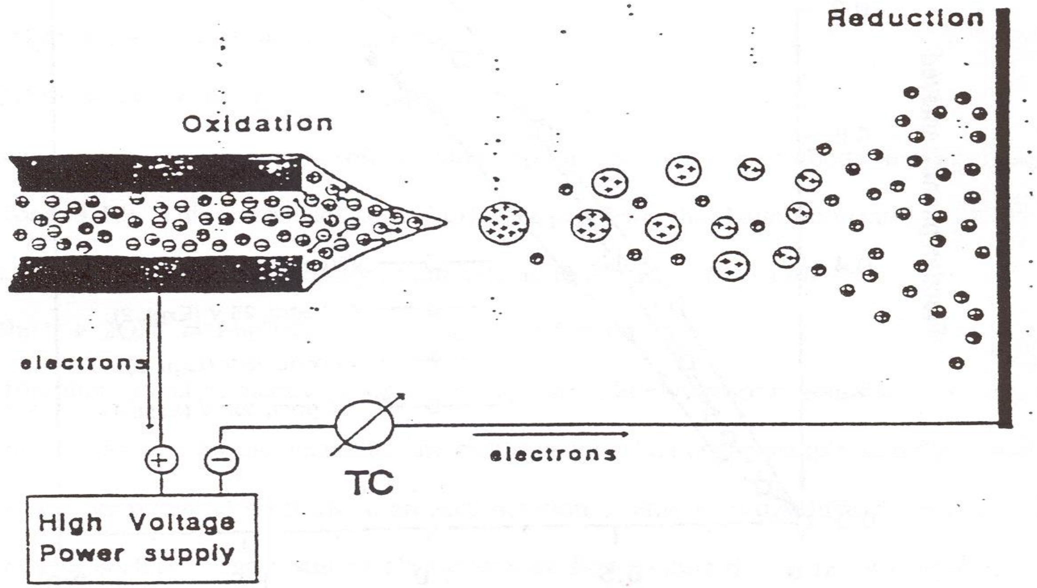
Combined effects of steady electro-osmotic flow (EOF) and magneto-hydrodynamics (MHD) with variable viscosity and thermal conductivity of the reactive fluid flow is assumed to vary exponentially with temperature was investigated. The dimensionless variables was used to dimensionalized the governing equations of the flow using suitable physical parameter. However, steady variable viscosity and thermal conductivity momentum and energy coupled nonlinear equations were solved by Weighted Residual (Collocation) method (**WRCM**) using collocation method to handle the integration.The graphical results was used to study the effects of thermophysical behavior of the model. The influence of electro-osmotic and magnetic field on the fluid flow was significant as Lorentz force retarded the flow while thermal conductivity dampened the fluid flow and viscosity enhanced the temperature field due to the thickness in the thermal boundary layer as the parameter increased.

This paper concluded that variable viscosity and thermal conductivity showed an increase in the velocity and temperature profiles for steady EOF-MHD flow. This information will be useful in chemical processing industry, combustion industry and allied of engineering.

***Keywords**:* Steady flow, Electro-osmotic; Magneto-hydrodynamic; variable viscosity; variable thermal conductivity; reactive fluid; Weighted Residual (Collocation) method (**WRCM**).

- INTRODUCTION
- ELECTRO-OSMOTIC FLOW (EOF)
- MAGNETO-HYRODYNAMIC (MHD)
- FUNDAMENTALS OF MHD
- VARIABLE VISCOSITY
- VARIABLE THERMAL CONDUCTIVITY
- REACTIVE FLUID

Electroosmoticflow used for
Electrosprayionization MassSpecimen



Electron transfer reactions may
Occur if the Electrode potentials
Are large: this can create positive ions which
move into the mass specimen

Figure 1.1: Electro-osmotic flow used for Electro-spray ionization Mass Specimen

Source: Tool vl Electrophoresis and MHD Microsoft PowerPoint.

Aim and Objectives of the Study

The aim of this research is to investigate the combined effects of steady electro-osmotic, magneto-hydrodynamics with variable viscosity and thermal conductivity in reactive fluid flow and to determine the effects of the thermophysical parameters on the fluid flow.

The objectives of this work are to:

(i) modify the previous work by incorporating electro-osmotic and magneto--hydrodynamic.

(ii) non-dimensionalise the governing equations.

(iii) solve the dimensionless equations of the model for a variable viscosity and Thermal conductivity.

(iv) determine the effects of the thermophysical parameters on velocity and temperature profiles for a variable Viscosity and Thermal conductivity.

Limitation of the study

The study is limited to steady Electro-osmotics, magneto-hydrodynamic with Variable viscosity and thermal conductivity in reactive fluid flow.

Scope of the study

The scope of this present presentation is to investigate the significant effects that the new terms had on both velocity profile and temperature profile of a variable Viscosity and thermal conductivity. This new terms are Electro-osmotic, Magneto-hydrodynamic with Variable Viscosity and thermal conductivity in a Reactive fluid flow.

LITERATURE REVIEW

S/N	YEAR	AUTHOR	TOPIC	METHOD	REMARKS
1.	2015	Kumar K. R.V.M.S.S	Examined Dufour Effect on MHD Free Convective Flow of Chemically Reactive and Radiation Absorption Fluid Past a Veritical Permeable Moving Plate with Variable Suction.	Analytical two term harmonic and non harmonic method	Dufour number and Radiation absorption, Heat absorption parameter and magnetic field parameter and time are significant.
2	2015	Moakher,P. Abbasi,M. and Khaki	Investigated new analytical solution of MHD fluid flow of fourth grade fluid through the channel with slip condition via collocation method.	Collocation method	Increasing the magnetic and slip parameter leads to decrease in the velocity profile.
3	2014	Suvankar, G. *et al*	Studies thermally developing combined electro osmotic and pressure-driven flow of Nano fluids in micro channel under the effect of magnetic field.	Semi- Analytical formalism	It helps to determine the operating parameters for optimum performance of micro/nano-scale devices characterized with MHD and electrokinetic effects
4	2014	Christian J.E and Yakubu I.S	Studies radiative MHD flow over a vertical plate with convective boundary condition.	Numerically through Fourth order runge-kutta algorithm with shooting method	Increasing the Eckert number, magnetic parameter leads to increase in the velocity boundary layer thickness and reverses it with increase in the Grashof and prandtl numbers of the fluid flow

