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Influence of Magnetic Induction on Chemically Reacting Radiative Flow over a Vertical Porous Plate

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Abstract: The Objective Of This Paper Is To Analyze Chemically Reacting Radiative MHD Flow Of An Incompressible Viscous Electrically Conducting Fluid Past An Infinite Vertical Porous Plate With Heat And Mass Transfer. The Governing Equations Are Solved By Using The Perturbation Technique. The Analytical Expressions For The Velocity, Temperature, Magnetic Field Induction, Concentration, Skin-Friction Coefficient, Nusselt And Sherwood Numbers Are Obtained And Results Are Explained Graphically. Applications Of This Study Arise In The Thermal Plasma Reactor Modeling, The Electric Magnetic Induction, And The Magneto Hydrodynamic Transport Phenomena In Chromatographic System And The Magnetic Field Control Of Materials Process. It Is Observed That The Rising Values Of The Magnetic Field Parameter And Thermal Grashof Number Decline The Heat Transfer Rate.

Key Words - Chemical Reaction, Heat Transfer MHD, Magnetic Induction, Radiation.

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I. INTRODUCTION

Analytical Solutions To The Problems Of Mixed Convective Flows, Which Arise In Fluids Due To The Interaction Of The Force Of Gravity And The Density Difference Caused By The Simultaneous Diffusion Of The Thermal Energy And Chemical Species, Have Been Presented By Many Authors Due To Their Applications In Geophysics And Engineering. The Problems Of Steady And Unsteady Combined Heat And Mass Transfer By Mixed Convection Along An Infinite And Semi-Infinite Vertical Plate With And Without Chemical Reactions Have Been Studied Extensively By Different Scholars.

In View Of This, Ahmmed Et Al. [1] Presented The Unsteady MHD Free Convection And Mass Transfer Boundary Layer Flow Past A Semi-Infinite Vertical Porous Plate Immersed In A Porous Medium With Heat Source And The Governing Equations Are Solved Analytical By Using Perturbation Technique. Dulal Pal And Babulal Talukdar [2] Analyzed The Combined Effect Of Mixed Convection With Thermal Radiation And Chemical Radiation On MHD Flow Of Viscous And Electrically Conducting Fluid Past A Vertical Permeable Surface Embedded In A Porous Medium. Sandeep And Sugunamma [3] Analyzed The Effects Of Inclined Magnetic Field And Radiation On Free Convective Flow Of Dissipative Fluid Past A Vertical Plate Through Porous Medium In Presence Of Heat Source And The Boundary Layer Equations Are Derived And The Resulting Approximate Nonlinear Ordinary Differential Equations Are Solved Analytically By Using Soundalgekar Proposed Perturbative Technique. The First Order Chemical Reaction Effects On Unsteady Free Convective Flow Of A Viscous Incompressible Flow Past An Infinite Isothermal Vertical Oscillating Plate With Mass Transfer In The Presence Of Aligned Magnetic Field And Heat Generation/Absorption Presented By Sandeep And Sugunamma [4]. Zueco And Ahmed [5] Presented An Exact And Numerical Solution To The Problem Of A Steady Mixed Convective MHD Flow Of An Incompressible Viscous Electrically Conducting Fluid Past An Infinite Vertical Porous Plate With Combined Heat And Mass Transfer. The Effect Of Heat Transfer On Unsteady MHD Oscillatory Flow Of Jeffery Fluid In A Horizontal Channel With Chemical Reaction Has Been Studied By Idowu Et Al. [6]. Sandeep And Sugunamma [7] Analyzed The Effects Of Inclined Magnetic Field And Radiation On Free Convective Flow Of Dissipative Past A Vertical Plate Through Porous Medium In Presence Of Heat Source. Sugunamma Et Al. [8] Analyzed The MHD, Radiation And Chemical Reaction Effects On Unsteady Flow, Heat And Mass Transfer Characteristics In A Viscous, Incompressible And Electrically Conducting Fluid Over A Semi-Infinite Vertical Porous Plate Through Porous Media In Presence Of Inclined Magnetic Field. Ramana Kumari And Krishnamacharya [9] Investigated The Effect Of Slip On Peristaltic Transport Of An Incompressible Newtonian Fluid In A Two-Dimensional Inclined Channel With Wall Effects. Prakash Et Al. [10] Investigated The Effects Of Heat Source And Radiation Absorption On Unsteady Hydro-Magnetic Heat And Mass Transfer Flow Of A Dusty Viscous Incompressible, Electrically Conducting Fluid Between Two Vertical Heated, Porous, Parallel Plates In The Presence Of Chemical Reaction Under The Influence Of A Transverse Applied Magnetic Field.

Combined Effects Of Free Convective Heat And Mass Transfer On The Steady Two-Dimensional, Laminar, Polar Fluid Flow Through A Porous Medium In The Presence Of Internal Heat Generation And Chemical Reaction Of The First Order Studied By Patil And Kulkarni [11]. Sahin Ahmed Et Al. [12] Presented Analytical Solution Of A Magneto Hydrodynamic Steady Mixed Convective Flow Of An Incompressible, Viscous, Newtonian, Electrically-Conducting And Chemically Reacting Fluid Over An Infinite Vertical Porous Plate With Combined Heat And Mass Transfer Is Presented In The Presence Of The Homogeneous Chemical Reaction Of First Order. The Effects Of Chemical Reactions On Unsteady MHD Free Convection And Mass Transfer Flow Of A Viscous, Incompressible, Electrically-Conducting Fluid Past An Infinite Hot Vertical Porous Plate Embedded In Porous Medium. Heat Generation/Absorption And Viscous Dissipation Effects Are Included And The Temperature Of The Plate Is Assumed To Be Span Wise Cosinusoidally Fluctuating With Time And The Governing Equations Are Solved By Perturbation Technique Studied Singh And Rakesh Kumar [13]. Sandeep Et Al. [14] Analyzed The Magneto Hydrodynamic, Radiation And Chemical Reaction Effects On Unsteady Flow, Heat And Mass Transfer Characteristics In A Viscous, In Compressible And Electrically Conduction Fluid Over A Semi-Infinite Vertical Porous Plate Through Porous Media. Hayat Et Al. [15] A Mathematical Model Was Analyzed In Order To Study The Heat And Mass Transfer Characteristic In Mixed Convection Boundary Layer Flow About A Linearly Stretching Vertical Surface In Porous Medium Filled With A Viscoelastic Fluid, By Taking Into Account The Diffusion-Thermo (Dufour) And Thermal-Diffusion (Soret) Effects. Heat And Mass Transfer Effect On Hydro Magnetic Flow Of A Moving Permeable Vertical Surface. An Analysis Was Performed To Study The Momentum, Heat And Mass Transfer Characteristics Of MHD Natural Convection Flow Over A Moving Permeable Surface Presented By Abdelkhalek [16]. Pushpalatha Et Al. [17] Investigated The Unsteady Free Convection Flow Of A Casson Fluid Bounded By A Moving Vertical Flat Plate In A Rotating System With Convective Boundary Conditions And The Governing Equations Of The Flow Have Been Solved Analytically Using Perturbation Technique. Sugunamma Et Al. [18] Investigates The Unsteady Free Convective Flow Through Porous Medium Past A Vertical Plate In The Presence Of Magnetic Field With Constant Heat Generation. Atul Kumar Singh Et Al. [19] Investigated Hydro Magnetic Heat And Mass Transfer In MHD Flow Of An Incompressible, Electrically Conducting, Viscous Fluid Past An Infinite Vertical Porous Plate Embedded With Porous Medium Of Time Depend Permeability Under Oscillatory Suction Velocity Normal To The Plate. The Unsteady Hydro Magnetic Free Convective Flow Of A Viscous Incompressible Electrically Conducting Fluid Past An Infinite Vertical Porous Plate Through A Porous Medium In Presence Of Constant And Source Analyzed By Das Et Al. [20].

