JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

A SIMULATION OF MHD INFLUENCED FLUID MOTION OVER AN EXPONENTIALLY POROUS STRETCHING SURFACE WITH THE EFFECTS OF HEAT TRANSFER AND CHEMICAL REACTION

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Abstract : A numerical analysis has been done to investigate the effects of heat and mass transfers of fluid motion under the influence of a transverse magnetic field. The permeable region is characterized by an exponential form of elongating sheet. Similarity transformation has been used to change the nature of governing equations. Due to the complexity introduced by non-linearity of these coupled equations, the analytical approach does not hold suitably. Therefore, the fourth order accuracy three stage Lobatto IIIa formula is utilized to solve these equations by developing MATLAB bvp4c code. Influences of various flow properties associated with this present problem are discussed graphically. From the results and discussion of this model, it is perceived that the magnetic parameter controls the motion of the fluid but enhance the thermal transmission.

***IndexTerms* - Heat and Mass Transfers, Chemical Reaction, MHD, Exponentially Stretching Sheet, MATLAB bvp4c.**

1. INTRODUCTION:

The boundary layer viscous fluid flow under the influence of magnetic field over an exponentially stretching/shrinking geometries has imperative appliances in manufacturing processes like MHD electrical power generation, production and extraction of rubber and paper production etc., medical sciences and many other fields. In the recent times, the significance of porous medium in biofluid dynamics and biomechanics has taken a great deal of interest into research areas. Some examples of natural porous mediums are water flows from the soil to the atmosphere, water with inorganic nutrients flows from the root to the leaves and homemade water treatments etc. The nature of flow induced by stretching/shrinking surface was first analysed by Crane (1970). Kumar (2015) has investigated the MHD fluid flow with porous medium by considering exponentially shrinking surface. Recently, the importance of this flow model increases and many authors influenced by this model and hence put their ideas by taking different fluids. Abbas *et al*. (2019) have shown the nature of hydro-magnetics influenced fluid motion over stretching surface. Petrovic *et al.* (2018) have expressed their ideas by taking thermally stratified MHD flow with porous medium. Dey (2017, 2016) has analysed the hydro-magnetic flow of non-Newtonian fluids by taking porous medium. Bhukta *et al.* (2014) have solved heat and mass transfer flow problem using non-Newtonian fluid model. Krishna *et al.* (2018) have inspected the MHD power law liquid stream in a permeable surface. Recently, Makinde *et al.* (2018) and Das *et al.* (2016) have given significant results on chemically reacting flow of different fluid models and conferred the importance of the chemically stratified flow in engineering and industrial processes.

The combined thermal and mass transfers analysis of the different fluids flow have received a huge amount of significance into research areas due to its applications in mechanical engineering sciences, medical sciences and industrial processes. The heat transfer with the stretching surface has many industrial processes such as annealing and thinning of Copper wire and extrusion of polymer etc. Recently, Kamal et al. (2018), Jahan *et al.* (2016) and Rehman *et al.* (2018) have studied the both thermal and mass diffusion effects on different fluid models and concluded with significant results. Again, Shampine and Kierzenka (2000) have utilized the bvp4c solver technique to come out their discussions and given the importance of this technique.

This study intends to analyse the magnetized viscous fluid flow on an exponentially extending face which is situated in porous medium with thermal and concentration distribution. The leading equations of this problem are modernized into solvable equations by utilizing similarity transformations. Due to the complexity introduced by the involving non-linear terms, these resulting equations are very difficult to solve analytically. Therefore, we have adapted “MATLAB built-in bvp4c solver technique” to solve these equations. The results of this study are discussed in terms of graphs of the motion, temperature and mass deposition of the fluid with different values of novel parameters. To validate our works, we have compared our numerical values of drag force at the surface with the analytical results of Kumar (2015), which reveals a ideal conformity.

