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Unsteady MHD Flow and Heat Transfer in Stretching Vertical Channel Embedded in a Porous Medium

Monika Miglani

Department of Mathematics
Haryana College of Technology & Management Kaithal-136027
Email: monika.kalra01@gmail.com

N. R. Garg

Department of Mathematics
M. D. University, Rohtak-124001
Email: nrgarg.math@gmail.com

Mukesh Kumar Sharma

Department of Mathematics
Guru Jambheshwer University of Science & Technology
Hisar-125001
Email: drms123@gmail.com

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Abstract: An analysis of unsteady MHD flow in a vertical channel embedded in a porous medium in the influence of a static transverse magnetic field $B(0, B_0, 0)$ is presented. The channel consisting two parallel plates which are stretched continuously in their own plane. One of the plates is permeable which subjected with a constant suction. The governing equations of motion and energy derived under usual Boussinesq approximations are nonlinear partial differential equations and solved with similarity transformations and Differential Transform Method (DTM). The effects of different physical parameters, namely Prandtl number Pr, Grashof number Gr, Hartmann number M, porosity parameter N and unsteadiness parameter S on the velocity and temperature distribution are computed, analyzed and shown through graphs. The suction velocity at the permeable plate can be implemented to control the skin friction at the plates of the channel. It is observed that higher order of unsteadiness in the stretching of plates enhances shear stress at both the plates.

Key words: Unsteady Flow; Stretching Plates; MHD; Porous Medium; Suction; Differential Transform Method (DTM).

AMS Mathematics Subject Classification: 76Dxx.

1. Introduction

MHD free-convection flows have great importance for the applications in the fields of planetary and terrestrial magnetospheres, aeronautics, chemical engineering, and electronics. The study of flow through porous medium is of great use in the fields of geophysics, agricultural engineering and technology. The interest in magnetohydrodynamics (MHD) convective flows with heat transfer is enhanced due to its importance in the design of MHD generators and accelerators in geophysics, in systems like underground water and energy storage. Study of flow over a stretching sheet has numerous significant importances in industrial, technological and engineering R & D. Extrusion processes, fibers spinning, manufacturing of plastic and rubber sheet, continuous casting and glass blowing are some of the examples of industrial applications of stretching of a surface in an ambient fluid. Flows past a stretching sheet have been extensively studied by several researchers theoretically and experimentally. The good amount of literature on MHD flow and heat transfer in porous medium has been generated by Eckert and Drake[1], Bear[2] , Jeffrey[3] , Bansal[4] and Schlichting[5] . Vafai and Tien[6] explained the effects of boundary and inertia on flow and heat transfer in porous media. Borkakoti and Bharali[7] worked out the MHD flow and heat transfer of a conducting fluid in a horizontal parallel plates channel with upper plate is porous and lower one is stretching. Kim and Vafai[8] analyzed natural convection about a vertical plate embedded in a porous media. Soundalgekar and Bhatt[9] examined laminar convection flow through a porous medium between two vertical plates. Nakayama et al.[10] have studied free convection through a porous medium between two paralleled plate channels. Kim et al.[11] considered free and forced convection through a porous medium between two paralleled plate channels. Attia and Kotb[12] have considered MHD flow and heat transfer between two parallel plates. Sharma and Sharma[13] discussed unsteady flow and heat transfer between two parallel plates. Sharma and Kumar[14] investigated unsteady flow and heat transfer between two horizontal plates in the presence of transverse magnetic field. Al-Nimr and Haddad[15] have elucidated the fully developed free convective flow in vertical channels with open ends and filled with porous material. Sharma and Mishra[16] investigated Steady MHD flow in a horizontal channel. The lower plate is stretching sheet and upper being permeable plate bounded by porous medium partially. Sharma and Chaturvedi[17] discussed unsteady flow and heat transfer of an electrically conducting viscous incompressible fluid between two non-conducting parallel porous plates under uniform transverse magnetic field. Sharma *et al.*[18] studied unsteady flow and heat transfer of a viscous incompressible fluid between parallel porous plates with heat source/sink. Sharma *et al.*[19]

investigated unsteady plane poiseuille flow and heat transfer in the presence of oscillatory temperature of the lower plate.

