https://dx.doi.org/10.4314/dujopas.v9i2a.13
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 9 No. 2a June 2023*

Magnetohydrodynamics Free Convection Couette Flow and Heat Transfer Through a Vertical Porous Plate with Heat Generation and Absorption Effect

Tafida M. Kabir[1], Ayuba M. Umar[2] and Lawal Umar[3]
[1,3]Department of Mathematics.
Federal College of Education,
Zaria, Nigeria.

[2]Division of Agricultural Colleges.
Ahmadu Bello University,
Zaria, Nigeria.

Email: mktafida.555@gmail.com

Abstract
This research examines the impact of suction/injection and permeability of porous materials on a steady natural convection Couette flow of a viscous incompressible fluid passing through a vertical porous plate. The dimensionless governing momentum and energy equations were solved exactly. Graphs were plotted to check the impact of the governing flow parameters and a table was plotted for comparison of the results. It was found from the investigation that, the fluid injection $(\lambda > 0)$ *increases the fluid velocity and temperature distributions while the magnetic field* (M) *retards the fluid velocity. It is also noteworthy to mention that the suction* $(\lambda < 0)$ *reduces the fluid velocity and temperature distributions in the channel. The velocity profile is observed to increase with increase in the permeability* (K) *of the materials.*

Keywords: Magnetic field, heat generation/absorption, permeability, suction/injection.

INTRODUCTION
The study of Magnetohydrodynamics natural convection flow with heat transfer through a vertical porous channel is vital because of its various applications in several physical problems which include geophysics, agricultural engineering and technology. Several researchers have studied Magnetohydrodynamics flow in channel. Manjunatha and Gireesha (2016) investigated variable viscosity and thermal conductivity effect on MHD flow and heat transfer of a dusty fluid. The outcome of the study showed that, the velocity components of both fluid and dust phases decrease due to an increase in magnetic field. Reddy *et al.* (2017) presented a result on MHD boundary layer flow of nanofluid and heat transfer over a porous exponentially stretching sheet in the presence of thermal radiation and chemical reaction with suction. They showed that, the magnetic field reduces the velocity profile and in the same work, it was observed that an increase in suction parameter leads to a fall in the velocity and temperature distributions. Ajibade and Ayuba (2014) examined combined effects of diffusion-

*Author for Correspondence

thermo and chemical reaction on an unsteady MHD double diffusive flow between two inclined parallel plates with heat and radiation absorption. They concluded that, an increase in the magnetic field across the boundary layer, the velocity profile decreases and also an increase in the permeability parameter, the velocity profile increases. Jat and Gopi (2013) formulated a model on MHD flow and heat transfer over an exponentially stretching sheet with viscous dissipation and radiation effects. Their findings showed that, an increase of magnetic field decreases the velocity distribution. Kalyani *et al.* (2015) studied MHD mixed convection flow past a vertical porous plate in a porous medium with heat source/sink and soret effects. Their results showed that, the effect of magnetic field is to reduce the velocity profile. In addition, wall suction stabilizes the velocity, thermal as well as concentration of the fluid. They also concluded that the wall injection disstabilizes the fluid motion. Raju *et al.* (2015) examined the effects of heat transfer on a viscous dissipative fluid in the presence of induced magnetic field in a vertical plate. They concluded that, an increase in magnetic field, velocity profile is to reduce for both water $(\mathrm{Pr} = 7.0)$ and air $(\mathrm{Pr} = 0.7)$. Dessie and Naikoti (2014) studied MHD effects on heat transfer over in a porous medium with variable viscosity, viscous dissipation and heat source/sink. Their conclusions revealed that, the magnetic field is to reduce for both dimensionless velocity and also skin friction coefficient values due to the internal heat sink. Fahad *et al.* (2017) studied the combined effects of viscous dissipation and radiation on an unsteady natural convective Non-Newtonian fluid along a continuously moving vertically stretched surface with No-Slip boundary condition. They concluded that, a strong magnetic field could be applied to enhance the wall temperature of the Pseudo-plastic fluids. Machireddy *et al.* (2015) studied the effects of viscous dissipation and heat source on unsteady MHD flow over a stretching sheet. Their conclusions revealed that, velocity profiles decrease with increase in magnetic field.