5	2009	Andrew J.P. and Todd M.S	Investigated induced charge electro osmosis over controllably contaminated electrodes.	Experimental measurement and theoretical predictions	It demonstrated an unprecedented agreement between theoretical predictions and experimental measurement of ICEO flow over controllably contaminated surfaces.
6	2011	Odutayo Rufia *et al.*	Investigated Temperature dependent Poiseuille fluid flow between parallel plates. .	Shooting method techniques	It shows that smaller value of maximium temperature corresponds to higher value of velocity and both velocity and temperature reaches the maximum at the middle of the channel.
7	2010	Makinde O.D	Examined Numerical study of unsteady hydromagnetic generalized couette flow of a reactive third-grade fluid with asymmetric convective cooling.	Semi-implicit finite difference scheme.	Large prandtl number corresponds to decrease in the strength of the source terms in the temperature profile hence in turn reduce the overall fluid temperature and this in turn decrease fluid viscosity and hence reduced fluid velocity.
8	1997	Hassanien A.	Comment on The effect of variable viscosity on the flow and heat transfer on a continuous stretching surface.	Exact solution and Finite difference method	The wall shear stress agreed with the two method however they agreed too for large values of temperature profile but the result diverge as it decreases which is due to well known fact that in boundary layer theory, large prandtl number corresponds to narrow temperature profiles and small prandtl number correspond to wider temperature profiles
9.	August.2017	Y. SWAPNA et.al	Magneto hydrodynamic (MHD) mixed convective periodic flow through porous medium in a rotating channel	Analytically super imposing of solution	Velocity increases with increasing values of modified Grashof number and Hall parameter while decreases with increasing values of chemical reaction and Schmidt number. Temperature decreases with increasing values of Peclet number Pe.

10.	April 2017	Y. SWAPNA et.al	Chemical reaction, thermal radiation and injection or suction effects on mhd mixed convective oscillatory flow through a porous medium bounded by two vertical porous plates	Approximating of Cogley et.al but by pressure gradient oscillating periodically	The findings shows that velocity decreases with increasing values of chemical reaction parameter, Hartmann number and Schmidt number. Temperature decreases with increasing values of Prandtl number Pr.
11.	July2017	N. Sandeep et. al.	Numerical exploration of magnetohydrodynamic nanofluid flow suspended with magnetite nanoparticles	Mathematical model, which deals with the flow of Jeffrey and Oldroyd-B	The momentum and thermal boundary layers of the Jeffrey nanofluid are highly affected by the Lorentz force. Therefore, the Lorentz force effectively controls the momentum boundary layer of the Jeffrey nanofluid. The study is very useful for designing the heat exchanger equipments and metallurgical processes

Old Model (Rufai, 2011)

Rufai *et.al*, (2011) investigated an incompressible viscous fluid; The equations governing the motion of the fluid are momentum equation and energy equation given as follows

$$\rho\left(\frac{\partial u}{\partial t} + V_o \frac{\partial u}{\partial y}\right) = \frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right) - \frac{\partial p}{\partial x} \tag{1}$$

$$\rho c_p\left(\frac{\partial T}{\partial t} + V_o \frac{\partial T}{\partial y}\right) = \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + Q\exp\left(\frac{-E}{RT}\right) \tag{2}$$

Where the boundary and initial conditions of the flow are

$$u(y,0)=0,\ T(y,0)=T_0$$

$$u(-h,t)=0,\ u(h,t)=0 \tag{3}$$

$$T(-h,t)=T_0,\ T(h,t)=T_0$$

A temperature dependent viscosity is assume as $\mu = \mu_0 \exp\alpha(T-T_0)$

Hence the new governing equations are as follows:

New Governing Equations

The new governing equation of the flow are Momentum, Energy and Electrical potential with incorporation of Electroosmotic and MHD were given as follows:

$$\rho\left(\frac{\partial u}{\partial t} + V_o \frac{\partial u}{\partial y}\right) = \frac{\partial}{\partial y}\left(\mu \frac{\partial u}{\partial y}\right) + E_x \rho_e - \frac{\partial p}{\partial x} - \beta_0^2 \sigma u \qquad (4)$$

$$\rho c_p\left(\frac{\partial T}{\partial t} + V_o \frac{\partial T}{\partial y}\right) = \frac{\partial}{\partial y}\left(k \frac{\partial T}{\partial y}\right) + \mu\left(\frac{\partial u}{\partial y}\right)^2 + \beta_0^2 u^2 + QC_0 A \exp\left(\frac{-E}{RT}\right) \qquad (5)$$

$$\frac{d^2\psi}{dy^2} = \frac{\rho_e}{B} \qquad (6)$$

The boundary and initial conditions of the flow are:

$$u(y,0) = 0, \ T(y,0) = T_0$$

$$u(-h,t) = 0, \ u(h,t) = 0 \qquad (7)$$

$$T(-h,t) = T_0, \ T(h,t) = T_0$$

a temperature dependent viscosity is assume as $\mu = \mu_0 \exp \alpha (T - T_0)$

$$\frac{d^2\psi}{d^2 y}(0) = 0, \ \psi(1) = \varsigma$$

Where,

ρ is the density

μ is the viscosity

C_p is heat capacity with constant pressure

UV_o are velocity components along x and y axis respectively

T is the temperature

P is pressure

K is the thermal conductivity

x is the co-ordinate in the direction of flow

E is the activation energy

R is the universal gas constant

Q is heat released per unit mass during reactions

σis the permittivity of electric field

ψ is the EDL electrostatic potential

ρ_e isthe net EDL charge density

ε is the dielectric constant or the permittivity of fluid

β_o is the magnetic field

C_O is the constant pressure gradient

E_x is the Electrical field

A is the rate of heat reaction.

Non Dimensionaliasation of the New Governing Equations

To solve the equations (4) – (7) the following non – dimensionless variable were introduced according to .

$$\theta = \frac{(T - T_0)E}{RT_0^{\,2}} \text{ such that } T - T_0 = \frac{RT_0^{\,2}\theta}{E} \qquad (8)$$

$$\phi = \frac{u}{\nu_0} \Rightarrow u = \phi\nu_0, \quad \bar{y} = \frac{y}{h} \Rightarrow y = \bar{y}h, \quad \bar{t} = \frac{t}{t_0} \Rightarrow t = \bar{t}t_0$$

Let $\mu = \mu_0 \exp\alpha(T - T_0), \rho_e = -2\left[z\ell\,\eta_0 \sinh\left(\frac{z\ell\varphi}{k_b\theta}\right)\right]$

For $\theta < 1$ i. e $\sin\ \theta = \theta$ (9)

Sinh $\theta = \theta$ so that: $\rho_e = \dfrac{-2z^2\ell^2\eta_0\varphi}{k_b\theta}$

Where t_0, μ_0 are references time and viscosity respectively.