Mohammed Ibrahim And K. Suneetha [21] Investigated Unsteady MHD Two-Dimensional Free Convection Flow Of A Viscous, Incompressible, Radiating, Chemically Reacting, Radiation Absorbing Kuvshinshiki Fluid Through A Porous Medium Past A Semi-Infinite Vertical Plate. The MHD And Chemical Reaction Effects On Unsteady Flow, Heat And Mass Transfer Characteristic In A Viscous, Incompressible And Electrically Conducting Fluid Over A Semi-Infinite Vertical Porous Plate In A Slip-Flow Regime Analyzed By Ahmed Sahin [22]. Prakash Et Al. [23] Studied The Behavior Of Convective Unsteady Flow Of A Binary Mixture Over A Moving Semi-Infinite Vertical, Stretching, Porous Plate With The Influence Of Chemical Reaction, Transverse Magnetic Field, Buoyancy And Taking Into The Account Of Internal Heat Absorption Effect. Ramana Reddy Et Al. [24] Investigated Unsteady Free Convective And Diffusive Boundary Conditions. They Considered Two Types Of Nano Fluids Namely Ag-Water And Tio_2 –Water And The Governing Equations Are Solved Analytically By Using Perturbation Technique. The Laminar Convective Flow Of A Dusty Viscous Fluid Of Non-Conducting Wall In The Presence Of Transverse Magnetic Field With Volume Fraction And The First Order Chemical Reaction Is Analyzed By Mohan Krishna Et Al. [25]. Muthuraj And Srinivas [26] Investigated The Problem Of Mixed Convection Heat And Mass Transfer Through A Vertical Wavy Channel With Porous Medium. The Unsteady Mixed Convection With Thermal Radiation And First-Order Chemical Reaction On MHD Boundary Layer Flow Of Viscous, Electrically Conducting Fluid Past A Vertical Permeable Plate Has Been Presented By Dulal Pal And Babulal [27]. The Effect Of The Steady Two-Dimensional Free Convection Heat And Mass Transfer Flow Electrically Conducting And Chemically Reacting Fluid Through A Porous Medium Bounded By A Vertical Infinite Surface With Constant Suction Velocity And Constant Heat Flux In The Presence Of A Uniform Magnetic Field Is Presented By Damala Ch. Kesavaiah Et Al. [28]. Sudheer Babu Et Al. [29] Analyzed The Radiation And Mass Transfer Effects On An Unsteady Two-Dimensional Laminar Mixed Convective Boundary Layer Flow Of A Viscous, Incompressible, Electrically Conducting Chemically Reacting Fluid, Along A Vertical Moving Semi-Infinite Permeable Plate With Suction, Embedded In A Uniform Porous Medium

In This Paper, We Analyzed The Chemically Reacting Radiative MHD Flow Of An Incompressible Viscous Electrically Conducting Fluid Past An Infinite Vertical Porous Plate With Heat And Mass Transfer. To The Authors' Knowledge, No Studies Reported On Heat And Mass Transfer Behavior In The Presence Of

Magnetic Induction With The Considered Physical Effects. The Governing Equations Are Solved By Using The Perturbation Technique. The Analytical Expressions For The Velocity, Temperature, Magnetic Field Induction, Concentration, Skin-Friction Coefficient, Nusselt And Sherwood Numbers Are Obtained And Results Are Explained Graphically.

II. MATHEMATICAL ANALYSIS

The Steady MHD Mixed Convection Heat And Mass Transfer Flow Of An Electrically-Conducting, Viscous Incompressible, Newtonian And Chemically Reacting Fluid Over A Porous Vertical Infinite Plate Taking Into The Magnetic Induction, Viscous Dissipation, Chemical Reaction Of First Order As Shown In Fig.1 With The Following Assumptions:

All The Fluid Properties Except The Density In The Buoyancy Force Term Are Constant.

- The Eckert Number Ec Is Small.
- The Plate Is Subject To A Constant Suction Velocity.
- A Magnetic Field Of A Uniform Strength B_0 Is Applied Transversely To The Direction Of The Main Stream With The Induced Magnetic Field.
- The Magnetic Prandtl Number Is Greater Than The Hartmann Number.
- There Exists A First-Order Homogeneous Chemical Reaction With A Constant Rate K^* Between The Diffusing Species And The Fluid.
- The Concentration Of The Diffusion Species In The Binary Mixture Is Assumed To Very Small In Comparison With The Other Chemical Species And Hence The Soret And Dufour Effects Are Negligible.

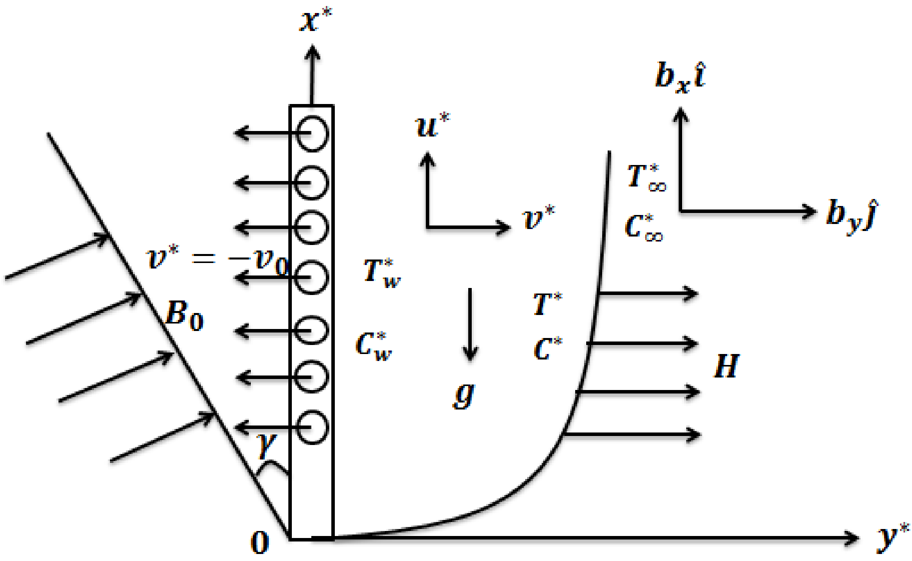

Fig.1.Physical Configuration And Coordinate System.

We Introduce A Coordinate System $\left(x^*, y^*, z^*\right)$ With The x^* - Axis Vertically Upwards Along The Plate, The y^* - Axis Normal To The Plate Into The Fluid Region And The z^* - Axis Along The Width Of The Plate. Let The Plate Be Long Enough In The x^*-Direction For The Flow To Be Parallel. Let $\left(u^*, v^*, 0\right)$ Be The Fluid Velocity And $\left(b_x^*, 0, 0\right)$ Be The Magnetic Induction Vector At A Point $\left(x^*, y^*, z^*\right)$ In The Fluid. Since The Plate Is Infinite In Length In The x^* - Direction, All The Physical Quantities Except Possibly The Pressure Are Assumed To Be Independent Of x^*. The Wall Is Maintained At The Constant Temperature T_w^* And The Concentration C_w^*, Which Are Higher Than The Ambient Temperature T_∞^* And The Concentration C_∞^* Respectively.

Above Following Assumptions, Boussinesq Approximation And Usual Boundary Layer Approximations, The Governing Equations Relevant To The Problem Are:

Conservation Of Mass:

$$\frac{\partial u^*}{\partial y^*} = 0 \tag{1}$$

Which Is Satisfied With $v^* = -v_0 = a$ Constant.

Gauss's Law Of Magnetism:

$$\frac{\partial b_y^*}{\partial y^*} = 0 \tag{2}$$

Which Holds For $b_y^* = B_0 = a$ Constant = Strength From Applied Magnetic Field.

Conservation Of Momentum:

$$\rho v^* \frac{\partial u^*}{\partial y^*} = -\frac{\partial p}{\partial x^*} - \rho g + \mu \frac{\partial^2 u^*}{\partial y^{*2}} - \sigma B_0^2 \sin^2 \gamma u^* - \sigma B_0 v_0 b_x^* \tag{3}$$

Since There Is No Large Velocity Gradient Here, The Viscous Term In Eqn.(3) Vanishes For Small μ And Hence For The Outer Flow, Beside There Is No Induced Magnetic Field Along x-Direction Gradient, So We Have

$$0 = -\frac{\partial p}{\partial x^*} - \rho_\infty g - \sigma B_0^2 \sin^2 \gamma U^* - \sigma B_0 v_0 b_0 \tag{4}$$

By Eliminating The Pressure Term From The Eqn. (3) And (4), We Obtain

$$\rho v^* \frac{\partial u^*}{\partial y^*} = \left(\rho_\infty - \rho\right) g + \mu \frac{\partial^2 u^*}{\partial y^{*2}} - \sigma B_0^2 \sin^2 \gamma \left(u^* - U^*\right) - \sigma B_0 v_0 \left(b_x^* - b_0\right) \tag{5}$$

The Boussinesq Approximation Gives

$$\rho_\infty - \rho = \rho_\infty \beta \left(T^* - T_\infty^*\right) + \rho_\infty \beta^* \left(C* - \mathrm{C}_\infty^*\right) \tag{6}$$

On Using (6) In The Eqn. (5) And Noting That ρ_∞ Is Approximately Equal To 1.