Sharma and Mehta[20] investigated MHD Unsteady slip flow and heat transfer in a channel with slip at the permeable boundaries. Guria et al.[21] have discussed three-dimensional free convection flow in a vertical channel filled with a porous medium. Ishak[22] investigated unsteady flow and heat transfer over a stretching plate in the presence transverse static magnetic field. Rashidi et al.[23] have obtained the stream function and temperature profiles for magnetohydrodynamic flow in a laminar liquid film from a horizontal stretching surface using Differential Transform Method and Pade Approximant. Free convection flow in a vertical channel embedded in porous media in the presence of radiation is discussed by Das et al.[24]. Jana et al.[25] obtained convection of radiating gas in a vertical channel through porous media. Rath et al.[26] observed three-dimensional free convection flow through porous medium in a vertical channel with heat source and chemical reaction. Kar et al.[27] have considered three-dimensional free convection MHD flow in a vertical channel through a porous medium in presence of heat source and chemical reaction. Cai et al.[28] has investigated unsteady convection flow and heat transfer over a vertical stretching surface. Unsteady MHD heat and mass transfer over a stretching sheet in porous medium with variable physical properties considering viscous dissipation and chemical reaction have been investigated by Hunegnaw et al.[29]. Prakash et al.[30] has investigated unsteady MHD flow over a vertical stretching plate embedded in a non-Darcy porous medium with non-uniform heat generation. Sharma and Mehta[31] has analyzed oscillatory flow of a viscous electrically conducting fluid and heat transfer through porous medium filled in a vertical channel in the presence of chemical reaction and heat source. The aim of the present study is to investigate the unsteady MHD flow and heat transfer through continuously stretching vertical channel embedded in a porous medium subjected to a uniform suction on one permeable plate.

2. Formulation of the Problem

The present model (Figure1) consist two parallel vertical plates of semi-infinite length placed at a distance H apart. The x-axis is taken vertically upward and y-axis is normal to it in the horizontal direction. One of the plates is taken along x-axis and the second plate is placed at a distance H in positive direction of y-axis. The plate at $y = H$ is impermeable while the plate at $y = 0$ is permeable subjected under time dependent suction. The temperature on both the plates is time dependent. Both the plates are stretched continuously in their own plane in positive x-direction with

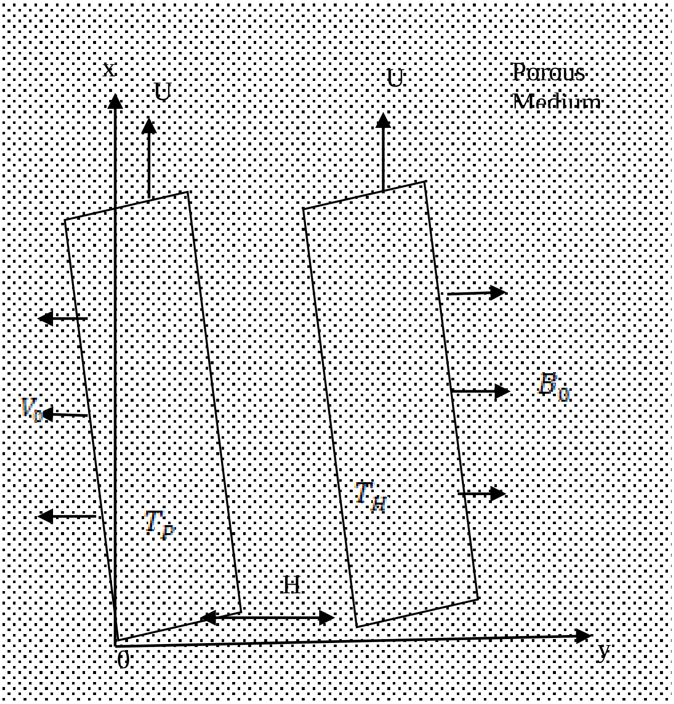

Figure 1. Geometry of the problem

velocity $U = \dfrac{bx}{1-at}$. A static transverse magnetic field $B(0, B_0, 0)$ of moderate intensity is applied. The current density $\vec{J}$ is defined by the generalized Ohm's law is given by $\vec{J} = \sigma(\vec{E} + \vec{V} \times \vec{B})$. Under the assumption of moderate magnetic field, the induced electric field is assumed to be negligible; therefore the Lorenz force on the flow field is given by $\vec{J} \times \vec{B} = -\sigma B_0^2 u\,\hat{i}$, where, σ is the electrical conductivity of the fluid. The plates are of semi-infinite length and flow is two dimensional, therefore $w = 0$, $\dfrac{\partial}{\partial z}(.) = 0$.

The equation of continuity for two-dimensional viscous incompressible fluid flows is

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

where (u,v) are component of fluid velocity along x and y axis respectively.

The governing equations of motion and heat equation for viscous incompressible fluid flow in the presence of magnetic field with usual Boussinesq approximation are given by

(2.2) $$\rho\frac{\partial u}{\partial t}+\rho(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y})=-\frac{\partial p}{\partial x}+\rho g\beta(T-T_0)$$
$$+\mu(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2})-\frac{\mu}{\kappa}u-\sigma B_0^2 u,$$

(2.3) $$\rho\frac{\partial v}{\partial t}+\rho(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y})=-\frac{\partial p}{\partial y}+\mu(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2})-\frac{\mu}{\kappa}v,$$

(2.4) $$\rho C_p\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\kappa\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right).$$

The associated boundary conditions are

(2.5) $$\begin{cases} y=0: \; u=U=\dfrac{bx}{1-at}, \quad v=V_0, \quad T=T_p=\dfrac{dx}{1-at} \\ \\ y=H: \; u=\dfrac{bx}{1-at}, \quad v=0, \quad T=T_H=\dfrac{cx}{1-at} \end{cases}$$

where, p the pressure, ρ the density of the fluid, μ the viscosity of the fluid, κ the thermal conductivity of the fluid, C_P specific heat of the fluid, β the coefficient of volumetric thermal expansion of fluid, T temperature of the fluid, T_P the temperature of the permeable plate, T_H the temperature of the plate at $y=H$, a and b are positive constants with dimension $(time)^{-1}$, c and d are constants.