Substituting (8)-(9) into (4)-(7),result into the following equations:

$$\frac{\partial\phi}{\partial\overline{t}}+\frac{\partial\phi}{\partial\overline{y}}=\gamma\frac{\partial}{\partial\overline{y}}\left(\exp\lambda\theta\frac{\partial\phi}{\partial\overline{y}}\right)+N\psi+P-L\phi \tag{10}$$

$$\frac{\partial\theta}{\partial\overline{t}}+a\frac{\partial\theta}{\partial\overline{y}}=d\exp\alpha\left(T-T_0\right)\frac{\partial}{\partial\overline{y}}\left(\frac{\partial\theta}{\partial\overline{y}}\right)+g\exp\alpha\left(T-T_0\right)\left(\frac{\partial\phi}{\partial\overline{y}}\right)^2+J\phi^2+F\exp\left(\frac{\theta}{1+\varepsilon\theta}\right) \tag{11}$$

$$\frac{d^2\psi}{dy^2}=\frac{2z^2\ell^2\eta_0\varphi}{Bk_b\theta} \tag{12}$$

$$where\,\gamma=\frac{t_0\mu_0}{\rho h^2},\lambda=\frac{\alpha RT_0^{\ 2}}{E},\psi=\frac{-2z^2\ell^2\eta_0\varphi}{k_0\theta},P=-\frac{t_0}{\rho\nu_0}\frac{\partial\rho}{\partial x},N=\frac{t_0E_x}{\nu_0\rho},L=-\frac{\beta_0^{\ 2}\sigma t_0}{\rho}$$

$$a=\frac{\nu_0t_0}{h},d=\frac{Et_0k_0}{\rho c_p h^2},g=\frac{Et_0\mu_0\nu_0^{\ 2}}{\rho c_p h^2RT_0^{\ 2}},J=\frac{\beta_0^2\nu_0^{\ 2}Et_0}{\rho c_pRT_0^{\ 2}},F=\frac{QC_0AEt_0}{\rho c_pRT_0^{\ 2}}\exp\left(\frac{-E}{RT_0}\right)$$

$K=z\ell\sqrt{\dfrac{2\eta_0}{Bk_b\theta}}$ and K is the Debye Huckel parameter and $\dfrac{1}{K}$ is Debyecharacteristics thickness of electric double layer (EDL).

The initial and boundary conditions are respectively:

$$u(y,o)=0, \text{ and } \theta(y,o)=0,$$

$$u(-1,t)=0,\ u(1,t)=0, \text{ and } \theta(-1,t)=0,\ \theta(1,t)=0 \qquad (13)$$

$$\frac{d^2\psi}{dy^2}(0)=0,\ \psi(1)=\varsigma$$

Solution of Electrical Potential Equation

Solving equation (12) and Using the boundary condition resulted into:

$$\psi(y)=\frac{\varsigma\cosh ky}{\cosh k} \qquad (15)$$

Weighted Residual (Collocation) method (WRCM)

In this method the weight functions are chosen to be Dirac delta functions

$$W_m(x) = \delta(x - x_m) \qquad (3.46)$$

such that the error is zero at the chosen nodes x_m. The Weighted Residual (Collocation) method was use to solve the steady state using collocation method to handle the integration..These are set of n-order linear equations which must be solve to obtain all the a_j *and* b_j coefficients in the assumed solution or trial solution.

Steady State Solution for Velocity and Temperature Profiles

The flow is independent of time hence:

Substituting (14) into equation (10) and simplifying, result into:

$$\frac{du}{dy} = \gamma \frac{d}{dy}\left(\exp \lambda\theta \frac{du}{dy} \right) + N\psi + P - Lu \qquad (16)$$

simplifying (16) *we have*;

$$\frac{du}{dy} = \gamma \exp \lambda\theta \frac{d^2u}{dy^2} + \gamma \frac{d(\exp \lambda\theta)}{dy} \frac{du}{dy} + N\psi + P - Lu \qquad (17)$$

Let $u(y) = y^5 a_5 + y^4 a_4 + y^3 a_3 + y^2 a_2 + y^1 a_1 + y^0 a_0$

$$\frac{du}{dy} = 5y^4 a_5 + 4y^3 a_4 + 3y^2 a_3 + 2ya_2 + a_1 \qquad (18)$$

$$\frac{d^2u}{dy^2} = 20y^3 a_5 + 12y^2 a_4 + 6ya_3 + 2a_2$$

similarly

Substituting $a=1$, $\varepsilon << 1$ and linearizing the exponential activation energy term (i.e.

$e^{\theta}=1+\theta$), neglecting the higher terms and putting this into equation (11) resulted to:

$$\frac{d\theta}{dy} = d\,\frac{d}{dy}\left(\exp\lambda\theta\frac{d\theta}{dy}\right) + g\left[\frac{du}{dy}\right]^2 + Ju^2 + f\,(1+\theta) \qquad (20)$$

let

$$\theta(y) = b_5 y^5 + b_4 y^4 + b_3 y^3 + b_2 y^2 + b_1 y^1 + b_0 y^0$$

$$\frac{d\theta}{dy} = 5b_5 y^4 + 4b_4 y^3 + 3b_3 y^2 + 2b_2 y^1 \qquad (21)$$

$$\frac{d^2\theta}{dy^2} = 20b_5 y^3 + 12b_4 y^2 + 6b_2 y^1 + 2b_2$$

The residual are given below as;

$$
\begin{aligned}
ur = {} & 5a_5y^4 + 4a_4y^3 + 3a_3y^2 + 2a_2y + a_1 - G\lambda e^{\lambda(b_5y^5 + b_4y^4 + b_3y^3 + b_2y^2 + b_1y^1 + b_0y^0)} \\
& (5a_5y^4 + 4a_4y^3 + 3a_3y^2 + 2a_2y + a_1) \\
& - G\lambda e^{\lambda(b_5y^5 + b_4y^4 + b_3y^3 + b_2y^2 + b_1y^1 + b_0y^0)}(20a_5y^3 + 12a_4y^2 + 6a_3y + 2a_2) \\
& - \frac{NZ\cosh(ky)}{\cosh(k)} - p + L(a_5y^5 + a_4y^4 + a_3y^3 + a_2y^2 + a_1y + a_0y^0)
\end{aligned} \tag{22}
$$

$$
\begin{aligned}
\theta r = {} & 5a_5y^4 + 4a_4y^3 + 3a_3y^2 + 2a_2y + a_1 \\
& - \delta\lambda e^{\lambda(b_5y^5 + b_4y^4 + b_3y^3 + b_2y^2 + b_1y + b_0y^0)}(5b_5y^4 + 4b_4y^3 + 3b_3y^2 + 2b_2y^1 + b_1) \\
& - \delta e^{\lambda(b_5y^5 + b_4y^4 + b_3y^3 + b_2y^2 + b_1y + b_0y^0)}(20b_5y^3 + 12b_4y^2 + 6b_3y + 2b_2) \\
& g(5a_5y^4 + 4a_4y^3 + 3a_3y^2 + 2a_2y + a_1)^2 - J(a_5y^5 + a_4y^4 + a_3y^3 + a_2y^2 \\
& + ya_1 + a_0)^2 - F(a_5y^5 + a_4y^4 + a_3y^3 + a_2y^2 + ya_1 + 1)
\end{aligned} \tag{23}
$$

