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A Stretched Sheet Immersed in a Porous Material Experiences Thermophoretic, Eckert Number, Thermal Radiation Impacts

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ABSTRACT

The exploration of compressible viscous fluid flowing past a heated stretched sheet travelling at variable speed, the magnetic field is applied to a porous substance, and the flow problem covered in this study. This fluid is moving in an unstable two-dimensional MHD laminar driven convective and stable boundary layer flow. Impacts of thermophoresis, thermal radiation viscous dissipation, thermal radiation diffusion, and thermal radiation viscosity. The partial differential equations that appear in the issue's governing equations are changed into a few nonlinear ordinary differential equations with the help of similarity transformations. The translated equations are numerically solved using the bvp4c method. Impacts of numerous parameters on temperature, velocity, and concentration distributions are displayed and analysed using a variety of graphs. Nusselt number and Sherwood number for skin-friction coefficient are examined.

KEYWORDS: MHD, Eckert Number, Thermophoresis, Thermal radiation, Porous medium.

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1. INTRODUCTION

Due to the significance of this material in numerous technical and environmental applications, the study of heat and mass transfer processes involving stretched sheets immersed in porous media has received significant scholarly attention and engineers. Stretched sheets interact with porous media to produce complex physical phenomena as thermal radiation, the Eckert number effect, and thermophoresis. These phenomena must be understood and controlled in order to optimise diverse engineering processes since they affect fluid flow and heat transfer properties both individually and collectively.

In porous structures, the phenomena of thermophoresis, which is influenced by temperature gradients, is essential for regulating particle mobility and deposition. Several studies have been done on the movement of particles in porous media under thermophoretic pressures. Hooper, Chen, and Armaly (1994) studied that Surface injection or suction combined with vertical plate convection in a porous medium. On a Steady MHD Flow over an Inclined Radiative Isothermal Permeable Surface with Variable Thermal Conductivity: impacts of Thermophoresis, Viscous Dissipation, and Joule Heating was analysed by M. G. Reddy (2014). Sarma and Pandit (2018) studied MHD free convection impacts of rotation, hall current, and Soret effects on heat and mass transfer flow through an accelerated vertical plate via a porous material. Saghir and Rahman (2021) researched about using nanofluid as a flow medium, Brownian motion and thermophoretic effects are studied. Kodi and Mopuri (2021) researched about an inclined vertical porous plate is passed by an unstable MHD oscillatory Casson fluid flow while a chemical reaction with Soret effects and heat absorption is present.

The energy conversion and heat transfer properties of a flow system are greatly influenced by Eckert number (Ec), which describes what the proportion of heat transfer to kinetic energy change. Knowing how Ec affects flow and heat transfer behaviour when a stretched sheet is put into a porous medium is essential. Makinde and Aziz (2010) researched about a vertical plate buried in a porous material with convective boundary condition produces MHD mixed convection. A vertical flat plate inserted in a fluid-saturated porous media with viscous dissipation, and impacts of radiation and cross-diffusion on mixed convection from that medium was studied Ahmed, Mohammed and Khidir (2016).

A crucial means of heat transport is thermal radiation, particularly in porous media characterized by intricate geometries and radioactive properties. B. Zigta (2018) investigated how chemical reaction, thermal radiation and viscous dissipation affected MHD flow. Slip Viscous Flow Over a Thermally

Convective Boundary Conditions Porous Sheet Exponentially Stretching; this was researched by Srinivasacharya and Jagadeeshwar (2017). Thermal radiation and chemical reaction are used to create the MHD Williamson nanofluid as it flows past a permeable stretching sheet, was analysed by Patil and co-authors (2022). Y. D. Reddy and et.al (2022) researched about how viscous dissipation and radiation affect MHD heat transfer a nonlinear stretching surface with chemical reaction and Casson nanofluid flow.