3. Method of Solution

In order to solve the coupled non-linear partial differential equations (2.2) to (2.4), we introduce the following similarity transformation

$$\eta = \left(\frac{b}{\upsilon(1-at)} \right)^{\frac{1}{2}} y, \tag{3.1}$$

$$\psi = \left(\frac{\upsilon b}{1-at} \right)^{\frac{1}{2}} x\, f(\eta), \tag{3.2}$$

$$\theta(\eta) = \frac{T - T_0}{T_H - T_0}\ , \quad \text{here } T_0 = \frac{(T_P + T_H)}{2} \tag{3.3}$$

and the stream function ψ as $u = \partial\psi/\partial y = bx/(1-at)\ f'(\eta)$ and $v = -\partial\psi/\partial x = -\sqrt{b\upsilon/(1-at)}\ f(\eta)$, then the equation of continuity is identically satisfied.

On eliminating the pressure term from the equation (2.2), (2.3) and invoking transformation given by (3.1) to (3.3), the equation of motion and heat equation are given by

$$\left(3/2\,S + \gamma^{-2} M + N\right) f'' + S/2\,\eta f''' + f f'' - f f''' - f^{1V} = Gr\theta', \tag{3.4}$$

$$S[\theta + \eta\theta'/2 + \lambda] + f'(\theta + \lambda) - f\theta' = 1/\Pr\theta''. \tag{3.5}$$

Here, primes denote differentiation with respect to η. The dimensionless parameters pertinent in the problem are, $S = a/b$ the parameter of unsteadiness, $Gr = (c-d)(1-at)g\beta/b^2$ the Grashoff number, $M = \sigma B_0^2 H^2/(\rho\upsilon)$ the Hartmann number, $N = (1-at)\nu/(\mathrm{b}\kappa)$ the porosity parameter, $Pr = \mu C_p/\kappa$ the Prandtl number and $\lambda = (c+d)/(c-d)$. The corresponding boundary conditions are

$$(3.6)\qquad \begin{cases} f'(0)=1, \quad f(0)=V, \quad \theta(0)=-1 \ at\,\eta=0 \\ f'(\eta)=1, \ f(\eta)=0, \quad \theta(\eta)=1 \quad at\,\eta=\gamma \end{cases}$$

where, $V=V_0\sqrt{1-at/b\upsilon}$ is suction/ injection parameter (for suction $V<0$) and $\gamma=\sqrt{b/\nu(1-at)}H$. In particular, taking the dimensionless parameter $\gamma=1$.

The equations (3.4) and (3.5) are non-linear ordinary differential equations are attempted to solve by the Differential Transform Method, Zhou[32]. The fundamental results of the DTM are listed in the Appendix A.

Let $F(k)=\frac{1}{k!}[\frac{d^k f(\eta)}{d\eta^k}]_{\eta=0}$ and $\Theta(k)=\frac{1}{k!}[\frac{d^k\theta(\eta)}{d\eta^k}]_{\eta=0}$ are the differential transform of $f(\eta)$ and $\theta(\eta)$ respectively, then on applying DTM on the equations (3.4) and (3.5), the recurrence relations in transform space with parameter k are

$$(3.7)\qquad \begin{cases} F(k+4)=\dfrac{1}{(k+1)(k+2)(k+3)(k+4)}[A_1(k+1)(k+2)F(k+2) \\ \qquad +\dfrac{S}{2}\sum\limits_{r=0}^{k}\delta(r-1)(k-r+1)(k-r+2)(k-r+3)F(k-r+3) \\ \qquad -\sum\limits_{r=0}^{k}F(r)(k-r+1)(k-r+2)(k-r+3)F(k-r+3) \\ \qquad +\sum\limits_{r=0}^{k}(r+1)F(r+1)(k-r+1)(k-r+2)F(k-r+2) \\ \qquad -Gr(k+1)\theta(k+1)]. \end{cases}$$

$$(3.8)\qquad \begin{cases} \Theta(k+2)=\Pr/(k+1)(k+2)\left[S\left\{\Theta(k)+1/2\sum\limits_{r=0}^{k}\begin{matrix}\delta(r-1)(k-r+1)\Theta(k-r+1) \\ +\lambda\,\delta(k)\end{matrix}\right\}\right. \\ \qquad +\sum\limits_{r=0}^{k}(k-r+1)\Theta(r)F(k-r+1)+\lambda(k+1)F(k+1) \\ \qquad \left.-\sum\limits_{r=0}^{k}(k-r+1)\Theta(k-r+1)F(r)\right]. \end{cases}$$