Substituting the initial conditions into the assumed solutions result into the equations below;

$$eq1 = a_0 - a_1 + a_2 + a_4 - a_5$$

$$eq2 = a_0 + a_1 + a_2 + a_4 + a_5$$

$$eq3 = b_0 - b_1 + b_2 + b_4 - b_5$$

$$eq4 = b_0 + b_1 + b_2 + b_4 + b_5$$

Similarly collocating between the boundary conditions and substituting the values of the various

parameter(Z:=1:F:=0.1:N:=0.1:lambda:=1:p:=1:L:=1:g:=1:delta:=1:k:=2:J:=0.1:G:=1:) result into equations (v) to (XII) .

Equating (I) to (XII) to zero and Solving the equations result to;

$$\{a_0 = 0.3449863200, a_1 = -0.006457611095, a_2 = -0.3110467470, a_3 = 0.007680423592, a_4 = -0.03393957301, a_5 = -0.001222812497, b_0 = 0.08830913625, b_1 = -0.001603406266, b_2 = -0.05379214633, b_3 = 0.0003815605281, b_4 = -0.03451698992, b_5 = 0.001221845738\}$$

$$u(y) = -0.001222812497y^5 - 0.03393957301y^4 + 0.007680423592y^3 - 0.3110467470y^2 - 0.006457611095y + 0.3449863200 \qquad for\ P = 1$$

repeating the same process for the various parameter except for P=1.3 and P=1.6 we have

respectively

$\{a_0 = 0.4382113601, a_1 = -0.01040840718, a_2 = -0.3961495033, a_3 = 0.01209071852, a_4 = -0.04206185680, a_5 = -0.001682311342, b_0 = 0.1106978034, b_1 = -0.002375313789, b_2 = -0.05596956500, b_3 = -0.0003339962896, b_4 = -0.05472823838, b_5 = 0.002709310079\}$

$\{a_0 = 0.5274359163, a_1 = -0.01544222567, a_2 = -0.4774075761, a_3 = 0.01763914678, a_4 = -0.05002834018, a_5 = -0.002196921112, b_0 = 0.1360267697, b_1 = -0.003383250716, b_2 = -0.05833680453, b_3 = -0.001533705001, b_4 = -0.07768996518, b_5 = 0.004916955717\}$

$$u(y) = -0.001682311342y^5 - 0.04206185680y^4 + 0.01209071852y^3 - 0.3961495033y^2 - 0.01040840718y + 0.4382113601 \qquad for\ P = 1.3$$

$$u(y) = -0.002196921112y^5 - 0.05002834018y^4 + 0.01763914678y^3 - 0.4774075761y^2 - 0.01544222567y + 0.5274359163 \qquad for\ P = 1.6$$

We follow the same procedure for all other thermophysical parameters for both the velocity and Temperature profiles

RESULT AND DISCUSSION

Here, the main results of this study are reported in graphical form. The mathematical model of the flow was considered with respect to their thermophysical parameters. The steady state solution for both velocity and temperature profiles was investigated for a variable viscosity and thermal conductivity.

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Results

Results of this study were reported in graphical form using maple software computer package.

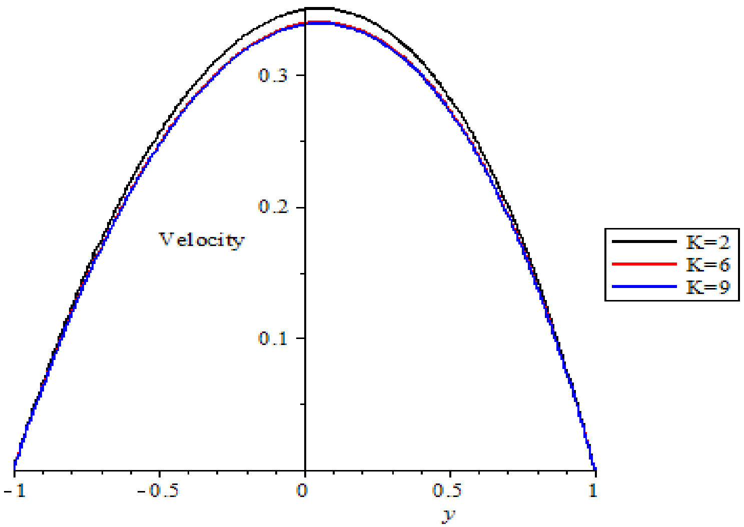

Figure1e: Velociy profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of Electro-kinetic parameter K

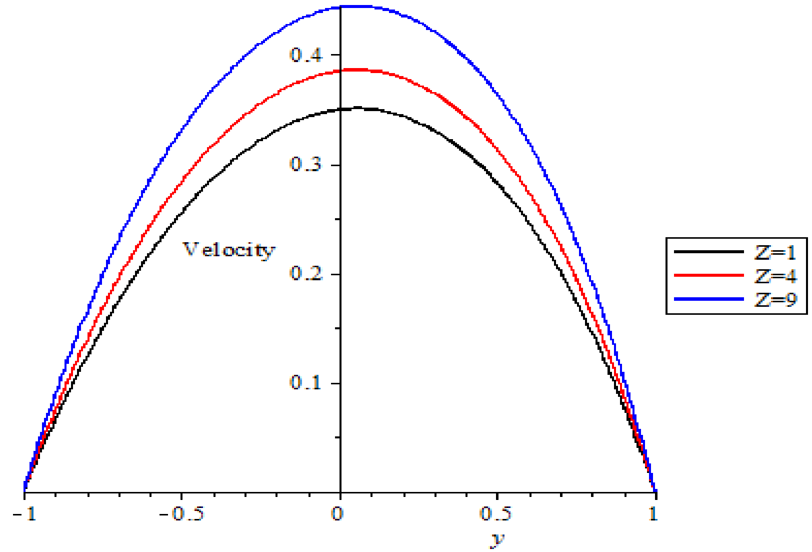

Figure1f: Velociy profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of Specific internal energy parameter Z