In this study work, we start a thorough investigation of multifaceted impacts of thermophoresis, the Eckert number, and thermal radiation on stretched fabric submerged in a porous substance. Our objective is to provide a holistic understanding of these complex interactions through an in-depth review of the relevant literature and the presentation of our own original research findings. The current study is a generalisation of Begum and Sarma's (2020) work that takes into account the impact of thermal radiation and thermophoresis on these flow parameters.

In-depth investigation of the impacts of thermal radiation and heat absorption on an unsteady MHD flow via a porous media on a stretching sheet is the purpose of this work. We intend to gain new insight into the intricate dynamics of such systems by investigating how these components interact, and we also expect to lay the foundation for performance optimisation in a variety of technical applications. In the parts that follow, we'll go over the governing equations, mathematical model, and numerical approaches used to simulate the complex flow and heat transfer behaviour. The study's conclusions will be discussed, with an emphasis on the implications for practical application.

2. MATHEMATICAL FORMULATION

With a heated stretched sheet travelling through a porous material at a variable speed u_w, we investigate the flow of an incompressible viscous fluid in an unstable two-dimensional MHD laminar driven convective and stable boundary layer. All forces, with the exception of the magnetic field, are presumed to be present, and the surface temperature is thought to be uniform and higher than the temperature of the air around it. The velocity's u' and v' components are measured on the x and y axes, which are both perpendicular to the sheet in the direction of motion. The x′ axis is parallel to the stretching surface. The sheet is subjected to a high, uniform B_0 magnetic field.

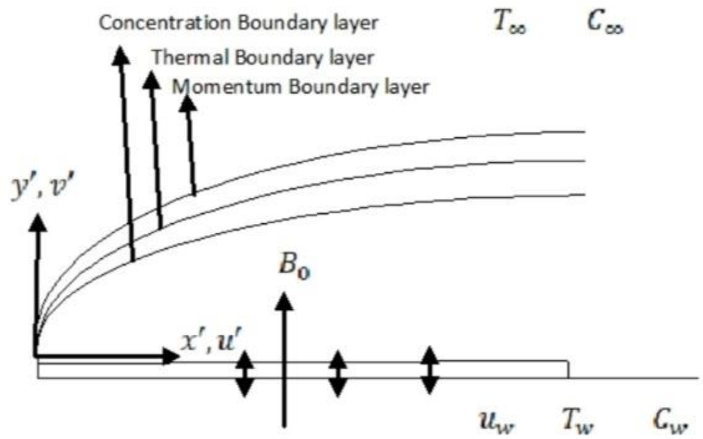

Figure 1: Physical configuration of this problem

The governing equation of the flow of the fluid for this system are:

$$\frac{\partial u'}{\partial x'} + \frac{\partial u'}{\partial y'} = 0 \tag{1}$$

$$\frac{\partial u'}{\partial t'} + u'\frac{\partial u'}{\partial x'} + v'\frac{\partial u'}{\partial y'} = -\frac{1}{\rho}\frac{\partial p}{\partial x'} + \frac{1}{\rho}\frac{\partial}{\partial y'}\left(\mu\frac{\partial u'}{\partial y'}\right) - \mu\frac{\phi}{k}u' - \frac{\sigma B_0^2}{\rho}u' \tag{2}$$

$$\frac{\partial T}{\partial t'} + u'\frac{\partial T}{\partial x'} + v'\frac{\partial T}{\partial y'} = \frac{1}{\rho C_p}\frac{\partial}{\partial y'}\left(k\frac{\partial T}{\partial y'}\right) + \frac{\mu}{\rho C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 - \frac{1}{\rho C_p}Q_0(T - T_\infty) \tag{3}$$

$$\frac{\partial C}{\partial t'} + u'\frac{\partial C}{\partial x'} + v'\frac{\partial C}{\partial y'} = D_m\frac{\partial^2 C}{\partial y'^2} - \frac{\partial}{\partial y'}[V_T(C - C_\infty)] \tag{4}$$