The boundary conditions at $\eta=0$ are transformed into

$$F(0)=V, \quad F(1)=1, \quad \Theta(0)=-1 \tag{3.9}$$

The boundary conditions at $\eta=1$ are transformed into

$$\sum_{k=0}^{N}\gamma^k F(k)=0, \quad \sum_{k=0}^{N}\gamma^k kF(k+1)=1, \quad \sum_{k=0}^{N}\gamma^k \Theta(k)=1. \tag{3.10}$$

Since, initial values of $f''(\eta)$, $f'''(\eta)$ and $\theta'(\eta)$ are unknown, therefore $F(2)$, $F(3)$ and $\Theta(1)$ are not known. Let, $F(2)=a_1, F(3)=a_2, \Theta(1)=b_1$ where a_1, a_2 and b_1 are unknown constants, to be determined by using prescribed boundary conditions.

For $k=0,1,......5,$ the equations (3.7) and (3.8) gives

$$F(4)=\frac{1}{24}[(2A_1+2)a_1-6.V.a_2-Grb_1],$$

$$F(5)=\frac{1}{5!}[a_1(A_4)+A_5a_2+b_1(D_3)+4a_1^2-2GrA_2]$$

$$F(6)=\frac{1}{360}[\{A_6a_1+a_2A_7+b_1A_8-2Va_1^2+12a_1a_2+A_9]$$

,

$$F(7)=\frac{1}{840}[A_{18}a_1+A_{19}a_2+b_1A_{20}+a_1b_1A_{21}+A_{22}+a_1^2A_{23}+12a_2^2-6Va_1a_2]$$

$$\Theta(2)=A_2+A_3b_1, \quad \Theta(3)=\frac{\Pr}{6}[D_1b_1+2a_1(\lambda-1)-D_2]$$

$$\Theta(4)=\frac{\Pr}{12}[A_{10}+a_1A_{11}+A_{12}b_1+3a_2(\lambda-1)+a_1b_1]$$

$$\Theta(5)=\frac{\Pr}{20}[A_{13}a_1+A_{14}a_2+A_{15}b_1+A_{16}a_1b_1+2a_2b_1+A_{17}]$$

$$\Theta(6)=\frac{\Pr}{30}[A_{24}a_1+A_{25}a_2+A_{26}b_1+A_{28}a_1^2-\frac{Gr}{8}b_1^2+A_{27}a_1b_1+A_{29}a_2b_1+A_{30}]$$

$$\Theta(7)=\frac{\Pr}{42}[A_{31}a_1+A_{32}a_2+A_{33}b_1+A_{34}a_1b_1+A_{35}a_2b_1+A_{36}a_1a_2 + A_{37}a_1^2+A_{38}b_1^2+A_{39}a_1^2b_1+A_{40}].$$

Under these values in the inversion of $F(k)$ and $\Theta(k)$, the expression for $f(\eta)$ and $\theta(\eta)$ are given by

(3.11) $$\begin{cases} f(\eta)=F(0)+F(1)\eta+F(2)\eta^2+F(3)\eta^3+F(4)\eta^4 \\ \qquad +F(5)\eta^5+F(6)\eta^6+F(7)\eta^7. \end{cases}$$

(3.12) $$\begin{cases} \theta(\eta)=\Theta(0)+\Theta(1)\eta+\Theta(2)\eta^2+\Theta(3)\eta^3+\Theta(4)\eta^4 \\ \qquad +\Theta(5)\eta^5+\Theta(6)\eta^6+\Theta(7)\eta^7. \end{cases}$$

The boundary conditions at $\eta=1$, gives the following the following system of non-linear algebraic equations in the unknowns a_1, a_2 and b_1 is obtained

(3.13) $$K_1a_1+K_2a_2+K_3b_1+K_4a_1^2+K_5a_2^2+K_6a_1b_1+K_7a_1a_2=K_8$$

(3.14) $$N_1a_1+N_2a_2+N_3b_1+N_4a_1^2+N_5a_2^2+N_6a_1b_1+N_7a_1a_2=N_8$$

(3.15) $$L_1a_1+L_2a_2+L_3b_1+L_4a_1^2+L_5b_1^2+L_6a_1b_1+L_7a_2b_1 +L_8a_1a_2+L_9a_1^2b_1=L_{10}.$$

where, K_1 to K_8; N_1 to N_8 and L_1 to L_{10} are constants whose expressions for the sake of brevity are not mentioned here. Using MATLAB, the system of equations (3.13) to (3.15) are solved numerically using modified Newton's Method for the unknown constants a_1, a_2 and b_1 at each set of physical parameters pertinent to the model. The effects of different physical parameters on the velocity and temperature profiles are computed and analyzed through graphs.