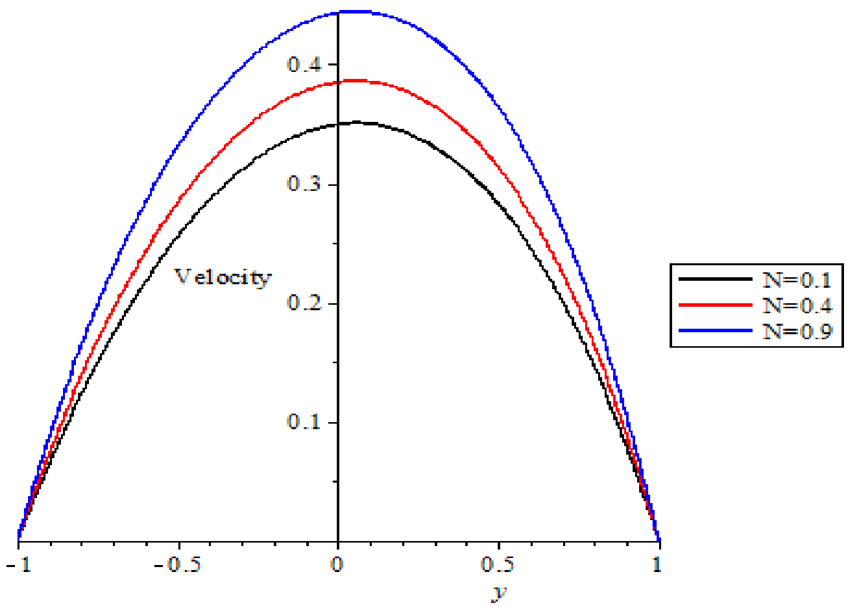

Figure1g: Velociy profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of Electro-Osmotic parameter N

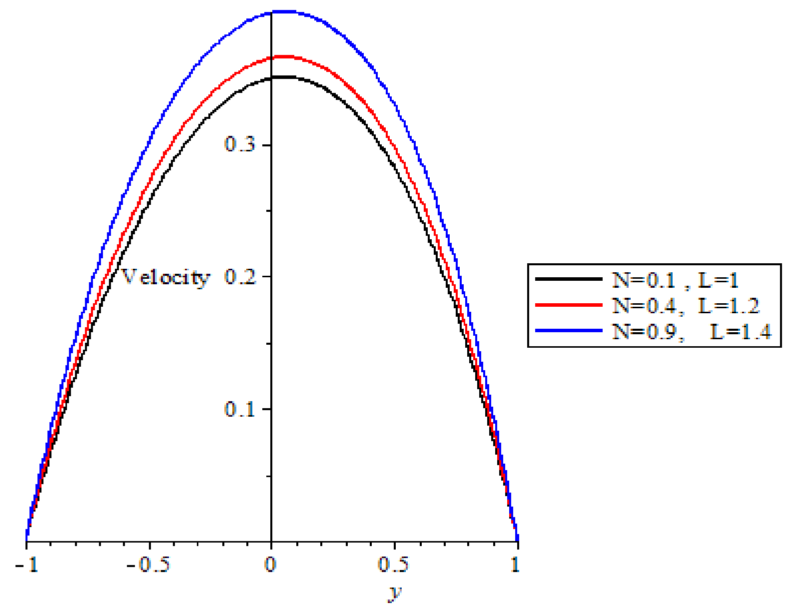

Figure1h: Velociy profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of Combined Electro-osmotic N and Magnetic parameter L

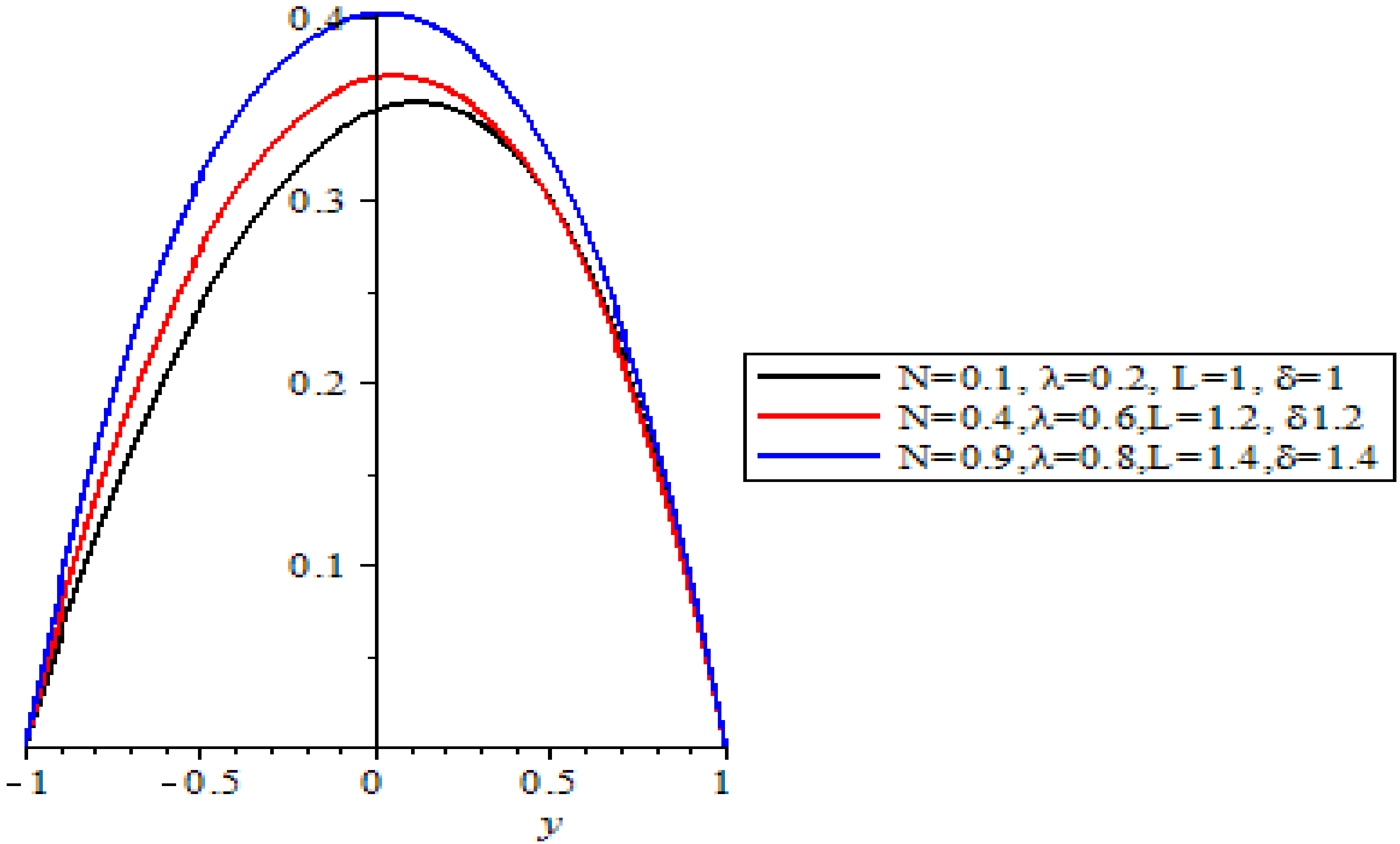

Figure1i: Velociy profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of Combined Electro-Osmotic N and Magnetic L with Vaiable Viscosity λ and Thermal conductivity parameter δ .