The boundary conditions are

$$u' = u_w(x,t) = \frac{cx}{1-\propto t}\ ; v' = v_w(t) = -v_0\sqrt{\frac{v_* x}{1-\propto t}}\ ; T = T_w(x,t);\ C = C_w(x,t)\ \ at\ \ y' = 0 \tag{5}$$

$$u' \to 0;\ T \to T_\infty;\ C \to C_\infty \quad at\ \ y' \to \infty \tag{6}$$

Using Rosseland approximation, thermal radiation is simulated, and therefore the radiative heat flux q_r' is given by,

$$q'_r = -\frac{4\sigma}{3\alpha^*}\frac{\partial T^4}{\partial y'} \tag{7}$$

where σ is the Stefan-Boltzmann constant and α^* is the Rosseland mean absorption coefficients. The term V_T is defined by;

$$V_T = -\frac{\nu k}{T_r}\frac{\partial T}{\partial y'} \tag{8}$$

The steam function $\psi(x, y)$ is:

$$u' = \frac{\partial \psi}{\partial y'},\ v' = -\frac{\partial \psi}{\partial x} \tag{9}$$

The non-dimensional quantities are:

$$\eta = y\sqrt{\frac{c}{v^*(1-\alpha t)}}\ ;\ \psi = \sqrt{\frac{v^* c}{(1-\alpha t)}}\,xf(\eta);\ T = T_\infty + \frac{c}{2v^* x^2}\sqrt{\frac{1}{(1-\propto t)^3}}\,\theta(\eta);$$

$$C = C_\infty + \frac{c}{2v^* x^2}\sqrt{\frac{1}{(1-\propto t)^3}}\phi(\eta);\ \theta = \frac{T - T_\infty}{T_w - T_\infty};\ \phi = \frac{C - C_\infty}{C_w - C_\infty}; k = k_\infty(1+\beta\theta);$$

$$\theta_r = \frac{T_r - T_\infty}{T_w - T_\infty};\ \mu = \mu_\infty\frac{\theta_r}{\theta_r - \theta}; Pr = \frac{\mu c_p}{k}; Sc = \frac{v^*}{D_m}; A = \frac{\propto}{c};\ v^* = \frac{\mu_\infty}{\rho};\ k_1 = \frac{k'(1-\alpha t)}{c};$$

$$M = \frac{\propto B_0^2(1-\alpha t)}{\rho c}; Q = \frac{Q_0 v}{U_0^2};\ \tau = -\frac{k(T_w - T_\infty)}{T_r}$$

With the help of these quantities the dimensionless equations are:

$$f''' = A\,\frac{\theta_r - \theta}{\theta_r}\left(\frac{\eta}{2}f'' + f'\right) + \frac{\theta_r - \theta}{\theta_r}f'^2 - \frac{\theta_r - \theta}{\theta_r}ff'' - \frac{\theta'}{\theta_r - \theta}f'' + M\frac{\theta_r - \theta}{\theta_r}f' + Kf' \tag{10}$$

$$\Pr\left(\frac{\theta_r - \theta}{\theta_r}\right)\left(\frac{1}{2}A\eta\theta' + \frac{3}{2}A\theta - 2f'\theta - f\theta'\right) = (1+\beta\theta)\beta\theta'^2 + \theta'' + EcPrf''^2 - Q\theta \tag{11}$$

$$\frac{1}{2}A\eta\phi' + \frac{3}{2}A\phi - 2f'\phi - f\phi' = \frac{1}{Sc}\phi'' + \tau(\theta'\phi' + \phi\theta'') \tag{12}$$

Here A is Unsteady parameter, K porous medium parameter, M Hartmann number, Ec, Pr, Sc, τ are respectively The Eckert number, Prandtl number, Schmidt number and thermophoretic parameter; Q is heat absorption parameter, θ_r viscosity parameter.