The Momentum Equation Reduces To

$$-v_0 \frac{du^*}{dy^*} = g\beta(\mathrm{T}^* - \mathrm{T}^*_\infty) + \mathrm{g}\,\beta^*(\mathrm{C}^* - \mathrm{C}^*_\infty) + v\frac{d^2u^*}{dy^{*2}} - \frac{\sigma B_0^2 \sin^2 \gamma(\mathrm{u}^* - U^*)}{\rho} - \frac{\sigma B_0 v_0 (\mathrm{b}_x^* - b_0)}{\rho} \tag{7}$$

Conservation Of Energy:

$$-v_0 \frac{dT^*}{dy^*} = \frac{k}{\rho C_p}\frac{d^2T^*}{dy^{*2}} + \frac{v}{C_p}\left(\frac{du^*}{dy^*}\right)^2 + \frac{\sigma}{\rho C_p}\left[\left(u^* - U^*\right)B_0 + v_0\left(b_x^* - b_0\right)\right]^2 + \frac{Q}{\rho C_p}\left(T^* - T_\infty^*\right) - \frac{1}{\rho C_p}\left(\frac{\partial q_r}{\partial y}\right) \tag{8}$$

Conservation Of Magnetic Induction:

$$\eta \frac{d^2 b_x^*}{dy^{*2}} + B_0 \sin^2 \gamma \frac{du^*}{dy^*} + v_0 \frac{db_x^*}{dy^*} = 0 \tag{9}$$

Conservation Of Species:

$$-v_0 \frac{dC^*}{dy^*} = D\frac{d^2C^*}{dy^{*2}} - K\left(C^* - C_\infty^*\right) \tag{10}$$

The Boundary Conditions Are:

$$\left.\begin{array}{l} y^* = 0 : u^* = 0,\ T^* = T_w^*,\ b_x^* = 0,\ C^* = C_w^* \\ y^* \to \infty : u^* \to U^*,\ T^* \to T_\infty^*,\ b_x^* \to b_0,\ C^* \to C_\infty^* \end{array}\right\} \tag{11}$$

The Local Radiant Gray Gas Is Expressed By

$$\frac{\partial q_r}{\partial y} = -4a^* \sigma \left(T_\infty^4 - T^4\right) \tag{12}$$

Where a^* Is Absorption Constant. The Temperature Difference With in The Flow Is Sufficiently Small Therefore, T^4 Can Be Expressed By Expanding T_∞ And Neglecting Higher-Order Terms

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{13}$$

The Non-Dimensional Quantities Are:

$$\left.\begin{aligned} & y=\frac{v_0 y^*}{v},\ u=\frac{u^*}{U^*},\ \theta=\frac{\left(T^*-T_\infty^*\right)}{\left(T_w^*-T_\infty^*\right)},\ \phi=\frac{\left(C^*-C_\infty^*\right)}{\left(C_w^*-C_\infty^*\right)}, \\ & Gr=\frac{g\beta v\left(T_w^*-T_\infty^*\right)}{U^* v_0^2},\ Gm=\frac{g\beta^* v\left(C_w^*-C_\infty^*\right)}{U^* v_0^2},\ Ec=\frac{U^{*2}}{C_p\left(T_w^*-T_\infty^*\right)}, \\ & \alpha=\frac{Qv^2}{kv_0^2},\ Sc=\frac{v}{D},\ M=\frac{\sigma v B_0^2}{\rho v_0^2},\ \Pr=\frac{\rho v C_p}{k},\ b_x=\frac{b_x^*}{b_0}, \\ & H=\frac{b_0}{B_0},\ \lambda=\frac{v_0}{U^*},\ Pm=\frac{v}{\eta},\ K=\frac{K^* v}{v_0^2},\ R=\frac{16a^*\sigma v^2 T_\infty^3}{kv_0^2}, \end{aligned}\right\} \tag{14}$$

The Non-Dimensional Forms Of (14), The Equations (7)-(10) Takes The Ordinary Differential Equations Are

$$\frac{d^2u}{dy^2}+\frac{du}{dy}-Mu\sin^2\gamma=-Gr-Gm\phi-M+MH\lambda\left(b_x-1\right) \tag{15}$$

$$\frac{d^2\theta}{dy^2}+\Pr\frac{d\theta}{dy}+\left(\alpha+R\right)\theta=-\Pr Ec\left(\frac{du}{dy}\right)^2-M\Pr Ec\left[\left(1-u\right)+\lambda H\left(1-b_x\right)\right]^2 \tag{16}$$

$$H\lambda\frac{d^2b_x}{dy^2}+PmH\lambda\frac{db_x}{dy}+Pm\sin^2\gamma\frac{du}{dy}=0 \tag{17}$$

$$\frac{d^2\phi}{dy^2}+Sc\frac{d\phi}{dy}-KSc\phi=0 \tag{18}$$

Here Pm Is The Magnetic Prandtl Number, $\Pr$ Is The Prandtl Number, K Is The Chemical Reaction Parameter, M Is The Magnetic Parameter, Ec Is The Eckert Number, Gr Is The Thermal Grashof Number, Gm Is The Mass Grashof Number, α Is The Heat Generation / Absorption Parameter, R Is The Radiation Parameter And Sc Is The Schmidt Number.

The Corresponding Boundary Conditions Are

$$\left.\begin{aligned} & y=0:\ u=0,\ \theta=1,\ b_x=0,\ \phi=1 \\ & y\to\infty:\ u\to1,\ \theta\to0,\ b_x\to1,\ \phi\to0 \end{aligned}\right\} \tag{19}$$

The Mass Diffusion Equation (18) Can Be Adjusted To Represent A Destructive Chemical Reaction (Means Endothermic, I.E., Heat Is Absorbed) If $K>0$ Or A Generative Chemical Reaction (Means Exothermic, I.E., Heat Is Generated) If $K<0$. In The Energy Equation (16), $\alpha>0$ Indicates Heat Generation While $\alpha<0$ Corresponds To Heat Absorption.

The System Comprising (15)-(18) Is Well Posed And Can Yield Either Semi-Analytical Solution. We Select To Seek Perturbation Solutions Here.

III. METHOD OF SOLUTION

The Perturbation Theory Leads To An Expression For The Desired Solution In Terms Of Power Series In Some "Small" Parameters Quantifying The Deviation From The Exactly Solvable Problem. The Leading Term In This Power Series Is The Solution To The Exactly Solvable Problem, While Further Terms Describe The Deviation In The Solution, Due To The Deviation From The Initial Problem. The Perturbation Theory Is Applicable If The Problem At Hand Can Be Formulated By Adding A "Small" Term To The Mathematical Description Of The Exactly Solvable Problem.

The Solution To (18) Subjected To The Boundary Condition (19) Is

$$\phi = e^{-\xi y} \tag{20}$$

Now To Solve (15), (16) And (17) Under The Boundary Conditions (19), Since $Ec < 1$ For All The Incompressible Fluids, It Is Assumed That The Solutions To The Equations Are Of The Form

$$\Re(y) = \Re_0(y) + Ec\Re_1(y) + O\left(Ec^2\right) \tag{21}$$

Where $\Re$ Stands For u , θ Or b_x .

Substituting (21) Into (15), (16) And (17) And Equating The Coefficients Of The Same Degree Terms And Neglecting Terms Of $O\left(Ec^2\right)$, The Following Differential Equations Are Obtained:

$$u_0'' + u_0' - M\sin^2\gamma u_0 = -Gr\theta_0 - Gm\phi - M + M\lambda H\left(b_{x_0} - 1\right) \tag{22}$$

$$u_1'' + u_1' - M\sin^2\gamma u_1 = -Gr\theta_1 + M\lambda H b_{x_1} \tag{23}$$

$$\theta_0'' + \Pr\theta_0' + (\alpha + R)\theta_0 = 0 \tag{24}$$

$$\theta_1'' + \Pr\theta_1' + (\alpha + R)\theta_1 = -\Pr\left(u_0'\right)^2 - M\Pr\left\{1 - u_0 + \lambda H\left(1 - b_{x_0}\right)\right\}^2 \tag{25}$$

$$\lambda H b_{x_0}'' + \lambda H Pm b_{x_0}' + Pm\sin^2\gamma u_0' = 0 \tag{26}$$

$$\lambda H b_{x_1}'' + \lambda H Pm b_{x_1}' + Pm\sin^2\gamma u_1' = 0 \tag{27}$$

The Boundary Conditions (19) Reduces To

$$\left.\begin{array}{l} y = 0: u_0 = 0, \quad u_1 = 0,\ \theta_0 = 1,\ \theta_1 = 0,\quad b_{x_0} = 0,\ b_{x_1} = 0 \\ y \to \infty: u_0 \to 1,\ u_1 \to 0,\ \theta_0 \to 0,\ \theta_1 \to 0,\ b_{x_0} \to 1,\ b_{x_0} \to 0 \end{array}\right\} \tag{28}$$