Figure 1e reveals velocity profile against y for different electro-kinetic parameter. The graph shows that velocity profile decreases with an increase in electro-kinetic parameter. For electrokinetic is relating to the motion of particles or liquids that results from or produces a difference of electric potential. Therefore, the velocity distribution decreases.

Figure 1f shows velocity profile against y for different specific internal energy parameter. The figure shows that velocity profile increases with increase in specific internal energy parameter due to an increase in the velocity boundary layer.

Figure 1g shows velocity profile for variable viscosity against y for different electro-osmotic parameter N. The figure shows that velocity profile increases with increases in electro-osmotic parameter as a result of thickness in the momentum boundary layer which increases the amount of heat within the system and thereby enhances the flow velocity field.

Figure 1h represent the combined effect of magnetic field and electro-osmotic parameters on the flow velocity distribution. An increase in the flow is experienced though is not as high when magnetic field is not combined. This is as a result of the Lorentz force that introduce damping into the flow but overturn by electro-osmotic force in the fluid flow.

Figure li portrays variation increase in the combined influence of magnetic field, electro-osmotic ,variable viscosity and thermal conductivity on the fluid flow in the system. From the figure, it is seen that momentum profile increases due to an increase in heat transfer that reduces the flow viscosity and Lorentz force but in turn increases the electro-osmotic and the flow boundary layers.

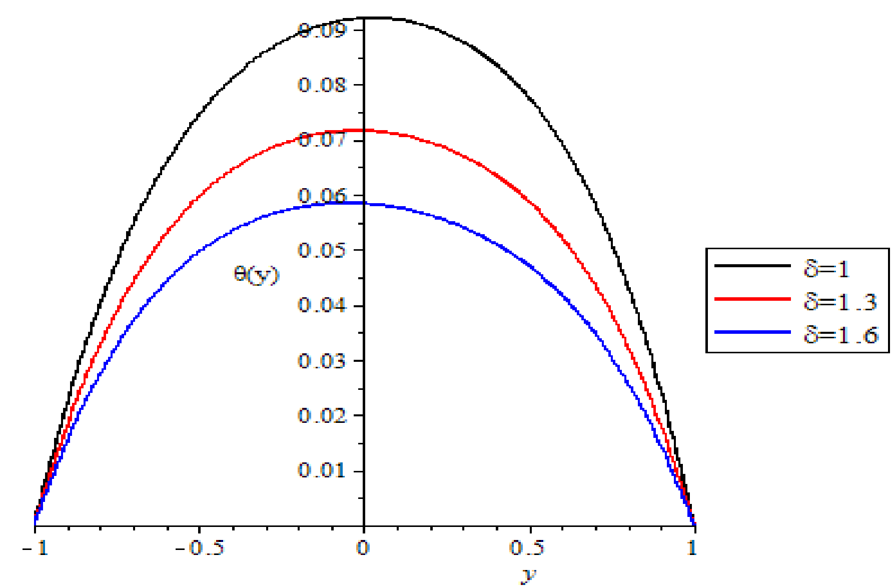

Figure1j: Temperature profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of Varible Thermal Conductivity parameter δ

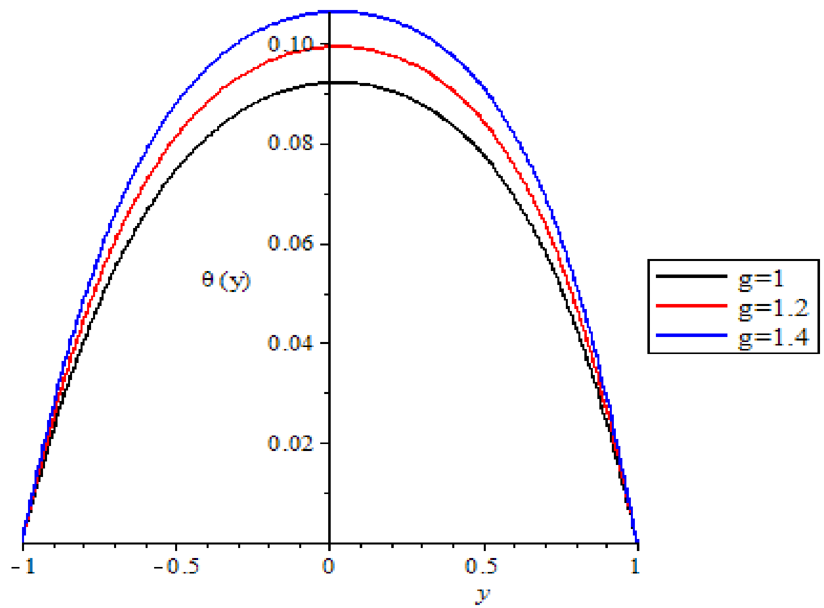

Figure1k: Temperature profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of Viscosity

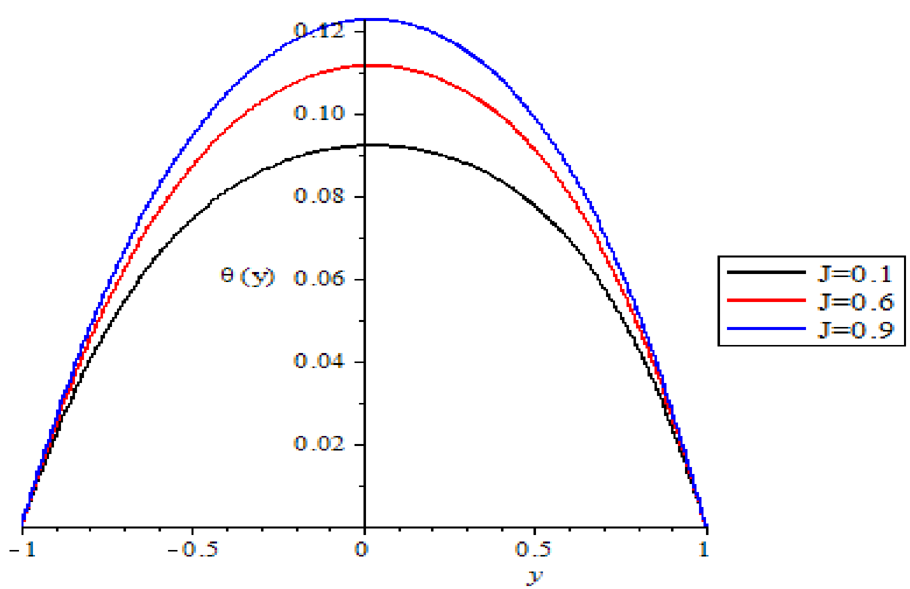

Figure1L: Temperature profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of Magnetic parameter J