And the non-dimensional boundary conditions are:

$$f = f_w; f' = 1;\ \theta = 1;\ \phi = 1 \quad at \quad \eta = 0 \tag{13}$$

$$f' = 0;\ \theta = 0;\ \phi = 0 \quad at \quad \eta \to \infty \tag{14}$$

3. RESOLUTION OF THE PROBLEM

By utilising all this dimensionless quantities, equations (1) - (4) with boundary conditions (5) to (6) are altered to become non-dimensional equations (10) to (12) together with the boundary conditions (13) to (14) and then these calculations are used to solve byBVP4C technique in MATLAB. By using this method, it is also possible to find numerical values for velocity, temperature and species concentration of the fluid. Also, analysis is done on the different Skin Friction, Nusselt, and Sherwood numbers' numerical values.

4. RESULTS AND DISCUSSION

Given the aforementioned considerations, the problem is numerically solved, and the behaviour of velocity, concentration along with temperature for different parameters—like porous media parameter (K),heat absorption parameter (Q), unsteadiness parameter (A), Eckert number (Ec), thermophoretic parameter (τ) and Schmidt number (Sc)are shown.

As seen in Fig. 2-4, the concentration increases as the unsteadiness parameter A increases, yet the velocity and temperature decrease. It is discovered that the velocity boundary layer thickness and the unsteadiness parameter both grow with time. Figure5 to 7, a graphic representation of the temperature, velocity and concentration distribution for various values of the Eckert number Ec versus is presented. The fluid's temperature and velocity rises, as Ec rises, but the fluid's concentration falls down. The values of fluids concentration, velocity as well as the temperature will decrease with the increasing value of porous media parameter K are shown in fig.8-10. As the value of Kgrows illustrates how an increase in K, resulting in a rise in velocity on the border of the system. The variation in velocity, temperature, and concentration as the value of the heat absorption parameter Q rises is seen in Fig 11-13. It is evident that when the value of Q increases, fluid's velocity along with temperature profile decrease while its concentration rises. Fig-11 describes a reduction in fluid speed when value of Q grows slowly, this is due to the buoyancy force's ability to reduce velocity in the presence of Q. The impact of the concentration profile's thermophoretic parameter and Schmidt numberare presentedin fig14 and 15. The fluid's concentration will drop as Sc increases in value showed in fig 14 but the fluid concentration will rise with growing thermophoretic parameter displayed in fig 15. Sc increases the effectiveness of mass and momentum transmission in the boundary layer concentration because it is a ratio of momentum to mass diffusivity. The reason for increase the concentration is that as the thermophoretic parameter rises, fluid particles begin to migrate away from cool environments.