The Solutions Of (22)-(27) Subjected To The Boundary Conditions (28) Are

$$\theta_0(y) = e^{-ay} \tag{29}$$

$$u_0(y) = A_1 e^{-ay} + A_2 e^{-\xi y} + A_3 e^{-by} \tag{30}$$

$$b_{x_0}(y) = A_4 e^{-ay} + A_5 e^{-\xi y} + A_6 e^{-by} + A_7 e^{-Pmy} \tag{31}$$

$$\begin{aligned} \theta_1(y) = {} & C_{11}e^{-2ay} + C_{12}e^{-2\xi y} + C_{13}e^{-2by} + C_{14}e^{-2Pmy} + C_{15}e^{-(a+\xi)y} + C_{16}e^{-(a+b)y} \\ & + C_{17}e^{-(a+Pm)y} + C_{18}e^{-(b+\xi)y} + C_{19}e^{-(\xi+Pm)y} + C_{20}e^{-(b+Pm)y} + C_{21}e^{-ay} \end{aligned} \tag{32}$$

$$\begin{aligned} u_1(y) = {} & B_{12}e^{-2ay} + B_{13}e^{-2\xi y} + B_{14}e^{-2by} + B_{15}e^{-2Pmy} + B_{16}e^{-(a+\xi)y} + B_{17}e^{-(a+b)y} + B_{18}e^{-(a+Pm)y} \\ & + B_{19}e^{-(b+\xi)y} + B_{20}e^{-(\xi+Pm)y} + B_{21}e^{-(b+Pm)y} + B_{22}e^{-ay} + B_{23}e^{-by} \end{aligned} \tag{33}$$

$$b_{x_1}(y) = \frac{Pm\sin^2\gamma}{\lambda H}\left[\begin{array}{l} D_1e^{-2ay} + D_2e^{-2\xi y} + D_3e^{-2by} + D_4e^{-2Pmy} + D_5e^{-(a+\xi)y} \\ +D_6e^{-(a+b)y} + D_7e^{-(a+Pm)y} + D_8e^{-(b+\xi)y} + D_9e^{-(\xi+Pm)y} \\ +D_{10}e^{-(b+Pm)y} + D_{11}e^{-ay} + D_{12}e^{-by} + D_{13}e^{-Pmy} \end{array}\right] \tag{34}$$

The Boundary Layer Produces A Drag On The Plate Due To The Viscous Stresses, Which Are Developed At The Wall. The Viscous Stress At The Surface Of The Plate Is Given By

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \tau_0 + Ec\tau_1 \tag{35}$$

Where $\tau_0 = u_0'(0) = -aA_1 - \xi A_2 - bA_3$ And

$$\begin{aligned} \tau_1 = u_1' = {} & -2aB_{12} - 2\xi B_{13} - 2bB_{14} - 2PmB_{15} - (a+\xi)B_{16} - (a+b)B_{17} - (a+Pm)B_{18} \\ & -(b+\xi)B_{19} - (\xi+Pm)B_{20} - (b+Pm)B_{21} - aB_{22} - bB_{23} \end{aligned}$$

The Nusselt Number Nu Is Often Used To Determine Heat Transfer. The Non-Dimensional Heat Flux At The Plate $y=0$ In Terms Of Nu Is Given By

$$Nu=\left(\frac{\partial\theta}{\partial y}\right)_{y=0}=Nu_0+EcNu_1 \tag{36}$$

Where $Nu_0=\theta_0'(0)=-a$ And

$$Nu_1=\theta_1'(0)=-2aC_{11}-2\xi C_{12}-2bC_{13}-2PmC_{14}-(a+\xi)C_{15}-(a+b)C_{16}$$
$$-(a+Pm)C_{17}-(b+\xi)C_{18}-(\xi+Pm)C_{19}-(b+Pm)C_{20}-aC_{21}$$

The Non-Dimensional Current Density (J) At The Plate $y=0$ Is Given By

$$J=\left(\frac{\partial b_x}{\partial y}\right)_{y=0}=J_0+EcJ_1 \tag{37}$$

Where $J_0=b_{x_0}'(0)=-aA_4-\xi A_5-bA_6-PmA_7$ And

$$J_1=b_{x_1}'(0)=\frac{Pm\sin^2\gamma}{\lambda H}\begin{bmatrix}-2aD_1-2\xi D_2-2bD_3-2PmD_4-(\xi+a)D_5-(b+a)D_6-(a+Pm)D_7\\-(\xi+b)D_8-(\xi+Pm)D_9-(b+Pm)D_{10}-aD_{11}-bD_{12}-PmD_{13}\end{bmatrix}$$

The Rate Of Mass Transfer In The Form Of Local Sherwood Number Sh_x Is Given By

$$Sh_x=\left(\frac{\partial\phi}{\partial y}\right)_{y=0}=-\xi \tag{38}$$

IV. RESULTS AND DISCUSSION

This Section Aims To Consider The Problem Of The Study Mixed Convective Flow With Combined Heat And Mass Transfer Of A Viscous Incompressible Electrically Conducting Fluid Past An Inclined Infinite Vertical Porous Plate In Presence Of A Transverse Magnetic Field Applied Transversely To The Direction Of The Flow With The Induced Magnetic Field And The Viscous And Magnetic Dissipations Of Energy In Presence Of First-Order Chemical Reaction. The Analytical Expressions For The Velocity Field, The Temperature, The Species Concentration, The Induced Magnetic Field, The Skin Friction, Nusselt Number And Current Density Are Obtained Using Perturbation Technique.

The Problems Have Been Shown Graphically Defined That The Different Values Of The Non-Dimensional Parameters. We Use The Following Default Values Are Gr =5, Gm =5, α =0.05, Sc =0.60, $\Pr$ =0.71, Pm =0.10, K =0.10, R =0.10, γ =0.60, M =1.0, Ec =0.01, λ =0.10, And H =0.10. It Is Observed That The Present Results Are In Good Agreement With The Analytical Solution.

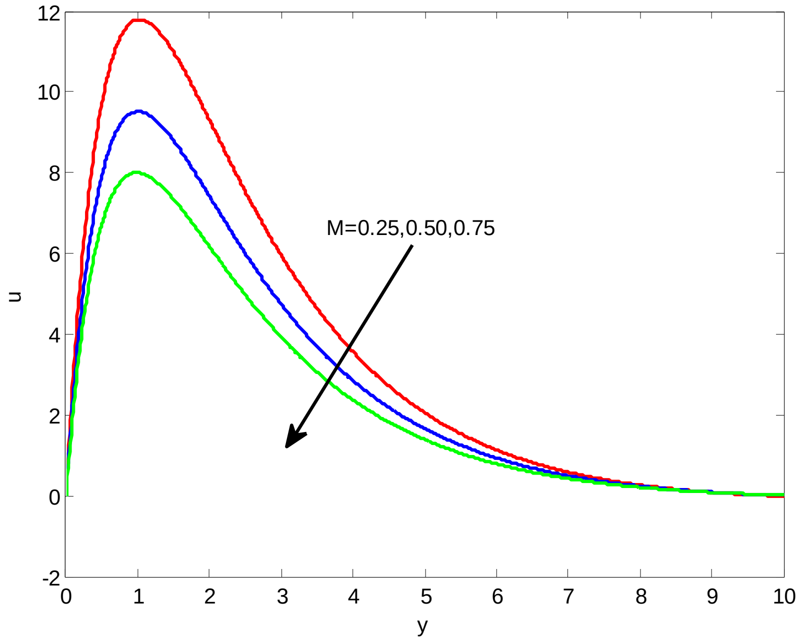

Fig.2. Velocity Field For Different Values Of Magnetic Parameter.

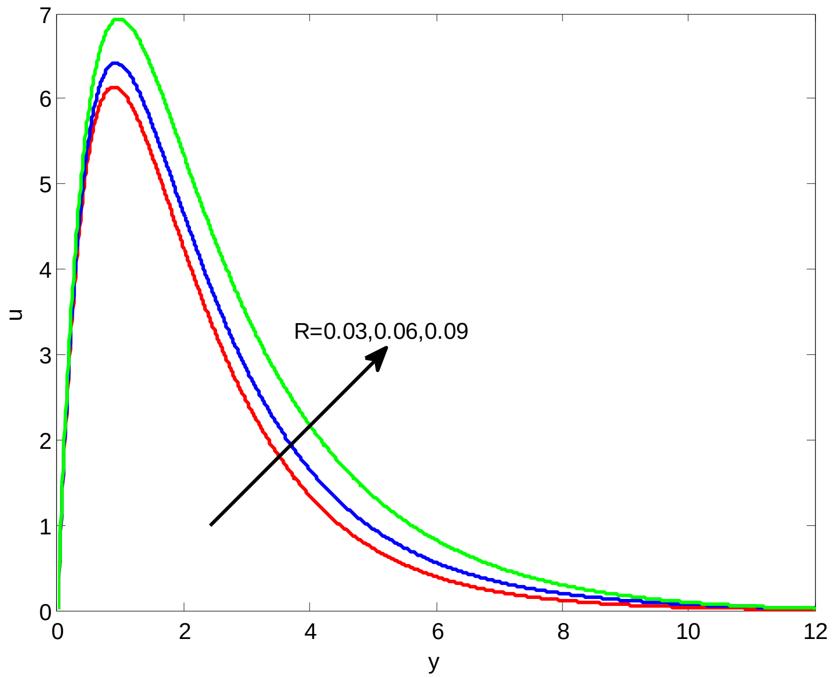

Fig.3. Velocity Field For Different Values Of Radiation Parameter.