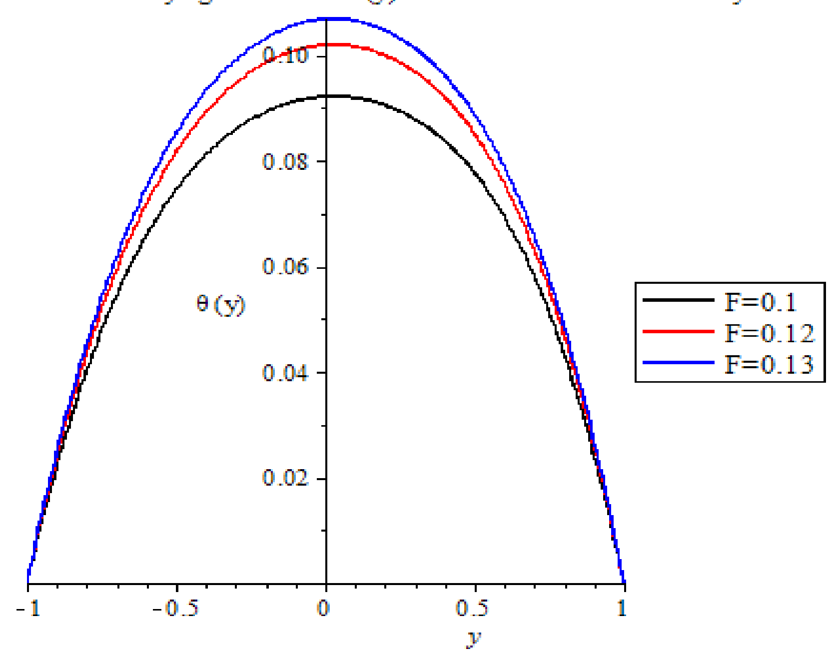

Figure 1m: Temperature profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of Reactive parameter F

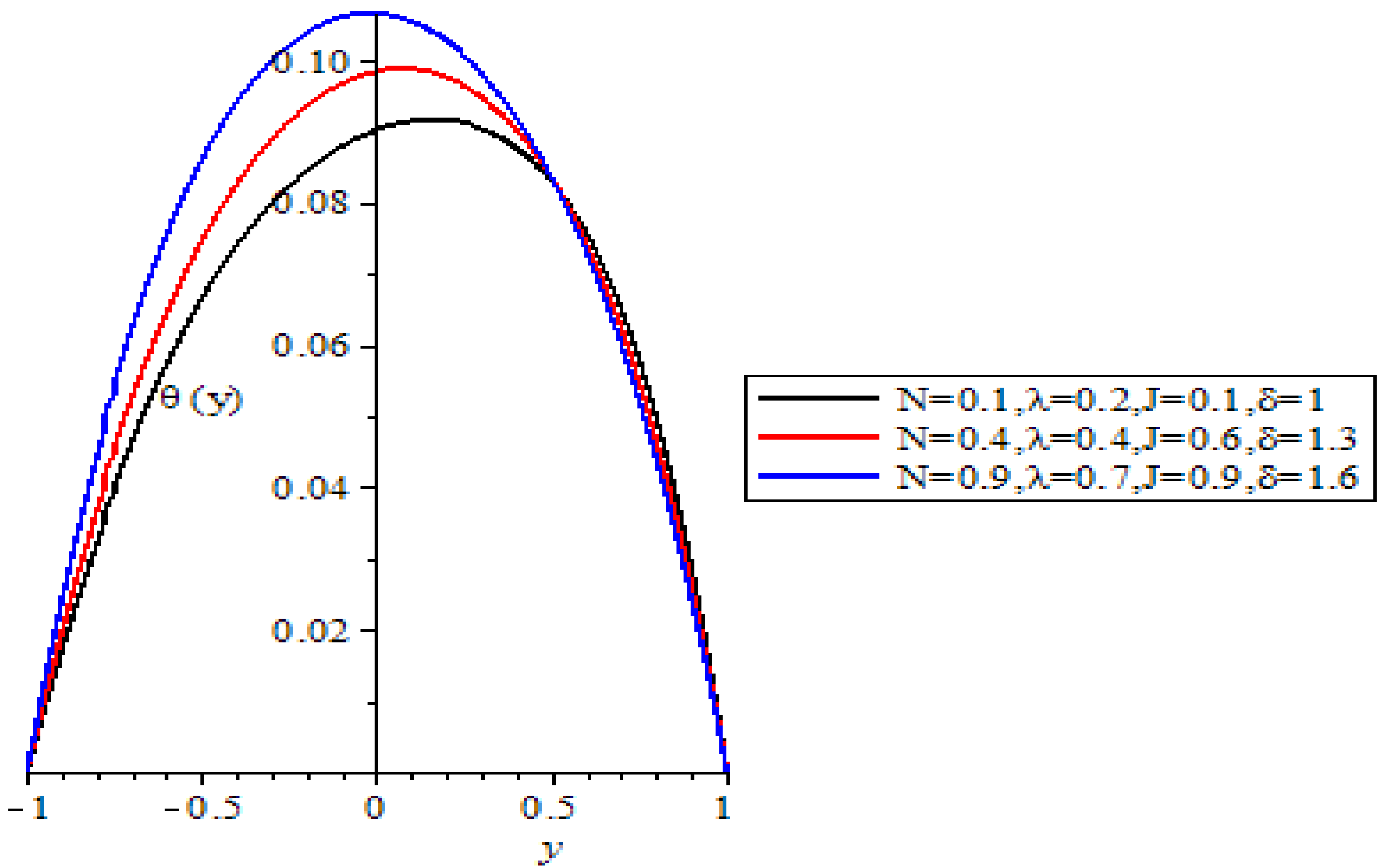

Figure1n: Temperature profile for Variable Viscosity and Thermal conductivity against distance (y) at different values of the combined Electro-Osmotic N and magnetic parameter L with Varible Viscosity λ and Thermal Conductivity parameter δ

Case B: Steady state solution for Temperature Profile

Figure 1k depicts variation in values of thermal conductivity for which the temperature profile retards due to decrease in the thermal boundary layer that causes heat to diffuse out of the system.