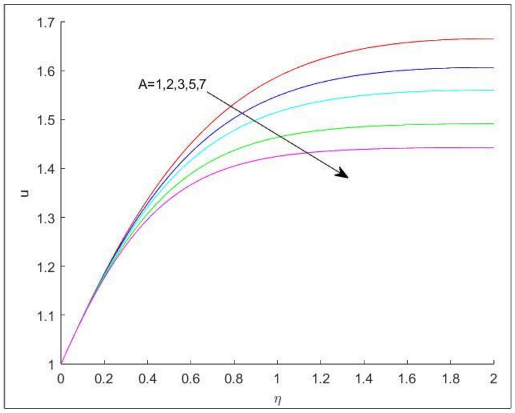

Figure 2 Velocity variation with A

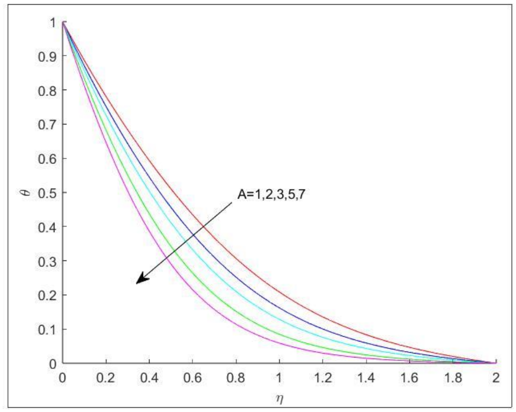

Figure 3 Temperature variation with A

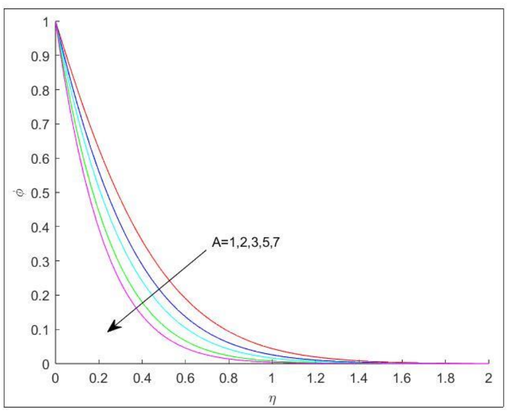

Figure 4 concentration changes with A

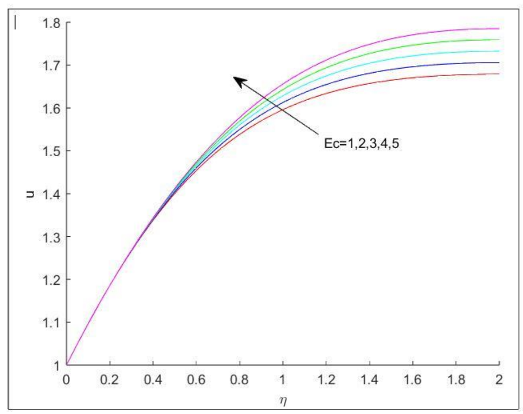

Figure 5 velocity variation with Ec

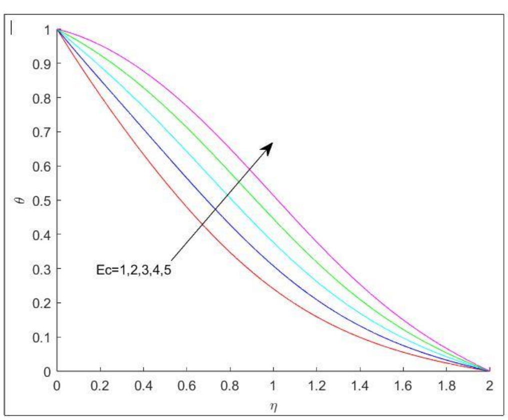

Figure 6 temperature variation with Ec

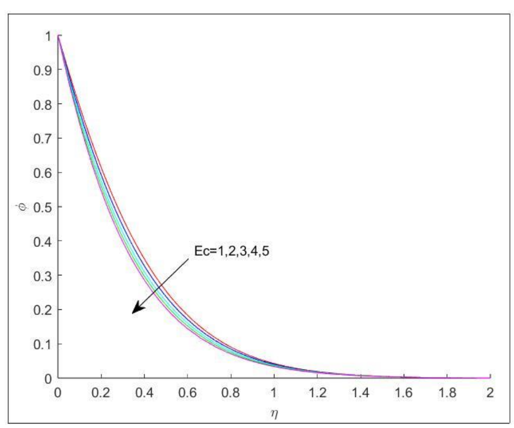

Figure 7 concentration variation with Ec

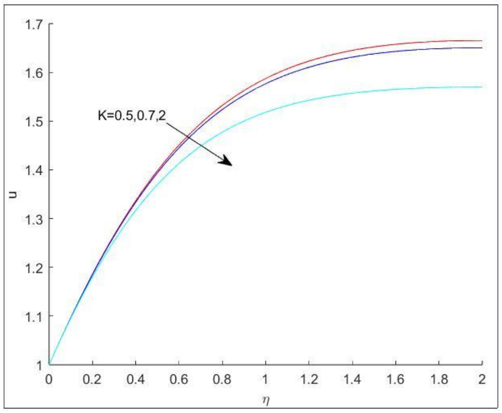

Figure 8 velocity variation with K

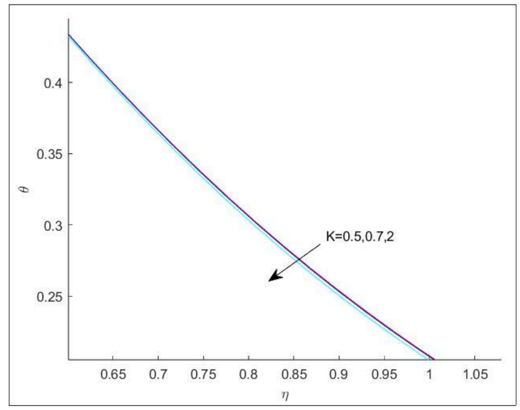

Figure 9 temperature variation with K

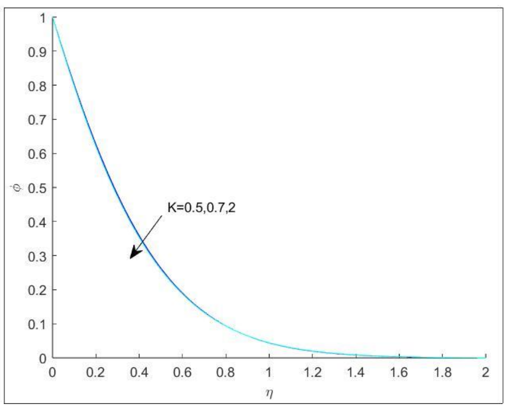

Figure 10 concentration variation with K

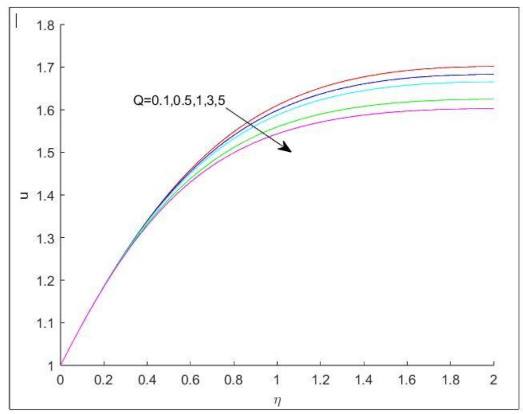

Figure 11 velocity variation with Q

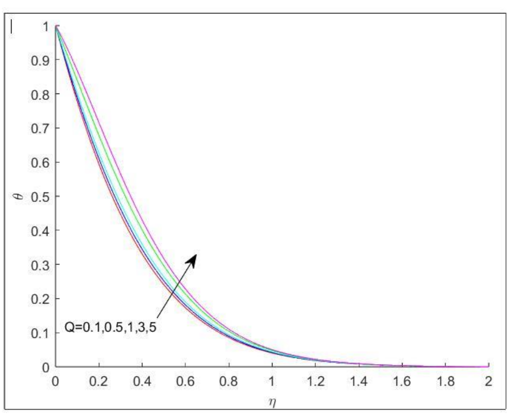

Figure 12 temperature variation with Q

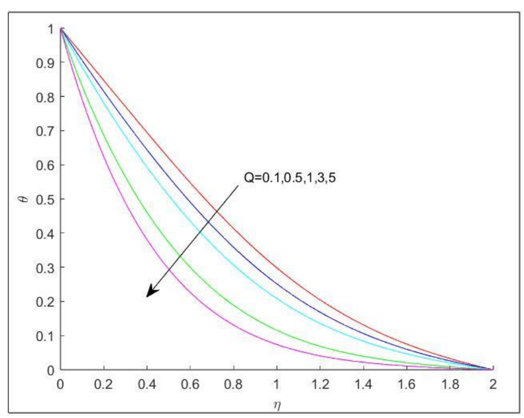

Figure 13 concentration variation with Q

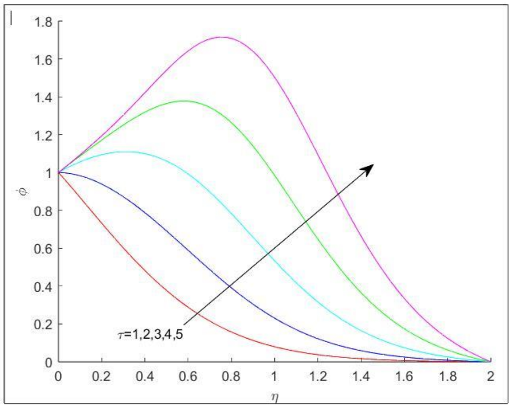

Figure 14concentration variation with Sc

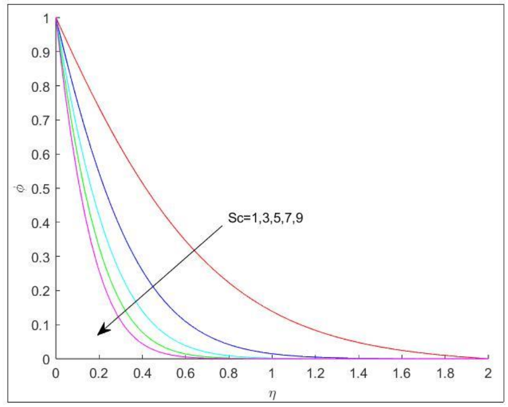

Figure 15 concentration variation with τ