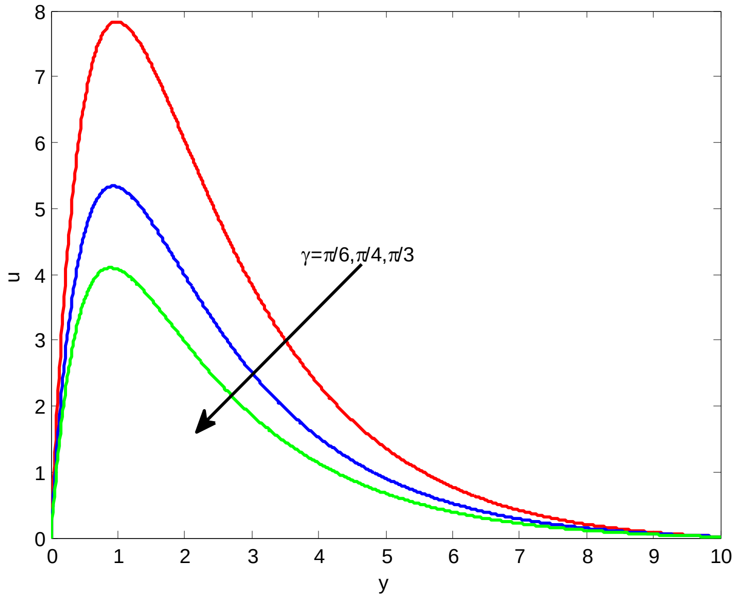

Fig.4. Velocity Field For Different Value Of Angle Of Inclination.

Fig.2. Illustrates The Influence Of Magnetic Parameter (M) On The Velocity And Increasing The Value Of Magnetic Parameter. The Velocity Profile Rise From The Wall To Reach Maximum Values And Decrease The Free Stream. From This Figure, It Observed That Rise In M Values Decreased In The Velocity Flow.

Fig.3. Show That The Influence Of Radiation Parameter (R) On The Velocity Field. The Velocity Field From Increasing In The Radiation Parameter, Clearly We Observed That Increased In The Velocity Flow. The Profile Represents For The Weak Transfer Magnetic Field.

Fig.4. The Velocity Profile Is Depicted For Different Values Of Angle Of Inclination (φ). We Can See From The Figure Increasing The Inclination Angle Value Causes A Decreases The Velocity Flow Field.

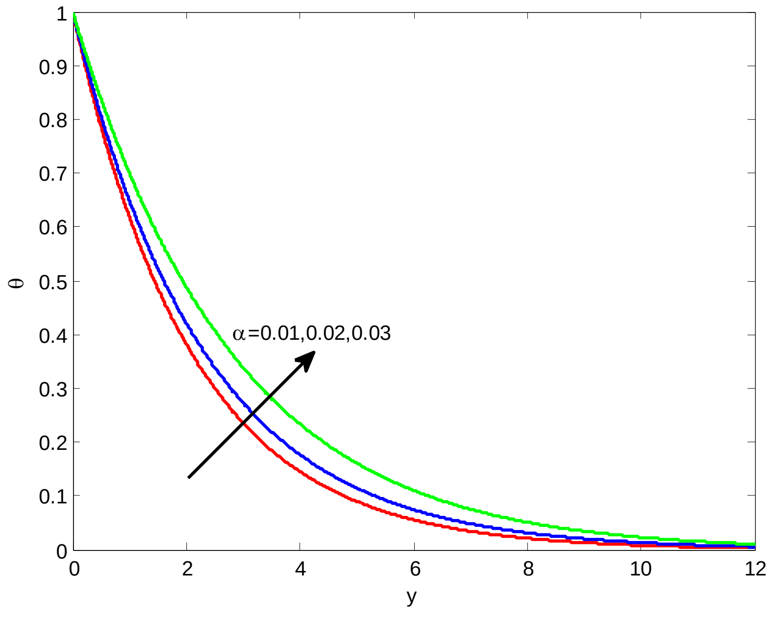

Fig.5. Temperature Field For Different Values Of Heat Absorption Parameter.

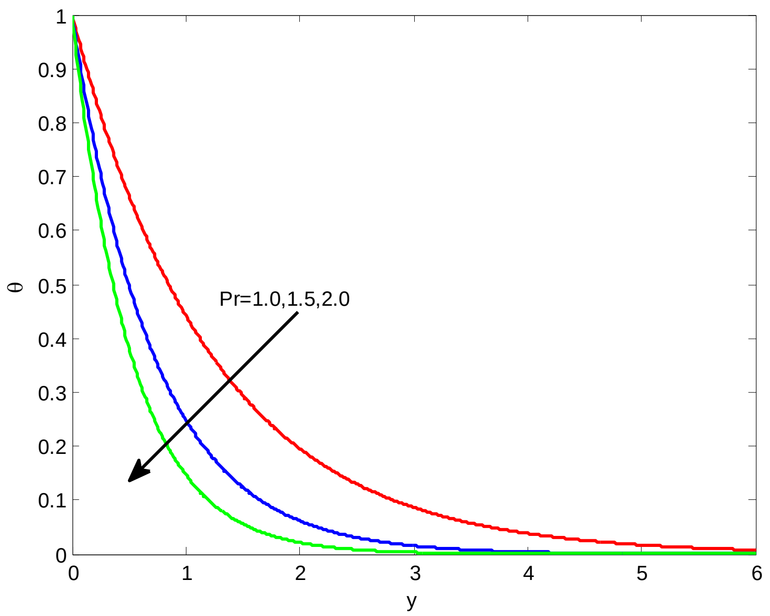

Fig.6. Temperature Field For Different Values Of Prandtl Number.

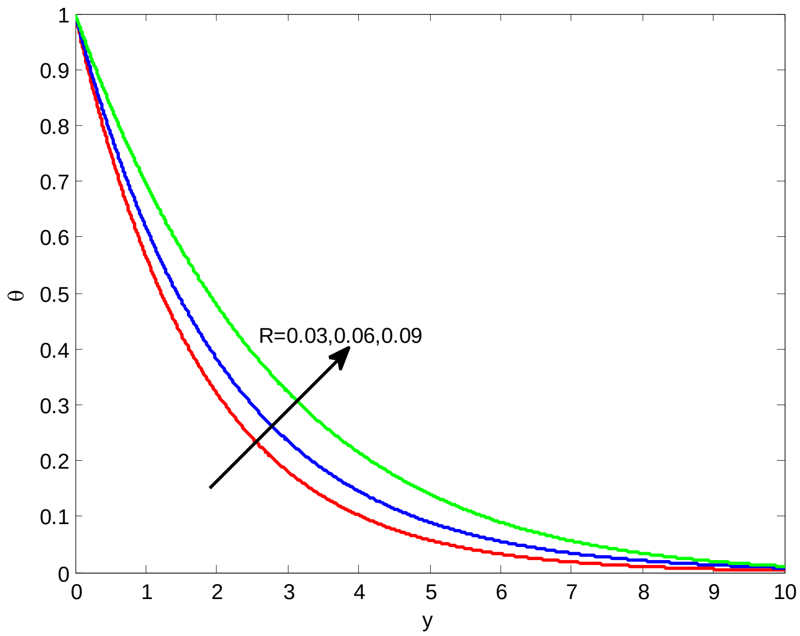

Fig.7. Temperature Field For Different Values Of Radiation Parameter.

Fig.5. Show That The Influence Of Absorption Parameter (α) On The Temperature Field. From Rising Absorption Parameter Values The Temperature Field Is Increased. It Is Clear That The Figure Increasing The Absorption Parameter Values On Temperature Field Is Increased.

Fig.6. From Observed That Increasing The Prandtl Number ($\Pr$) On The Temperature. The Temperature Field Increasing The Prandtl Number Caused By The Thermal Boundary Thickness Is Decreased. The Temperature Field Attains Its Maximum Value At The Surface And Decreases Gradually To The Free Stream Zero Value For Away From The Plate.