Ahmed *et al.* (2015) examined an analytical study on an unsteady MHD free convection and mass transfer flow past a vertical porous channel. They concluded that fluid velocity increases due to an increase in permeability parameter. Jha and Ajibade (2010) studied unsteady natural convective Couette flow of heat generating/absorbing fluid. Their outcome showed that the rate of heat transfer increases due to an increase in heat absorption on the heated wall and the reverse trend observed on the cold wall. Another work titled viscous dissipation effect on MHD natural convection flow with heat generation was studied by Kabir *et al.* (2013). Their findings showed that, the velocity, temperature and skin friction coefficient enhance as a result of higher values of internal heat generation while the rate of heat transfer reduces. Veena *et al.* (2011) investigated MHD flow and heat transfer with temperature gradient dependent heat sink in a porous medium past a stretching surface. Their outcome showed that, an increase in permeability parameter increases the skin friction. Furthermore, an increase in suction, wall temperature and heat sink parameters result in lowering the temperature field steadily. Madhu and Srinivasa (2015) studied Joule heating effect on MHD natural convective heat generating/absorbing viscous dissipative Newtonian fluid with variable temperature. They reported that, due to the increasing values of porosity parameter the fluid velocity grows, but in the case of magnetic parameter, a reverse trend is observed. Ajibade and Tafida (2018) studied transient natural convection flow of heat generating fluid between two vertical parallel plates in the presence of suction/injection with isothermal and adiabatic condition. They concluded that, the velocity and temperature increase with growing injection on the isothermal wall while the opposite trend is found on the adiabatic wall.

Madhasudhana *et al.* (2013) studied MHD transient free convection and chemically reactive flow past a porous vertical plate with radiation and temperature gradient dependent heat source in slip flow regime. They concluded that, the velocity increases with an increase in permeability of porous medium and it shows the reverse effect with an increase in magnetic and heat source parameters. Sinha *et al.* (2017) examined MHD free convective flow through a porous medium past a vertical plate with ramped wall temperature. Their findings of the analysis showed that, an increase in permeability parameter, fluid velocity increases, whereas the velocity of the fluid decreases in the presence of magnetic field. Ajibade and Tafida (2020) investigated combined effect of variable viscosity and variable thermal conductivity on natural convection Couette flow. They concluded that, fluid temperature and velocity increase due to the increase in heat generation and decrease due to the increasing heat absorption. Anas (2018) studied effects of radiation and radial magnetic field on steady free convective flow in a vertical porous concentric annular due to convective surface boundary condition. Anas reported that, the maximum flow velocity and temperature are recorded at the lower plate by increasing the symmetric wall temperature and the reverse trend is observed at the upper plate.

The objective of the present study is to investigate the Magnetohydrodynamics free convection Couette flow and heat transfer through a vertical porous plate with heat generation/absorption effect. The present investigation could be applied in food processing and food preserving industries, fuel drilling and power generating industries.

MATHEMATICAL ANALYSIS

Consider a laminar flow of an MHD free-convective, viscous incompressible and electrically conducting fluid in the presence of suction/injection effects and the transverse magnetic field. One of the plates is stationary and kept at ambient temperature while the other is heated and moves with a constant velocity (U). The flow is assumed to be laminar and fully developed. The fluid properties are assumed to be constant. Following the Boussinesq's approximation, the required governing momentum and energy equations for the present problem are:

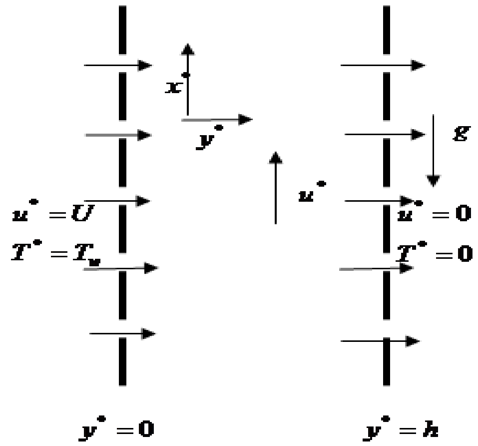


Figure 1: Schematic diagram of the problem

$$\lambda^* \frac{du^*}{dy^*} = \nu \frac{d^2u^*}{dy^{*2}} - \left(\frac{\sigma B_0^2}{\rho} + \frac{\nu}{k^*}\right)u^* + g\beta(T^* - T_0) = 0$$