2. MATHEMATICAL FORMULATION:

The following assumptions are made to formulate the present problem:

(i) The two-dimensional, steady and incompressible fluid motion caused due to an exponential form of stretching surface which is situated in porous medium,

(ii) The sheet is characterised by the stretching velocity $U_w(x) = ce^{-\frac{x}{L}}$ where, the constant $c > 0$ corresponds to stretch at the surface of the sheet,

(iii) A variable magnetic $B = \left(0, B_y, 0\right) = B_0 e^{\frac{x}{2L}}$ is applied along the normal direction of the flow and

(iv) Referring Kumar (2015), the form of the variable porosity of the porous medium is $K^* = K_0 e^{-\frac{x}{2L}}$ where, K_0 the constant.

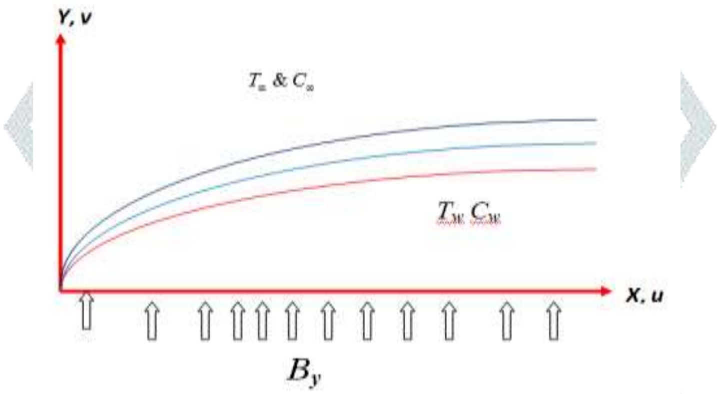

Fig.1 Flow diagram

By using boundary layer assumptions, the governing equations are:

$$\frac{\partial u}{\partial x} = -\frac{\partial v}{\partial y}, \tag{2.1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \upsilon\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_y{}^2}{\rho}u - \frac{\upsilon}{K^*}u \tag{2.2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho C_P}\frac{\partial^2 T}{\partial y^2}, \tag{2.3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - Kr^*(C - C_\infty). \tag{2.4}$$

The interconnected boundary conditions are:

$$\begin{aligned} &y = 0 : u - U_w(x) = 0, v - v_w = 0, T = T_w(x) = T_\infty + T_0 e^{\frac{x}{2L}}, C = C_w(x) = C_\infty + C_0 e^{\frac{x}{2L}}; \\ &y \to \infty : u \to 0, T \to 0, C \to 0. \end{aligned} \tag{2.5}$$

2.1. Similarity Transformation and Similarity Equations:

The following similarity transformations (following Kumar [2]) are utilized to alter the equations [(2.1)-(2.4)] into a set of solvable equations:

$$\psi = \sqrt{2\upsilon Lc}\, e^{\frac{x}{2L}} f(\eta), \eta = \sqrt{\frac{c}{2\upsilon L}}\, y e^{\frac{x}{2L}}, \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}. \tag{2.1.1}$$

Where ψ is characterized in the form of velocity components as $u = \frac{\partial \psi}{\partial y}$ & $v = -\frac{\partial \psi}{\partial x}$. The continuity equation (2.1) is clearly hold and the other equations [(2.2)-(2.4)] become in the following form:

$$Kf''' + Kff'' - 2Kf'^2 - 2KMf' - 2f' = 0\,, \tag{2.1.2}$$

$$\theta'' + \Pr\left(f\theta' - f'\theta\right) = 0\,, \tag{2.1.3}$$

$$\phi'' + Sc\left(f\phi' - f'\phi\right) - ScKr\phi = 0\,. \tag{2.1.4}$$

The relevant boundary conditions (2.5) receive the subsequent form:

$$\eta = 0 : f(\eta) = s, f'(\eta) = 1, \theta(\eta) = 1, \phi(\eta) = 1;$$
$$\eta \to \infty : f'(\eta) \to 0, \theta(\eta) \to 0, \phi(\eta) \to 0. \quad (2.1.5)$$