Fig.7. Illustrate That Rising The Radiation Parameter (R) Value On The Temperature. It Is Clearly Presented The Increasing The Radiation Parameter Value From The Thermal Boundary Layer Is Increased. From Low Value Of The Radiation Parameter The Fluid Temperature Attained That Maximum Range.

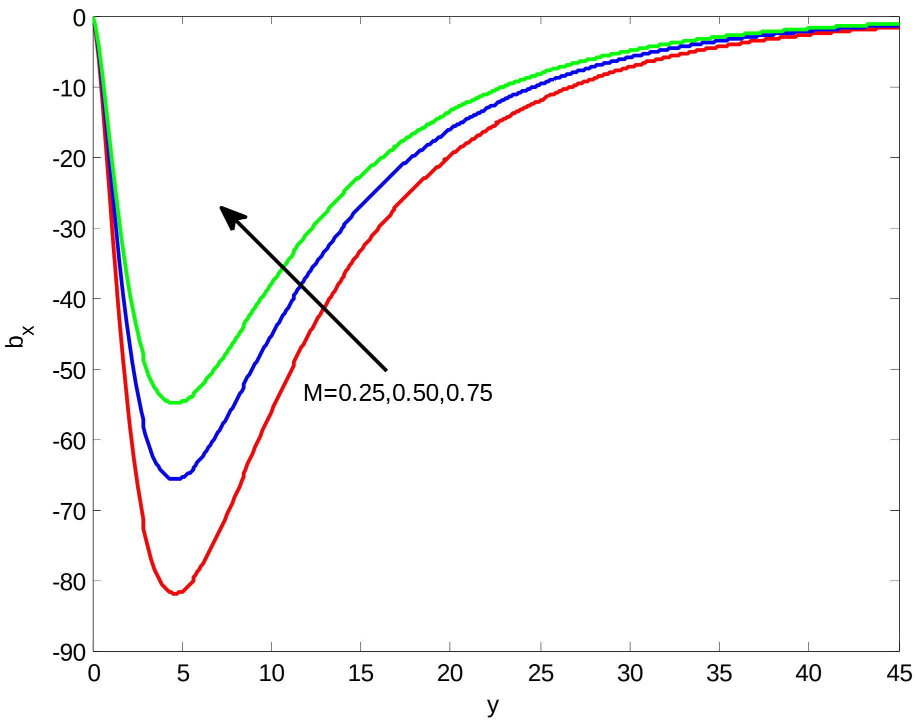

Fig.8. Induced Magnetic Field For Different Values Of Magnetic Parameter.

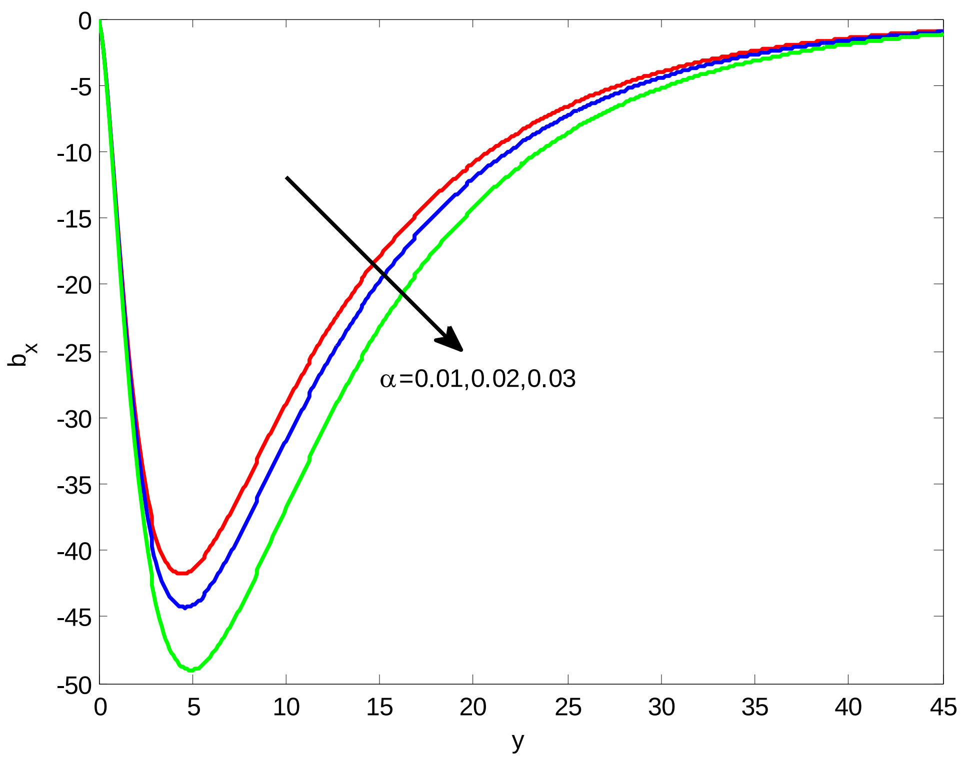

Fig.9. Induced Magnetic Field For Different Values Of Absorption Parameter.

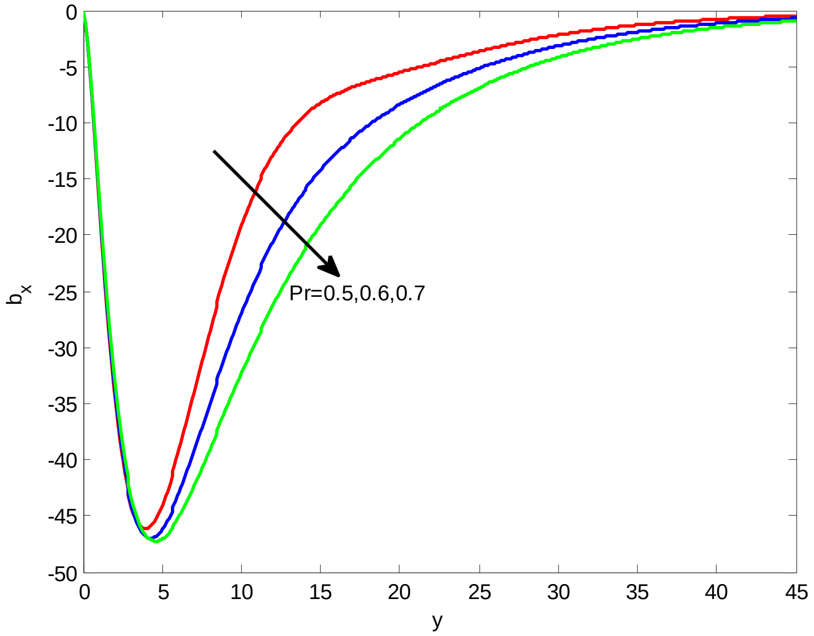

Fig.10. Induced Magnetic Field For Different Values Of Prandtl Number.

Fig.8. Show That Increasing The Magnetic Parameter Values On The Induced Magnetic Field. The Induced Magnetic Field Is Very Interesting Is One Of The Velocity, Temperature. Its Special Is The Induced Magnetic Field Increasing From Very Lowest Value Of The Magnetic Parameter. It Is Clearly That The Magnetic Field Is Opposite Flow.

Fig.9. Represent Induced Magnetic Profile For Absorption Parameter Increasing The Magnetic Field Is Decreased And Fig.10. Illustrate The Influence Of Prandtl Number On The Induced Magnetic Profile. However Increasing The Value Of The Prandtl Number Then The Induced Magnetic Field Is Decreased.

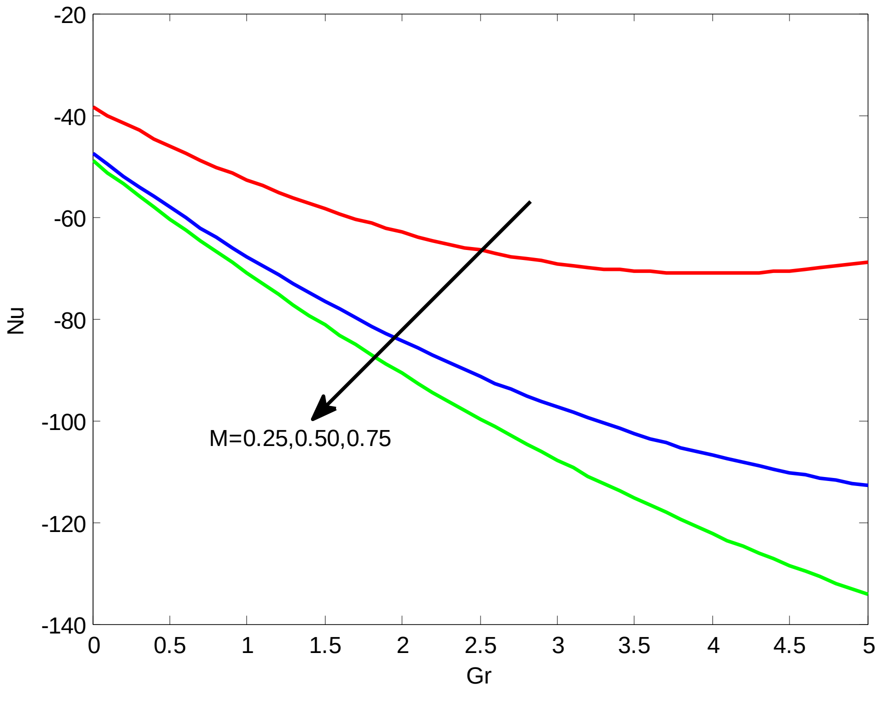

Fig.11. Nusselt Number For Different Values Of Magnetic Parameter.