(1)

$$\lambda^* \frac{dT^*}{dy^*} = \frac{k}{\rho cp}\frac{d^2T^*}{dy^{*2}} - \frac{Q_0}{\rho cp}(T^* - T_0) = 0$$

(2)

Here λ^* is the dimensional suction/injection parameter, ν kinematic viscosity of the fluid, u^* is the dimensional velocity, T^* is the dimensional temperature, y^* is the dimensional distance. ρ is the fluid density, B_0 is the magnetic induction, c_p is the specific heat at constant pressure, Q_0 is the heat generation/absorption coefficient, k is the thermal conductivity and g is the acceleration due to gravity,

while the boundary conditions that satisfy the problem are:

$$u^* = U, T^* = T_w \text{ at } y^* = 0,$$
$$u^* = 0, T^* = T_0 \text{ at } y^* = h.$$

(3)

Here U is the velocity of the moving plate, T_w is the temperature of the heated plate and T_0 temperature of the cold plate respectively. By introducing the following dimensionless quantities:

$$u = \frac{u^*}{U}, y = \frac{y^*}{h}, T = \frac{T^* - T_0}{T_w - T_0}, \lambda = \frac{\lambda^* h}{\nu}$$
$$\Pr = \frac{\mu cp}{k}, S = \frac{Q_0 h^2}{k}, Gr = \frac{g\beta h^2 (T_w - T_0)}{\upsilon U}$$

(4)

Where $u, T, \lambda, \Pr, S$ and Gr are the non-dimensional velocity, non-dimensional temperature, non-dimensional coordinate normal to the channel plate, suction/injection parameter, Prandtl number, heat generation/absorption parameter and thermal Grashof number respectively.

Momentum equation (1) and energy equation (2) are transformed into non-dimensional form as:

$$\frac{d^2u}{dy^2} - \lambda\frac{du}{dy} - \left(M + \frac{1}{k}\right)u + GrT = 0 \quad (5)$$

$$\frac{d^2T}{dy^2} - \lambda \Pr\frac{dT}{dy} - ST - 0 \quad (6)$$

and the boundary conditions into non-dimensional form as:

$$u = 1, T = 1, \text{ at } y = 0,$$
$$u = 0, T = 0, \text{ at } y = 1. \quad (7)$$

METHOD OF SOLUTION

Using the method of undetermined coefficients, the solution of equations (5) and (6) under the boundary condition (7) can be written as:

$$u = C_3 e^{m_3 y} + C_4 e^{m_4 y} + A_1 e^{m_1 y} + A_2 e^{m_2 y}, \tag{8}$$
$$T = C_1 e^{m_1 y} + C_2 e^{m_2 y}. \tag{9}$$

By the use of equations (8) and (9), the skin friction and rate of heat transfer on the heated plates $(y = 0)$ are expressed as

$$\tau_0 = C_3 m_3 + C_4 m_4 + A_1 m_1 + A_2 m_2, \tag{10}$$
$$Nu_0 = C_1 m_1 + C_2 m_2, \tag{11}$$

Respectively, while on the cold pate $(y = 1)$, the skin-friction and rate of heat transfer are expressed as

$$\tau_1 = C_3 m_3 e^{m_3} + C_4 m_4 e^{m_4} + A_1 m_1 e^{m_1} + A_2 m_2 e^{m_2}, \tag{12}$$
$$Nu_1 = C_1 m_1 e^{m_1} + C_2 m_2 e^{m_2}, \tag{13}$$

To find the mass flux Q, we integrate $\int_0^1 udy$ to get

$$Q = \int_0^1 udy \tag{14}$$

where,

$$A_1 = \frac{-GrC_1}{m_1^2 - \lambda m_1 - (M + \frac{1}{K})}, \qquad A_2 = \frac{-GrC_2}{m_2^2 - \lambda m_2 - (M + \frac{1}{K})},$$

$$C_1 = \frac{e^{m_2}}{e^{m_2} - e^{m_1}}, \quad C_2 = 1 - C_1, \qquad C_3 = 1 - A_1 - A_2 - C_4,$$

$$C_4 = \frac{(1 - A_1 - A_2)e^{m_3} + A_1 e^{m_1} + A_2 e^{m_2}}{e^{m_3} - e^{m_4}}, \qquad m_1 = \frac{\lambda \Pr + \sqrt{(\lambda \Pr)^2 + 4S}}{2},$$