Figure 1L shows energy distribution of various viscosity parameter on fluid flow. It is revealed that the temperature profile increases as viscosity parameter rises because more heat is released into the system as a result of friction that occur at the boundary layer.

Effect of magnetic field on temperature profile is revealed in figure 1m. It is observed that an increase in the magnetic field enhances the heat transfer of the flow as a result of thermal boundary layer that reduces the amount of heat that evolve out of the system.

The response of energy profile to a rise in an exothermic chemical reaction is illustrated in figure 1n. It is noticed that an increase in the reactive parameter magnifies heat transfer within the system due to the energy that is added to the system from the reactive flow that cause the fluid particle to collide at a higher rate thereby enhances the Temperature distribution of the fluid flow.

The combined effect of electro-osmotic parameter, magnetic field, variable viscosity and thermal conductivity on energy profile is showed in figure 1o. It is seen that temperature distribution increases from the lower boundary layer through to the symmetry and there after decreases towards the upper boundary layer of the fluid flow. This is because of higher heat transfer from thermal conductivity towards the upper boundary layer, which overturn the electro-osmotic parameter and magnetic field in the flow .

Conclusion

The combined effect of steady electro-osmotic, magneto hydrodynamic with variable viscosity and thermal conductivity shows a direct relationship with velocity profile and temperature profile of a reactive fluid flow. The influence of electro-osmotic and magnetic field on the flow fluid is significant as Lorentz force retards the flow while thermal conductivity damps the fluid flow but viscosity enhances the temperature field due to the thickness in thermal boundary layer as the parameter increases.

Reference

Akgul, M.B, M. Pakdemirlib (2008) Analytic and Numerical Solution of Electro-Osmotically driven flow of a third grade fluid between micro-parallel plates, international journal of non-linear mechanics ; 43, 985-992

Andrew J.P. and Todd M.S. Dec. (2009), Induced Charge Electro-osmosis over Controllably Contaminated Electrodes Department of Chemical Engineering, University of California, Santa Barbara, California, USA.

Billingham,(2003) Steady-Static Solutions for strongly exothermic ignition in symmetric geometrics, IMAJ. APPL. Math 2003; 65 283-313

Chandra Reddy P., Raju M. C, Raju G. S. S (2016), Magneto – hydrodynamic convective Double Diffusive Laminar Boundary Layer Flow Past an accelerated Vertical Plate International Journal of Engineering Research in Africa Vol. 20 pp. 80 – 92 Trans Tech Publication, Switzerland.

Christian J.E., Yakubu I.S. and Daniel A. Z. May. (2015) , MHD Thermal Boundary Layer Flow over a Flat Plate with Internal Heat Generation, Viscous Dissipation and Convective Surface Boundary Conditions. International Journal of Emerging Technology and Advanced Engineering 5(5), 335-342.ISSN 2250-2459, ISO 9001:2008 Certified Journal

Dulal Pal, Hiranmoy Mondal May (2013), Effect of temperature –dependent viscosity and variable thermal conductivity on MHD non-Darcy mixed convective diffusion of species over a stretching sheet. Journal of the Egyptian Mathematical Society.Vol. 22. 123-133.

Ehsan Roohi, Shahab Kharazmi and Yaghoub Farjami, May (2009), Application of the Homotopy method for analytical solution of non-Newtonian channels flows Phys.Scr. 79 065009

Escandon, J.P, Santiago, F, and Bautista O. (2013), Temperature distributions in a parallel flat plate microchannel with electro-osmotic and magnetohdyrodynamicmicropumps, proceedings of the 2013 international conference on mechanics, fluids, heat, elasticity and electomagnetic fields.

Etwire, C.J,Seini Y.I June (2014),Radiative MHD flow over a vertical plate with convective boundary condition, American Journal of Applied Mathematicsvol.2,No. 6,2014,pp.214-220.

F. O. Akinpelu and J. O. Ajilore (2017) The Combined Effects of Electro-osmotic and Magneto-hydrodynamic with Viscosity and Thermal Conductivity in Reactive Fluid Flow Asian Research Journal of Mathematics 3(2): 1-11, 2017; Article no.ARJOM.30641

Iseries Arien (1996), A first course in the numerical analysis of Differential Equations, Cambridge University Press, ISBN 978-0-521.

J. O. Ajilore and F. O. Akinpelu (2018) The Combined Effects of Unsteady Electro-osmotic and Magneto-hydrodynamic with Viscosity and Thermal Conductivity in Reactive Fluid Flow International Journal of Engineering Technologies and Management Research, 5(1), 123-134, DOI: 10.5281/zenodo. 1173924.

Kamenetskii, D. A. (1969), Diffusion and Heat Transfer in Chemical Kinetics, second ed. Plenum press, New York

Makinde, O. B., on thermal stability of a reactive third grade fluid in a channel with convertible cooling ther walls, Appl Math. Comp. 2009;213, 170-176

Odutayo, R. Rufai Ademola M. Rabiu, Ismail B. Adefeso, Kazeem O. Sanusi and Sarafa O. Azeez Temperature dependent Poiseuille fluid flow between parallel plates, Canadian, Journal on Sciences and Engineering Mathematics2011; 2(3), 146-152

Suvankar G., Sandip S., Tapan K.H., Manoranjan M.Thermally developing combined electro-osmotic and pressure driven flow of nanofluids in a microchannel under the effect of magnetic field. Chemical Engineering science. 2015;26, 10-12.

White M. F., Viscous fluid flow 2nd Edition (New York: McGraw Hill) 1999

Yihao Zhery, L. G. Alejandro and J. B. Aldor, (2002) comparison of Kinetic Theory hydrodynamics for poiseuille flow, J. of Stat. Phys.;109 (314), 495-505.

Animasaun, I. L.; Prakash, J.; Vijayaragavan, R.; Sandeep, N. Stagnation Flow of Nanofluid Embedded with Dust Particles Over an Inclined Stretching Sheet with Induced Magnetic Field and Suction. Journal of nanofluids. 2017;6 (10), 28-37.

Animasaun, I.L.. Raju, C.S.K and Sandeep, N Unequal diffusivities case of homogeneous–heterogeneous reactions within viscoelastic fluid flow in the presence of induced magnetic-field and nonlinear thermal radiation. Alexandria Engineering Journal, 2016; 55, 1595-1606.

Sandeep,N. Sulochana, C, snd Animasaun, I. L (2016) Stagnation point flow of a Jeffrey nanofluid over a stretching surface with induced magnetic field and chemical reaction. International Journal of Engineering Research in Africa, 20, 93-111