2.2 Physical Quantity:

In many physical areas, some physical quantities have played an important role to characterize impact of fluid flow at the surface of the geometries. The dimensionless numbers which are very important examined in the present problem are viscous drag coefficient (C_f), thermal diffusion rate at the surface [Nusselt number-(Nu)] and concentration accumulation rate [Sherwood number-(Sh)]. Mathematical expressions of these quantities are:

$$C_f = \frac{\mu}{\rho U_w^2}\left(\frac{\partial u}{\partial y}\right)_{y=0}, Nu = -\frac{L}{T_w - T_\infty}\left(\frac{\partial T}{\partial y}\right)_{y=0} \;\&\; Sh = -\frac{L}{C_w - C_\infty}\left(\frac{\partial C}{\partial y}\right)_{y=0}. \quad (2.2.1)$$

Applying the equation (2.1.1) into equation (2.2.1), we have got the following quantities:

$$C_f\sqrt{2\mathrm{Re}}e^{\frac{x}{2L}} = f''(0), \sqrt{\frac{2}{\mathrm{Re}}}e^{-\frac{x}{2L}}Nu = -\theta'(0) \;\&\; \sqrt{\frac{2}{\mathrm{Re}}}e^{-\frac{x}{2L}}Sh = -\phi'(0). \quad (2.2.2)$$

Where, $\mathrm{Re} = \frac{cL}{\upsilon}$ the Reynolds number.

3. NUMERICAL PROCEDURE:

Due to the complexity introduced by the non-linearity of the coupled equations [(2.1.2)-(2.1.4)], the exact solution is very difficult to obtain. In this study, the MATLAB routine bvp4c scheme [referring, Shampine and Kierzenka (2000), Zaib *et al.* (2016) and Adnan *et al.* (2019)], is employed to solve the coupled equations [(2.1.2)-(2.1.4)] with the analogous boundary condition (2.1.5). The solver needs to follow the following two steps:

(a) Introduction of following variables to convert the system into some first order ordinary differential equations:

$$f = y_1, f' = y_2, f'' = y_3, \theta = y_4, \theta' = y_5, \phi = y_6, \phi' = y_7.$$

Then, the system of equations become:

$$y_1' = y_2, y_2' = y_3, y_3' = 2y_2^2 + 2My_2 + \frac{2}{K}y_2 - y_1y_3;$$
$$y_4' = y_5, y_5' = \Pr\left(y_2y_4 - y_1y_5\right);$$
$$y_6' = y_7, y_7' = Sc\left(y_2y_6 - y_1y_7\right) + KrScy_6.$$

(b) relevant boundary conditions can be written as:

$$y0(1) - s, y0(2) - 1, y0(4) - 1, y0(6) - 1;$$
$$y1(2), y1(4), y1(6).$$

4. DISCUSSION OF THE RESULTS:

In this study, we have focused our intention to find out the influences some flow characteristics: M, K, Kr and s on the consequent flow problem.

4.1 Validation of the results:

In the nonappearance of chemical reaction effects and mass-diffusion equations, the governing equations of this present problem [(2.1)-(2.3)] are equivalent to published work of Kumar (2015). We have compared our numerical values of shear stress at the surface [see **Table-1**] with suction parameter with the results of Kumar (2015) which gives a perfect agreement of the truth of our results.

Table-1. Numerical values of skin friction coefficient $f''(0)$ for exponentially shrinking sheet when $Sc = 0, Kr = 0 \,\&\, \Pr = 0.71$.

Values of s	Value of K	Value of M	Analytical Solutions (Kumar, 2015) of $f''(0)$	Numerical Solutions (Present results) of $f''(0)$
2	0.5	1	0.5938	0.5920
3			1.7500	1.7560
4			2.9805	2.9617
5			4.1540	4.1020

The $f''(0)$ (viscous drag at surface) and $-\phi'(0)$ (mass accumulation per unit time) are shown pictorially for some random values of flow parameters. The Fig. 2(a) portrays the viscous drag aligned with the parameter s for improving values of permeability factor (K). It is perceived that the permeability parameter (K) has ability to develop the shear stress and the same way mass accumulation rate is enhanced at the surface of the sheet with chemical reaction parameter (Kr) [see Fig. 2(b)].