$$m_2 = \frac{\lambda \Pr - \sqrt{(\lambda \Pr)^2 + 4S}}{2}, \qquad m_3 = \frac{\lambda + \sqrt{\lambda^2 + 4\left(M + \frac{1}{K}\right)}}{2},$$

$$m_4 = \frac{\lambda - \sqrt{\lambda^2 + 4\left(M + \frac{1}{K}\right)}}{2}$$

RESULTS AND DISCUSSION

The present work analysed the MHD free convection Couette flow and heat transfer through a vertical porous channel with heat generation/absorption and magnetic field effect. The velocity and temperature fields are presented graphically in figures 2 – 10 for different values of magnetic field (M), Prandtl number $(\Pr)$, heat generation/absorption (S), suction/injection (λ) and Grashof number (Gr). The skin friction, rate of heat transfer and mass flux are presented in tables.

The impact of heat generation/absorption on the fluid velocity and temperature are presented in figures 2 – 3. It could be viewed from the figures that fluid temperature and velocity increase due to increasing heat generation $(S < 0)$. In addition, fluid velocity and temperature drop due to growing values of heat absorption. Increasing the heat absorption contributes a drop in fluid temperature and the thermal boundary layer thickness becomes thinner thereby reducing the velocity distribution of the working fluid. Increase in the fluid velocity and temperature distributions as a result of increase in heat generation has resulted to an increase in thermal boundary layer thickness of the fluid which strengthens the convection current of the fluid.

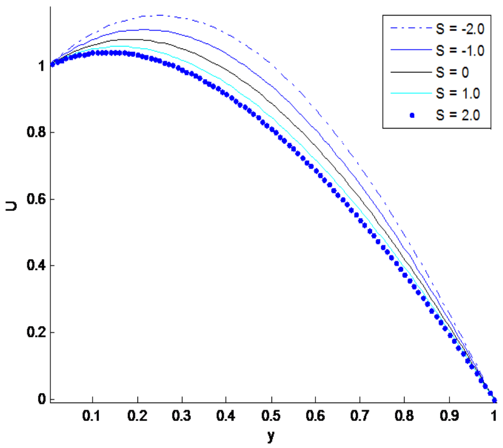


Fig 2: Velocity profile for different values of $S(\Pr = 0.71, Gr = 8.0, \lambda = 0.6, K = 0.5, M = 0.3)$

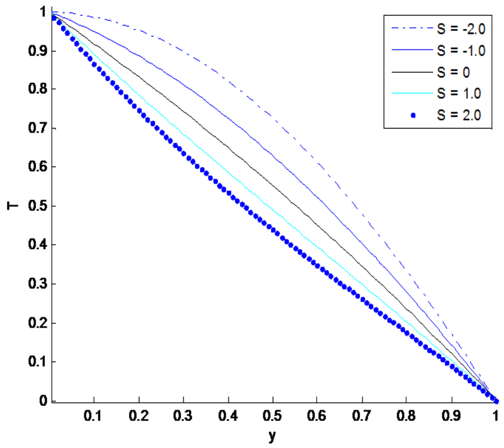
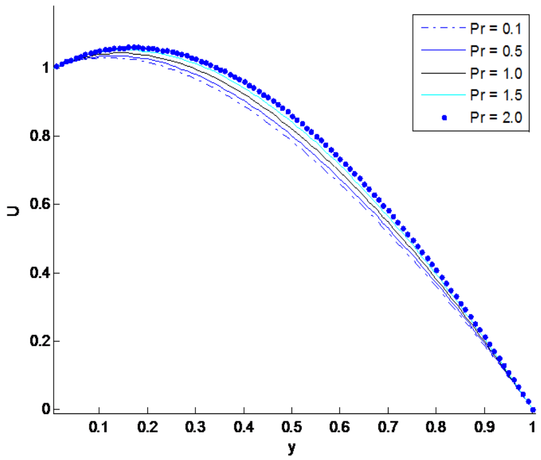


Fig 3: Temperature profile for different values $S(\Pr = 0.71, Gr = 8.0, \lambda = 0.6, K = 0.5, M = 0.3)$

The nature of velocity and temperature profiles for various values of Prandtl number $\Pr$ are presented in figures 4 and 5. An obvious fact is that the fluid velocity and temperature distribution increase with the increasing values of Prandtl number $\Pr$. This is physically expected, since when the momentum diffusivity of a fluid is higher than the thermal diffusivity, the convection current of the fluid strengthens which eventually raises the temperature of the fluid and consequently growing the fluid velocity as well.