Table-1: Values of C_f,Nu and Sh for various values of Q; Ec; τ; Sc.

Q	Ec	τ	Sc	C_f	Nu	Sh
1				0.5821	1.1834	2.0854
2	0.5	0.1	2	0.5563	1.5422	1.7926
3				0.5395	1.8394	1.5476
	0.2			0.5735	1.2766	2.0127
2	0.5	0.1	2	0.5821	1.1834	2.0854
	1			0.5969	1.0363	2.2005
		0				2.9963
2	0.5	0.1	2	0.5821	1.1834	2. 8075
		0.5				2.0854
			1			1.4053
2	0.5	0.1	2	0.5821	1.1834	2.0854
			3			2.6800

Table -1 displays the values forskin friction(C_f), Nusselt number (Nu)andSherwood number(Sh). The table shows that as the buoyancy forces increase, the local skin-friction coefficient, local heat transfer, and local mass transfer at the plate all increase. It was observed that as Q, Ec, and Sc increase, local skin-friction coefficient increases while the local heat and mass transfer rates at the plate drop. Sherwood number falls as Q or τ rises. While Nu decreases with rising Ec, the Nusselt number rises with rising Q.

5. CONCLUSION

This study investigated the two-dimensional unsteady MHD convective laminar forced and stable boundary layer flow past a heated stretched sheet moving at a variable speed in a porous medium under the influence of Dufour effects, thermal diffusion and radiation. The governing equations of the problem are similarly transformed to ODEs. The bvp4c approach is used to solve these equations. The results are examined and represented graphically. The following results are examined.

The investigation done for this project yields the following findings:

- When a thermophoretic parameter's value grew, the fluid's velocity rose.
- Eckert's number Ec reduces the fluid's concentration while raising its temperature and velocity.
- The temperature profile, velocity and concentration distribution all drop due to rise in unsteady parameter.
- Temperature and fluid's velocity falls with rises in Q values, but concentration dispersion increases.
- A higher Kvalue causes the velocity, concentration as well as temperature to drop.
- The local skin friction increases with Q *and* Ec whereas Nusselt number decrease with Q; but increase with Ec.
- The local Sherwood number grow with growing Ec *and* Sc; whereas falls down with rising Q *and* τ.

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