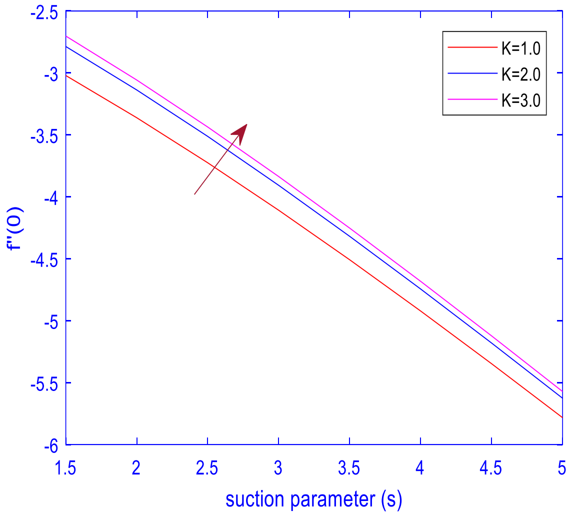

Fig. 2(a) Sketch of Skin friction coefficient.

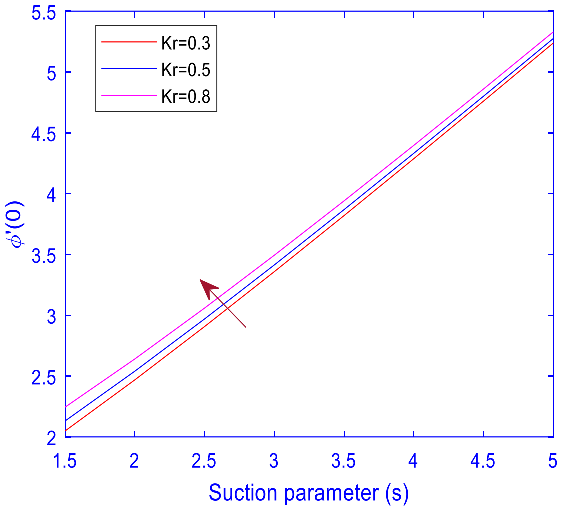

Fig.2(b) Sketch of Sherwood number.

The Fig. 3(a) and Fig. 3(b) reveal the velocity and temperature distributions of the fluid flow with the strong values of M when $K=1 \& Kr=0.1$. Due to the applications of variable magnetic field along the transverse direction of the flow, a resistive type force called " Lorentz Force" is built up which has capability to reduce the speed of the flow and raise the temperature of the fluid. From the Fig. 3(a), it is achieved that motion is retarded with incremental values of M, but the Fig. 3(b) said that the temperature of the fluid grows up with M because the Lorentz force helps to develop Ohmic heating which generates heat. That is we may control the motion of the fluid by applying the magnetic field. But, we should not apply the strong magnitudes of magnetic parameter for which the system may be damaged by the excessive amount of temperature of the fluid.

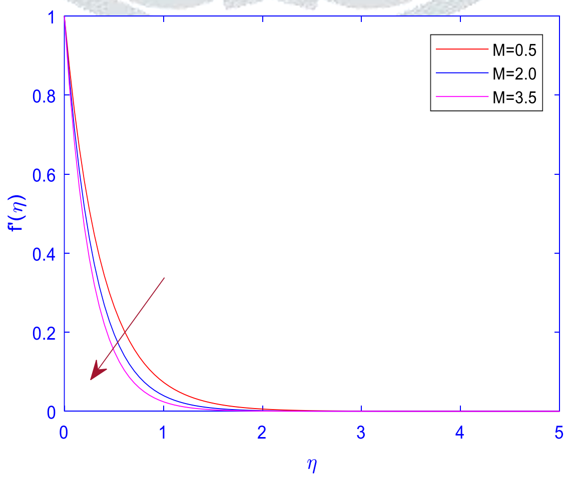

Fig. 3(a) Velocity Profile $f'(\eta)$ when $s=1$.