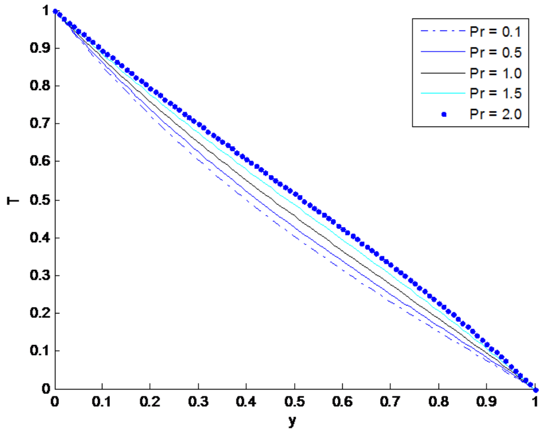
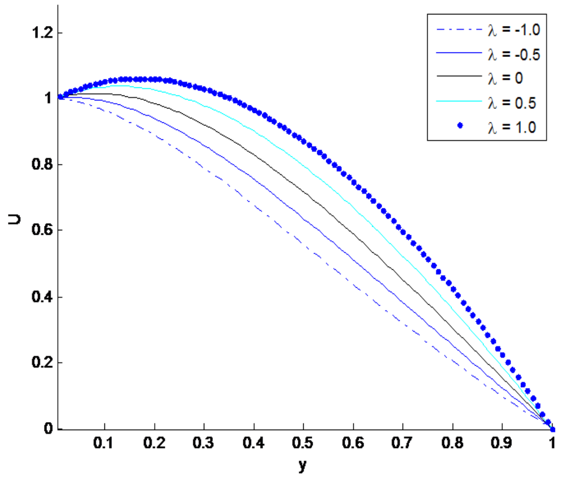


Fig 4: Velocity profile for different values of $\Pr(S = 2.0, Gr = 8.0, \lambda = 0.6, K = 0.5, M = 0.3)$

Fig 5: Temperature profile for different values $\Pr(S = 2.0, Gr = 8.0, \lambda = 0.6, K = 0.5, M = 0.3)$

Figures 6 and 7 present the effect of suction/injection on the fluid velocity and temperature distribution. It is noticed that $(\lambda < 0)$ represents suction with a corresponding injection $(\lambda > 0)$. It is observed that fluid velocity and temperature distribution increase due to increasing values of injection. This is attributed to the fact that the fluid injected through the system is more energetic than the fluid in the system which rises the temperature of the fluid and adversely increases the fluid velocity. It is further observed that the velocity and temperature profiles decrease with increase in suction. The suction of the fluid weakens the convection current of the fluid which makes the fluid to be more dense as a result of releasing heated fluid away from the system.



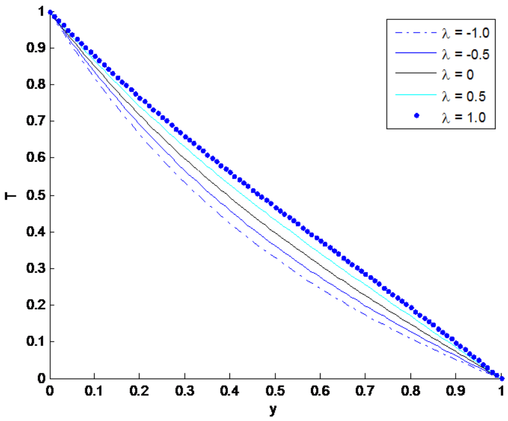


Fig 6: Velocity profile for different values of $\lambda(\Pr = 0.71, S = 2.0, Gr = 8.0, K = 0.5, M = 0.3)$

Fig 7: Temperature profile for different values $\lambda(\Pr = 0.71, S = 2.0, Gr = 8.0, K = 0.5, M = 0.3)$

The effect of Grashof number on fluid velocity is plotted in figure 8. An observation from this figure shows that, the velocity of the fluid field is increased due to increase in Grashof number. Increase in the thermal buoyancy leads to increase in thermal boundary layer thickness of the fluid which strengthens the convection current of the fluid hence increases the velocity of the fluid.