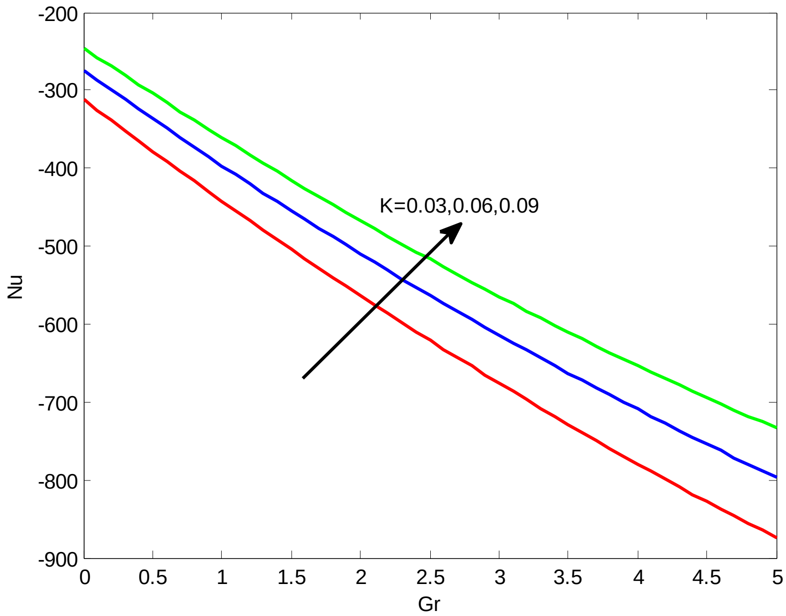

Fig.12. Nusselt Number For Different Values Of Chemical Reaction Parameter.

Fig.11. Show That The Influence Of Different Values Of Magnetic Parameter Over The Rate Of The Heat Transfer Of The Field. It's Represents The Dimensionless Rate Of Heat Transfer Decreased For Different Values Of The Magnetic Parameter.

Fig.12. Observed That The Influence Of The Chemical Reaction Parameter Over The Rate Of Heat Transfer. Increasing The Value Of The Chemical Reaction Parameter Then The Rate Of Heat Transfer Is Increased.

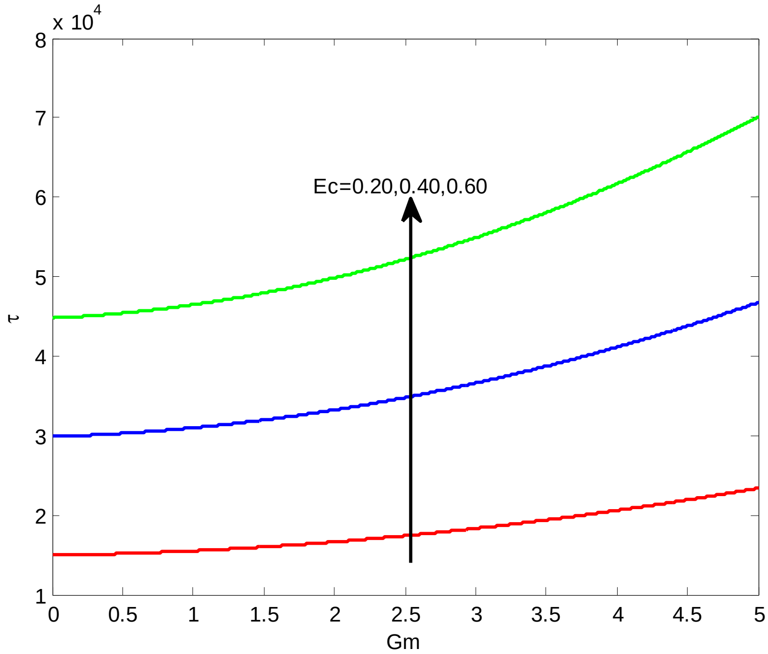

Fig.13. Skin-Friction For Different Values Of Eckert Number.

Fig.13. Illustrate The Influence Of Eckert Number On The Skin Friction. In This Figure Realized That The Distribution Of The Skin Friction Is Increased With The Eckert Number Increasing. Which Is The Result Is Increasing The Thermal Boundary Layer Thickness With Stronger Heat Generation.

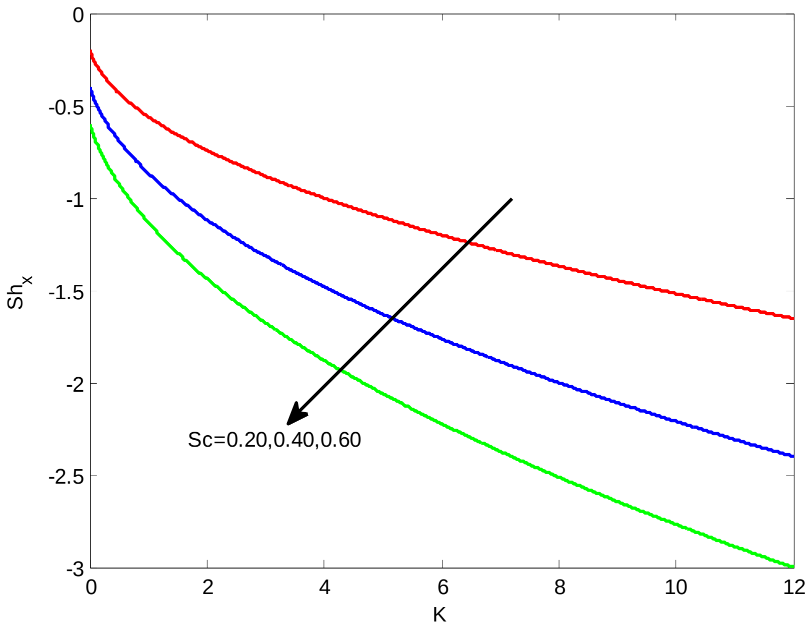

Fig.14. Sherwood Number For Different Values Of Schmidt Number.

Sherwood Number Is Studied In Fig.14 For Various Values Of Schmidt Number. From This Figure It Is Observed That Sherwood Number Decrease With An Increase In Schmidt Number (Sc).

V. CONCLUSIONS

Conclusions Of The Study Are As Follows:

- The Magnetic Parameter (M) Values Increasing Both The Velocity, Induced Magnetic Field And Nusselt Number Are Also Decreased.
- The Thermal Radiation Parameter (R) Increasing The Influence Attained The Velocity; Temperature And The Heat Transfer Are Also Increased.
- The Absorption Parameter (α) Value Increases The Temperature Field Increases Thickness Of The Thermal Boundary Layer And Decreased Induced Magnetic Field.
- The Temperature And Induced Magnetic Field Decreases With Increasing The Prandtl Number ($\Pr$).
- However The Values Of Eckert Number (Ec) Increasing With Increased Skin-Friction Coefficient.
- Sherwood Number Decreased With Increasing The Schmidt Number (Sc).