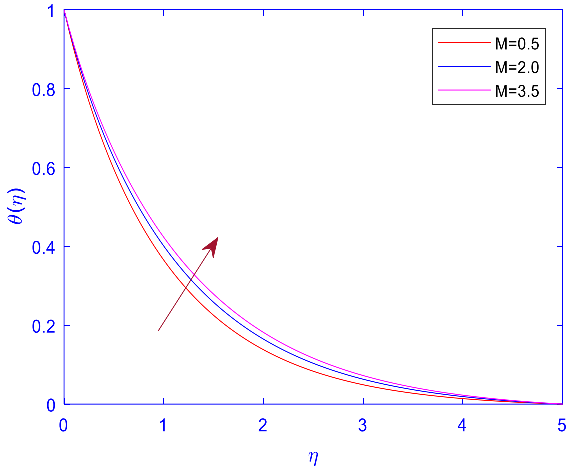

Fig. 3(b) Temperature Profile $\theta(\eta)$ when $s = 0.5$.

The permeability parameter (K) (responsible for porous medium) has the ability to accelerate the fluid motion. The figures [4(a)-4(c)] signify the three flow unknowns from mathematical equations for $M = 0.5$ & $Kr = 0.3$. From these figures, it is noticed that the speed of the fluid enhances with increasing value of K, but an opposite nature observed in the case of temperature and concentration of the fluid.

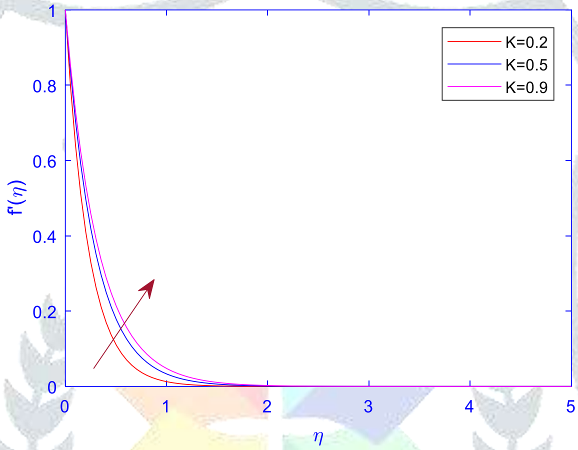

Fig. 4 (a) Velocity Profile when $s = 1.6$.

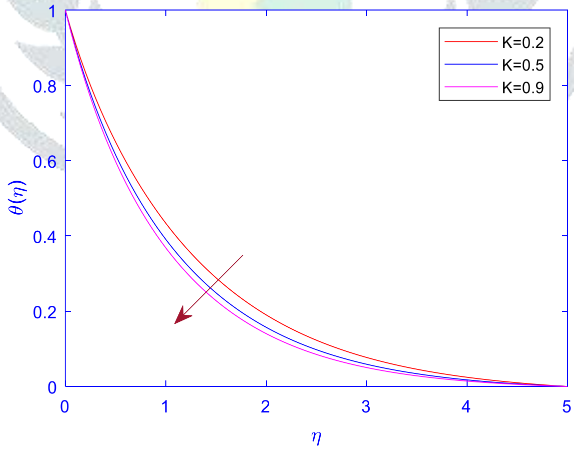

Fig. 4 (b) Temperature Profile when $s = 0.5$.