4. Skin Friction Coefficient

The non-dimensional shearing stress in terms of local skin-friction coefficient is obtained on the surface of the channel and computed values are given in the Table-1.

$$C_f = \tau_H / (\frac{\rho U^2}{2}) = \mu(\frac{\partial u}{\partial \eta}) / (\frac{\rho}{2}U^2). \tag{4.1}$$

5. Nusselt Number

The non-dimensional coefficient of heat transfer is derived on the surface of the channel and computed values are given in the Table-2.

$$Nu = q_\eta x / \kappa(T_H - T_0) = x(-\kappa \frac{\partial T}{\partial y}) / \kappa(T_H - T_0). \tag{5.1}$$

Table 1: Numerical values of skin friction coefficient on the surface of the channel for various values of physical parameters

S	M	N	Gr	Pr	V	C_f (at η=0)	C_f (at η=1)
1.2	2	2	10	0.1	-1.5	0.8454	-5.1388
0.5	2	2	10	0.1	-1.5	0.8120	-5.1044
1.2	5	2	10	0.1	-1.5	0.9537	-5.0406
1.2	8	2	10	0.1	-1.5	1.0468	-5.0151
1.2	2	0.1	10	0.1	-1.5	0.7724	-5.2121
1.2	2	1	10	0.1	-1.5	0.8072	-5.1776
1.2	2	2	20	0.1	-1.5	0.2791	-6.3574
1.2	2	2	30	0.1	-1.5	-0.2460	-7.3061
1.2	2	2	10	0.71	-1.5	1.0218	-5.1065
1.2	2	2	10	1	-1.5	1.1089	-4.9695
1.2	2	2	10	0.1	-0.5	-2.0267	3.3215
1.2	2	2	10	0.1	-2.5	3.5556	-13.1213
1.2	2	2	10	0.1	-3.5	5.9870	-21.9102

Table 2: Numerical values of Nusselt number on the surface of the channel for various values of physical parameters

S	M	N	Gr	Pr	V	Nu (at η=0)	Nu (at η=1)
1.2	2	2	10	0.1	-1.5	1.7284	2.3590
0.5	2	2	10	0.1	-1.5	1.7766	2.2704
1.2	5	2	10	0.1	-1.5	1.7284	2.3590
1.2	8	2	10	0.1	-1.5	1.7287	2.3573
1.2	2	0.1	10	0.1	-1.5	1.7285	2.3579
1.2	2	1	10	0.1	-1.5	1.7285	2.3585
1.2	2	2	20	0.1	-1.5	1.7275	2.3674
1.2	2	2	30	0.1	-1.5	1.7267	2.3739
1.2	2	2	10	0.71	-1.5	0.5468	4.7686
1.2	2	2	10	1	-1.5	0.1931	6.0544
1.2	2	2	10	0.1	-0.5	1.8540	2.2261
1.2	2	2	10	0.1	-2.5	1.6020	2.5434
1.2	2	2	10	0.1	-3.5	1.4788	2.7609

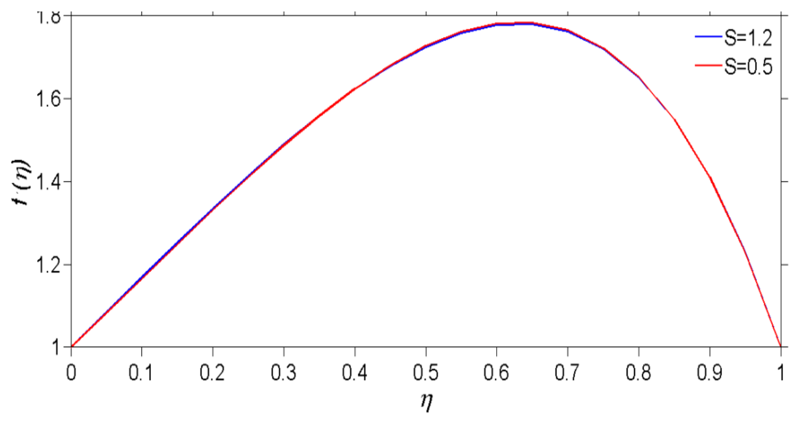

Fig 2. Variation in velocity with unsteadiness parameter S

at Pr =0.1; M =2; N =2; V =-1.5; Gr =10; λ =1.5

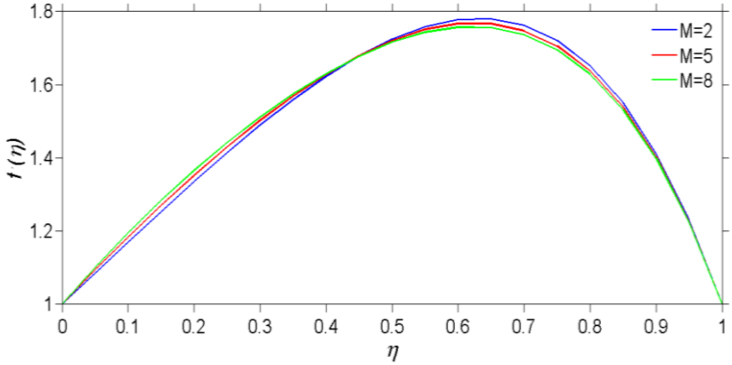

Fig 3. Variation in velocity with Magnetic parameter M at Pr =0.1; N =2; S =1.2; V =-1.5; Gr =10; λ =1.5