NOMENCLATURE

u - Dimensionless Velocity Components In The x - Direction, ($m \cdot s^{-1}$)

U - Dimensionless Free Stream Velocity, ($m \cdot s^{-1}$)

v_0 - Dimensionless Suction Velocity, ($m \cdot s^{-1}$)

B_0 - Uniform Magnetic Field

b_x^* - Induced Magnetic Field Along The x - Direction

C^* - Species Concentration, ($kg.m^{-3}$)

C_f - Skin-Friction Coefficient

C_p - Specific Heat At A Constant Pressure, ($J \cdot kg^{-1} \cdot K^{-1}$)

C_∞^* - Species Concentration In The Free Stream, ($kg \cdot m^{-3}$)

C_w^* - Species Concentration At The Surface, ($kg \cdot m^{-3}$)

D - Chemical Molecular Diffusivity, ($m^2 \cdot s^{-1}$)

Ec - Eckert Number / Dissipative Heat
g - Acceleration Due To Gravity, ($m \cdot s^{-2}$)
Gr - Thermal Grashof Number
Gm - Mass Grashof Number
H - Ratio Of The Induced Magnetic Field At Infinity To The Applied Magnetic Field
J -Electric Current Density
K - Chemical Reaction Parameter
M - Hartmann Number / Magnetic Parameter
N - Number Of Cells
Nu -Nusselt Number
p - Pressure, (Pa)
Pm - Magnetic Prandtl Number
$\Pr$ - Prandtl Number
Q -Heat Source / Sink
Sc - Schmidt Number
Sh - Sherwood Number
T^* - Temperature, (K)
T_w^* - Fluid Temperature At The Surface, (K)
T_∞^* - Fluid Temperature In The Free Stream, (K)
R - Radiation Parameter

GREEK SYMBOLS
α - Heat Generation / Absorption Parameter
β - Coefficient Of Volume Expansion For Heat Transfer, (K^{-1})
β^* - Coefficient Of Volume Expansion For Mass Transfer, (K^{-1})
η - Magnetic Diffusivity
θ - Dimensionless Fluid Temperature, (K)
λ - Thermal Conductivity, ($W \cdot m^{-1} \cdot K^{-1}$)
μ - Magnetic Permeability, ($H \cdot m^{-1}$)
υ - Kinetic Viscosity, ($m^2 \cdot s^{-1}$)
ρ - Density, ($kg \cdot m^{-3}$)
σ - Electrical Conductivity, ($S \cdot m^{-1}$)
τ - Shearing Stress, ($N \cdot m^{-2}$)
ϕ - Dimensionless Species Concentration, ($kg \cdot m^{-3}$)

SUBSCRIPTS
w - Conditions On The Wall
∞ - Free Stream Conditions

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APPENDIX

$$\xi=\frac{\left[Sc+\sqrt{Sc^2+4KSc}\right]}{2},\ a=\frac{\left[\Pr+\sqrt{\Pr^2-4(\alpha+R)}\right]}{2},$$

$$b=\frac{\left[1+Pm+\sqrt{(1-Pm)^2+4M\sin^2\gamma}\right]}{2},$$

$$A_1=\frac{Gr(a-Pm)}{-a^3+(1+Pm)a^2+\left(M\sin^2\gamma-Pm\right)a},\ A_2=\frac{Gm(\xi-Pm)}{-\xi^3+(1+Pm)\xi^2+\left(M\sin^2\gamma-Pm\right)\xi},$$

$$A_3=-(A_1+A_2),\ A_4=\frac{A_1Pm\sin^2\gamma}{\lambda H(a-Pm)},\ A_5=\frac{A_2Pm\sin^2\gamma}{\lambda H(\xi-Pm)},\ A_6=\frac{A_3Pm\sin^2\gamma}{\lambda H(b-Pm)},$$

$$A_7=-(A_4+A_5+A_6),\ C_1=-\Pr a^2A_1^2-M\Pr A_4^2,\ C_2=-\Pr\xi^2A_2^2-M\Pr A_5^2,$$

$$C_3=-\Pr b^2A_3^2-M\Pr A_6^2,\ C_4=-M\Pr A_7^2,\ C_5=-2\Pr a\xi A_1A_2-2M\Pr A_4A_5,$$

$$C_6=-2\Pr abA_1A_3,$$

$$C_7=-2M\Pr A_4A_7,\ C_8=-2\Pr\xi bA_2A_3-2M\Pr A_5A_6,\ C_9=-2M\Pr A_5A_7,\ C_{10}=-2M\Pr A_6A_7,$$

$$C_{11}=\frac{C_1}{4a^2-2a\Pr+(\alpha+R)},\ C_{12}=\frac{C_2}{4\xi^2-2\xi\Pr+(\alpha+R)},\ C_{13}=\frac{C_3}{4b^2-2b\Pr+(\alpha+R)},$$

$$C_{14}=\frac{C_4}{4Pm^2-2Pm\Pr+(\alpha+R)},\ C_{15}=\frac{C_5}{(a+\xi)^2-(a+\xi)\Pr+(\alpha+R)},$$

$$C_{16}=\frac{C_6}{(a+b)^2-(a+b)\Pr+(\alpha+R)},\ C_{17}=\frac{C_7}{(a+Pm)^2-(a+Pm)\Pr+(\alpha+R)},$$

$$C_{18}=\frac{C_8}{(a+\xi)^2-(a+\xi)\Pr+(\alpha+R)},\ C_{19}=\frac{C_9}{(\xi+Pm)^2-(\xi+Pm)\Pr+(\alpha+R)},$$

$$C_{20}=\frac{C_{10}}{(b+Pm)^2-(b+Pm)\Pr+(\alpha+R)},$$

$$C_{21}=-(C_{11}+C_{12}+C_{13}+C_{14}+C_{15}+C_{16}+C_{17}+C_{18}+C_{19}+C_{20}),\ B_1=Gr(Pm-2a)C_{11},$$

$$B_2=Gr(Pm-2\xi)C_{12},\ B_3=Gr(Pm-2b)C_{13},\ B_4=-GrPmC_{14},\ B_5=Gr\left[Pm-(a+\xi)\right]C_{15},$$

$$B_6 = Gr\left[Pm-(a+b)\right]C_{16},\ B_7 = Gr\left[Pm-(a+Pm)\right]C_{17},\ B_8 = Gr\left[Pm-(b+\xi)\right]C_{18},$$

$$B_9 = Gr\left[Pm-(Pm+\xi)\right]C_{19},\ B_{10} = Gr\left[Pm-(b+Pm)\right]C_{20},\ B_{11} = Gr(Pm-a)C_{21},$$

$$B_{12} = \frac{B_1}{8a^3-4a^2(1+Pm)+2a\left(Pm-M\sin^2\gamma\right)},\ B_{13} = \frac{B_2}{8\xi^3-4\xi^2(1+Pm)+2\xi\left(Pm-M\sin^2\gamma\right)}$$

$$,B_{14} = \frac{B_3}{8b^3-4b^2(1+Pm)+2b\left(Pm-M\sin^2\gamma\right)},$$

$$B_{15} = \frac{B_4}{8Pm^3-4Pm^2(1+Pm)+2Pm\left(Pm-M\sin^2\gamma\right)},$$

$$B_{16} = \frac{B_5}{(a+\xi)\left\{(a+\xi)^2-(a+\xi)(1+Pm)+\left(Pm-M\sin^2\gamma\right)\right\}},$$

$$B_{17} = \frac{B_6}{(a+b)\left\{(a+b)^2-(a+b)(1+Pm)+\left(Pm-M\sin^2\gamma\right)\right\}},$$

$$B_{18} = \frac{B_7}{(a+Pm)\left\{(a+Pm)^2-(a+Pm)(1+Pm)+\left(Pm-M\sin^2\gamma\right)\right\}},$$

$$B_{19} = \frac{B_8}{(b+\xi)\left\{(b+\xi)^2-(b+\xi)(1+Pm)+\left(Pm-M\sin^2\gamma\right)\right\}},$$

$$B_{20} = \frac{B_9}{(Pm+\xi)\left\{(Pm+\xi)^2-(Pm+\xi)(1+Pm)+\left(Pm-M\sin^2\gamma\right)\right\}},$$

$$B_{21} = \frac{B_{10}}{(b+Pm)\left\{(b+Pm)^2-(b+Pm)(1+Pm)+\left(Pm-M\sin^2\gamma\right)\right\}},$$

$$B_{22} = \frac{B_{11}}{a\left\{a^2-a(1+Pm)+\left(Pm-M\sin^2\gamma\right)\right\}},$$

$$B_{23} = -\left(B_{12}+B_{13}+B_{14}+B_{15}+B_{16}+B_{17}+B_{18}+B_{19}+B_{20}+B_{21}+B_{22}\right),\ D_1 = \frac{B_{12}}{2a-Pm},$$

$$D_2 = \frac{B_{13}}{2\xi-Pm},\ D_3 = \frac{B_{14}}{2b-Pm},\ D_4 = \frac{B_{15}}{Pm},\ D_5 = \frac{B_{16}}{(a+\xi)-Pm},\ D_6 = \frac{B_{17}}{(a+b)-Pm},\ D_7 = \frac{B_{18}}{a},$$

$$D_8 = \frac{B_{19}}{(b+\xi)-Pm},\ D_9 = \frac{B_{20}}{\xi},\ D_{10} = \frac{B_{21}}{b},\ D_{11} = \frac{B_{22}}{a-Pm},\ D_{12} = \frac{B_{23}}{b-Pm},$$

$$D_{13} = -\left(D_1+D_2+D_3+D_4+D_5+D_6+D_7+D_8+D_9+D_{10}+D_{11}+D_{12}\right).$$

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