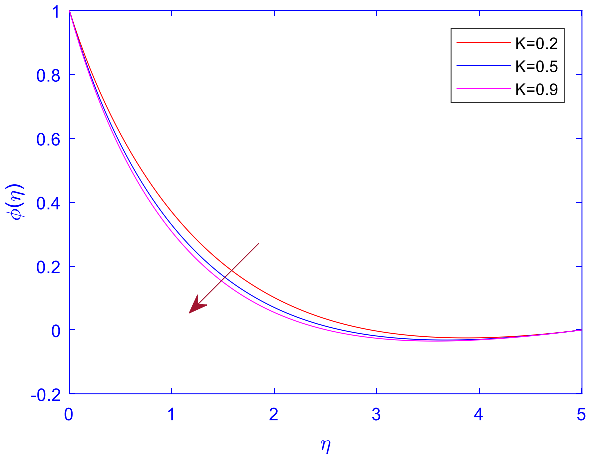

Fig. 4 (c) Concentration Profile when $s=1.6$.

The Fig. 5(a) is depicted to show the effects of Kr on concentration of the fluid flow for $M=0.5\,\&\,K=1$. It is noticed that the mass decomposition of the fluid is higher at the surface of the sheet and then it follows reduction with increasing values of Kr.

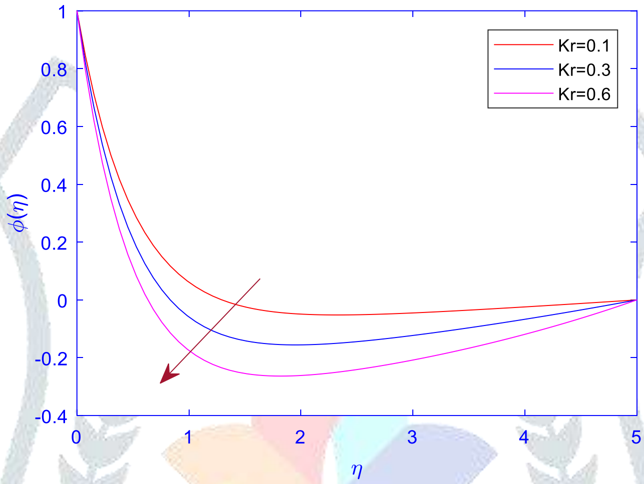

Fig.5 (a). Concentration Profile when $s=1.6$.

5. CONCLUSIONS:

From this study, we have achieved that all the flow distributions have satisfied the far-field boundary conditions asymptotically. The following points concluded from this study are:

- ❖ The permeability and the Chemical reaction parameters have ability to accelerate the shear stress and mass accumulation rate at the surface of the sheet.
- ❖ The magnetic field plays an essential role to control the motion of the fluid, but we should maintain the strength of the magnetic field such that excessive strength of magnetic field damages the system by increasing the temperature of the fluid.
- ❖ The permeability parameter assist to improve the motion of the fluid.
- ❖ The chemical reaction parameter helps to condense the mass deposition of the fluid.

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NOMENCLATURE:

$(u,v)-$ velocity components along $(x,y)-$ directions, $(T_w,C_w)-$ wall temperature and concentration, $(T_\infty,C_\infty)-$ ambient temperature and concentration, $(T,C)-$ temperature and concentration of the fluid, $(L,T_0\,\&\,C_0)-$ characteristics length, temperature and concentration, $(D,k)-$ mass diffusivity and thermal conductivity, $(\sigma,C_p)-$ electrical conductivity and specific heat at constant pressure, $(\mu,\upsilon)-$ dynamic and kinematic viscosity, $M=\frac{\sigma B_0{}^2 L}{\rho c}-$ Magnetic parameter, $K=\frac{K_0 c}{\upsilon L}-$ permeability of the porous medium, $\Pr=\frac{\mu C_p}{k}-$ Prandtl number, $Sc=\frac{\upsilon}{D}-$ Schmidt number, $Kr=\frac{2LKr^*}{ce^{\frac{x}{L}}}-$ local chemical reaction parameter, Kr^*- chemical reaction rate on the species concentration, $s-$ suction/injection parameter, $\psi-$ stream function, C_f- skin friction coefficient, $Nu-$ Nusselt number, $Sh-$ Sherwood number.