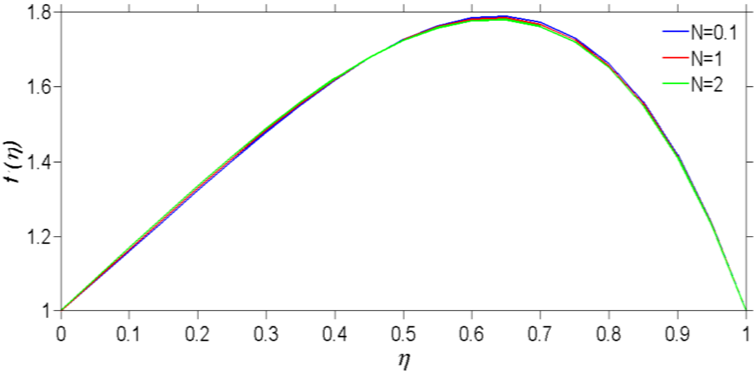

Fig 4. Variation in velocity with porosity parameter N at Pr =0.1; M =2; S =1.2; V =-1.5; Gr =10; λ =1.5.

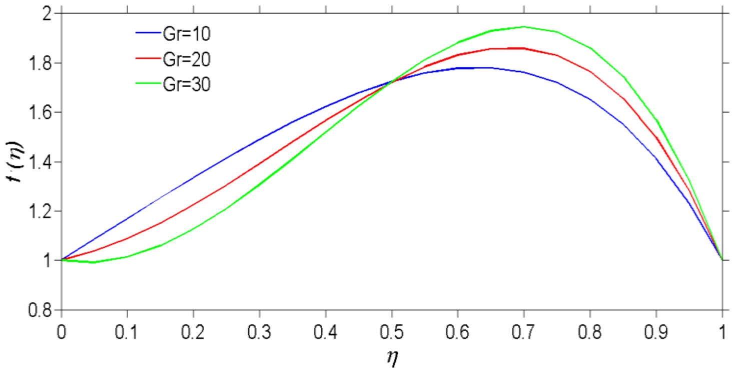

Fig 5. Variation in velocity with Grashof number Gr at Pr =0.1; M =2; N =2; S =1.2; V =-1.5; λ =1.5

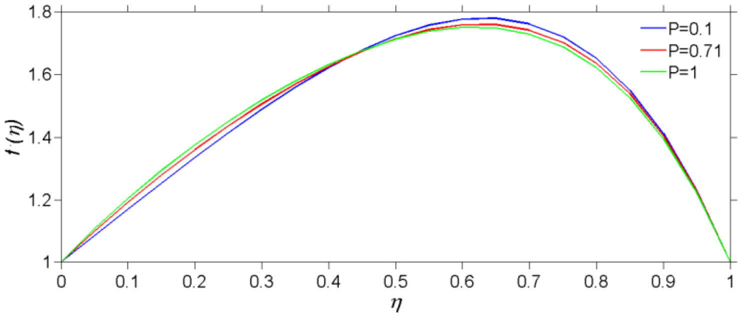

Fig 6. Variation in velocity with Prandtl number Pr
at M =2; S =1.2; V =-1.5; Gr =10; N =2; λ =1.5

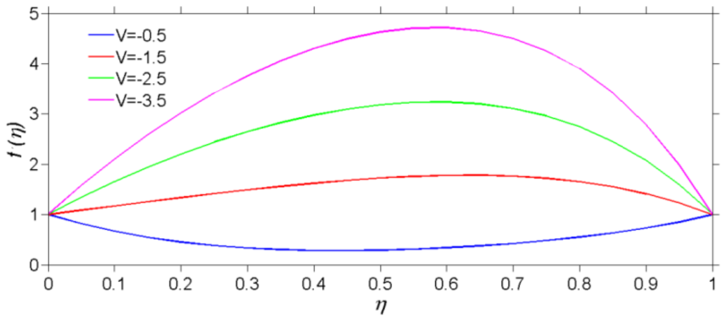

Fig 7. Variation in velocity with Suction parameter V

at Pr =0.1; M =2; N =2; S =1.2; Gr =10; λ =1.5

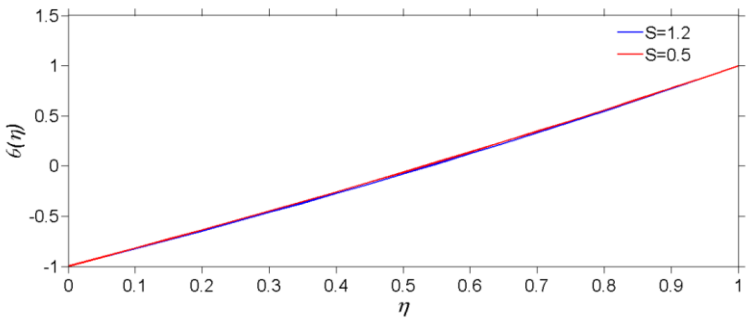

Fig 8. Variation in temperature with unsteadiness parameter S

at Pr =0.1; M =2; N =2; V =10; Gr =10; λ =1.5

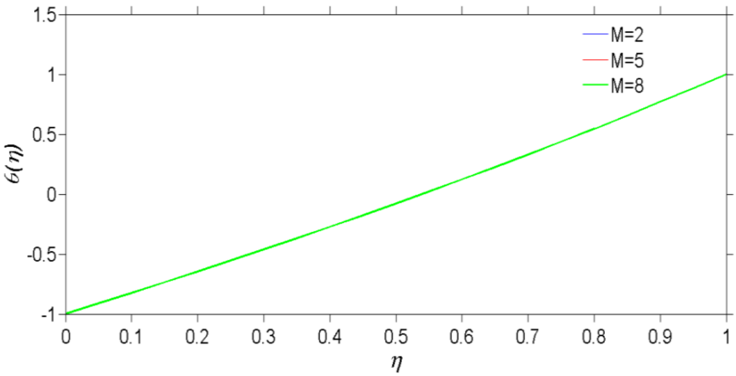

Fig 9. Variation in temperature with Magnetic parameter M
at Pr =0.1; N =2; S =1.2; V =-1.5; Gr =10; λ =1.5

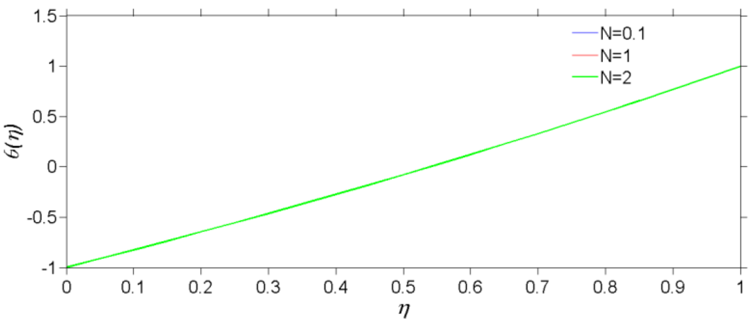

Fig 10. Variation in temperature with porosity parameter N
at Pr =0.1; M =2; S =1.2; V =-1.5; Gr =10; λ =1.5

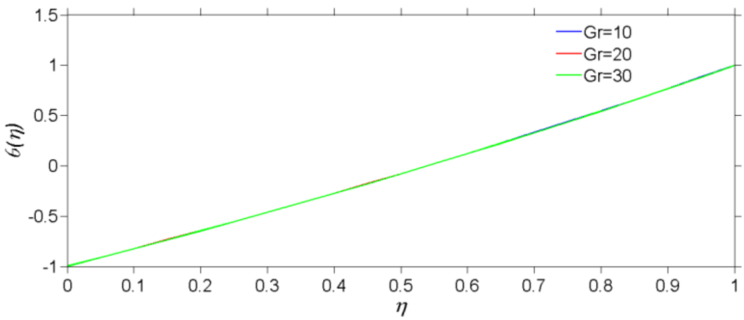

Fig 11. Variation in temperature with Grashof number Gr
at Pr =0.1; M =2; N =2; S =1.2; V =-1.5; λ =1.5

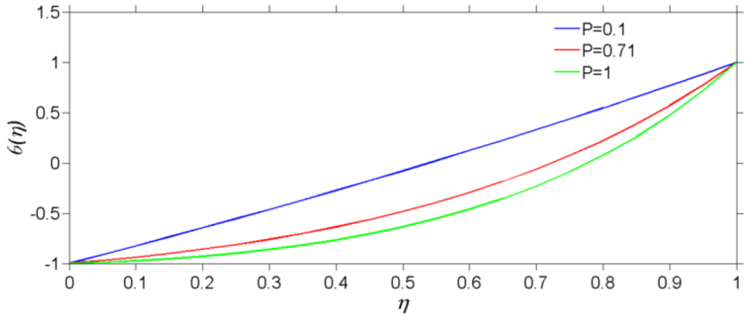

Fig 12. Variation in temperature with Prandtl number Pr at M =2; N =2; S =1.2; V =-1.5; Gr =10; λ =1.5

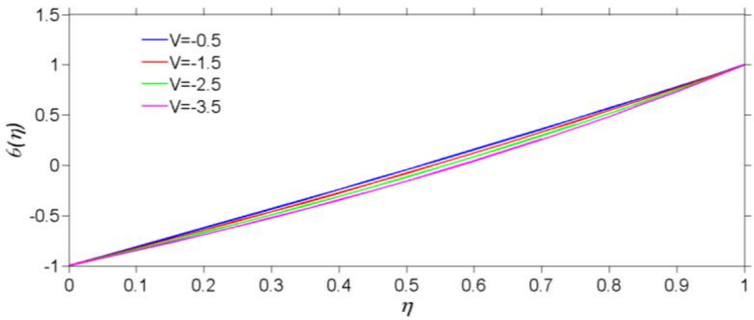

Fig 13. Variation in temperature with Suction parameter V at Pr =0.1; M =2; N =2; S =1.2; Gr =10; λ =1.5

6. Results and Discussion

The effects of different physical parameters on the skin friction coefficient and Nusselt number at both the plates are computed and tabulated in the Table1and Table2, respectively. Table1 demonstrates the increase of unsteadiness parameter (S) the magnitude of skin-friction coefficient enhanced at both the plates. The magnitude of skin-friction coefficient increases with the increase of Hartmann number (M) and porosity parameter (N) at the permeable plate while decreases at the non permeable plate. Increase in the value of Grashof number (Gr) the magnitude of skin-friction coefficient decreases at the permeable plate while increases at the non permeable plate. Increase in the value of Prandtl number (Pr) the magnitude of skin-friction coefficient increases at the permeable plate, while it decreases at non permeable plate. When the

Suction at the permeable plate is increases the magnitude of skin friction coefficient enhanced significantly at both plates.

Table 2 demonstrates that with the increase of unsteadiness parameter and Grashof number the magnitude of heat transfer coefficient (Nu) decreases at the permeable plate and increases at the non permeable plate. Increase of Hartmann number slightly increases the magnitude of heat transfer coefficient at the permeable plate and slightly decreases at the non permeable plate. The meager effect of magnetic field on convection of heat can be explained in the way that the magnetic field is weak and the Joule effect in the energy equation was not included. With the increase of porosity parameter the magnitude of heat transfer coefficient slightly decreases at the permeable plate and slightly increases at the non permeable plate. The increase of Prandtl number the magnitude of coefficient of heat transfer decreases significantly at the permeable plate and increases significantly at the non permeable plate. With the increase of Suction at permeable plate the convective heat transfer decreases at the permeable plate and increases at the non permeable plate.

Fig. 2 and Fig. 4 show that for small variations in the value of unsteadiness parameter and porosity parameter the changes in the profiles of $f'(\eta)$ are less effective. Figure 3, shows that with the increase in Hartmann number $f'(\eta)$ increases in the vicinity of the permeable plate while decreases in region close to non permeable wall. Fig. 5 shows that with the increase in Grashof number $f'(\eta)$ decreases in the proximity of the permeable plate while increases in region close to non permeable wall. In Fig. 6 the same trend has been observed with the increase in the Prandtl number. Fig. 7 shows that on increasing suction at the permeable plate the $f'(\eta)$ increases significantly. Fig. 8, Fig. 9, Fig. 10 and Fig. 11 show that for small variations in the value of unsteadiness parameter, Hartmann number, porosity parameter, and Grashof number are less effective on the temperature profiles $\theta(\eta)$. Fig. 12 shows that the temperature profiles decreases significantly with increase in the value of Prandtl number. Fig. 13 shows that with the increase in suction velocity the temperature of the fluid in the channel decreases.

7. Conclusions

1. The suction velocity at the permeable plate can be implemented to control the skin friction at the plates of the channel.

2. The higher order of unsteadiness in the stretching of plates enhances shear stress at both the plates.
3. In the stretching channel with one permeable plate, the effect of transverse magnetic field on the flow near to plate subjected to suction is reversed to the Lorenzian effect at non permeable plate.
4. The heat convection from the permeable plate subjected to a suction reduces with increase of Prandtl number while enhanced significantly at the non permeable plate.

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Appendix A: The fundamental mathematical operations under DTM

Function	***Differential transform***
$u(x)=f(x)\pm g(x)$	$U(k)=F(x)\pm G(x)$
$u(x)=\lambda g(x)$	$U(k)=\lambda G(x)$
$u(x)=\dfrac{\partial g(x)}{\partial x}$	$U(k)=(k+1)G(k+1)$
$u(x)=\dfrac{\partial^m g(x)}{\partial x^m}$	$U(k)=(k+1)...(k+m)G(k+m)$
$u(x)=x^m$	$U(k)=\delta(k-m)=\begin{cases}1 & at \quad k=m\\ 0 & otherwise\end{cases}$
$u(x)=f(x)g(x)$	$U(k)=\sum_{r=0}^{k} F(r)G(k-r)$
$u(x)=f_1(x)f_2(x)...f_m(x)$	$U(k)=\sum_{k_1}^{k}...\sum_{k_{m-1}=0}^{k_2} F_1(k_1)F_2(k_2-k_1)....F_m(k-k_{m-1})$