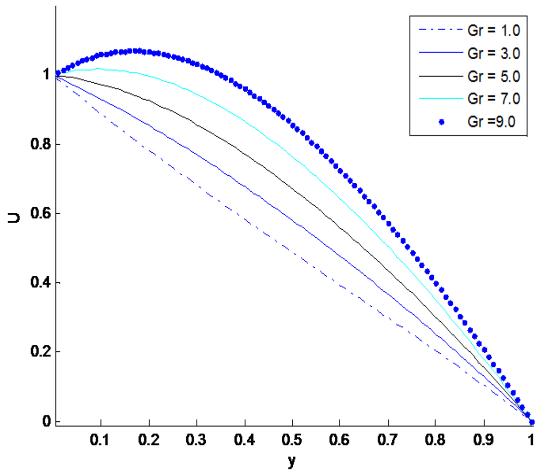


Fig 8: Velocity profile for different values of $Gr(\Pr = 0.71, S = 2.0, \lambda = 0.6, K = 0.5, M = 0.3)$

The velocity profile is shown in figure 9, for different values of permeability parameter. It is evident from the figure that the permeability of the porous material K is to increase the velocity distribution of the fluid. Increase in the permeability of the porous materials leads to increase in the free flow of the fluid particles which increase the flow of the fluid.

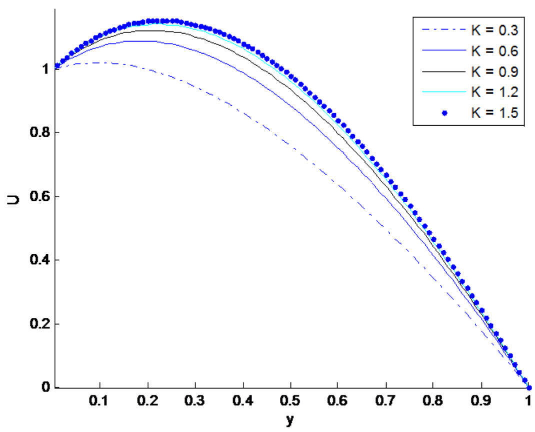


Fig 9: Velocity profile for different values $K(\Pr = 0.71, S = 2.0, Gr = 8.0, \lambda = 0.6, M = 0.3)$

A clear view from figure 10 shows that, the velocity profile decelerates with an increase in magnetic field. This is attributed to the force called Lorentz force which drags the fluid flow.

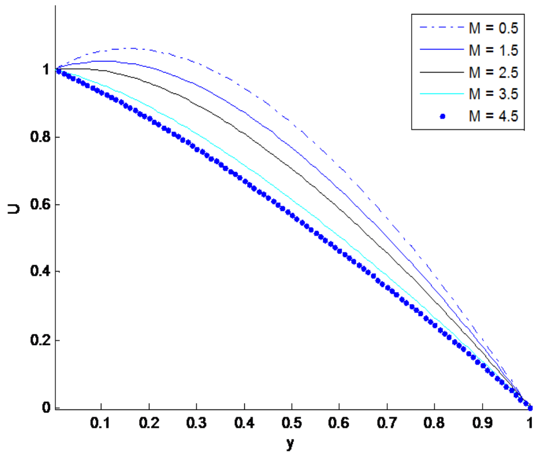


Fig 10: Velocity profile for different values of $M\,(\Pr = 0.71, S = 2.0, Gr = 8.0, \lambda = 0.6, K = 0.5)$

The impacts of the governing parameters regarding the skin-friction and rate of heat transfer on the boundaries are shown in tables 1 and 2.
Table 1 presents the skin friction between the plates and the fluid. It is observed that the skin friction on both plates decreases as magnetic field increases. Physically, this is expected because an increase in magnetic field enhances the drag force which retards the fluid flow thereby reducing the skin friction. The table further shows that the skin friction on both moving and stationary plates increase due to increase in permeability of the porous materials. Finally, the skin friction on both moving and stationary plates increases with increasing injection and decreases on both the plates with growing suction.

Table 1: Numerical values of Skin friction τ_0 and τ_1

	$(M = 2.0, K = 0.5)$		$(M = 3.0, K = 0.5)$		$(M = 3.0, K = 1.0)$	
λ	τ_0	τ_1	τ_0	τ_1	τ_0	τ_1
-2.0	0.36305	0.14366	0.35666	0.12675	1.27155	1.22838
-1.0	0.39074	0.15602	0.37394	0.14870	1.29069	1.38777
0	0.40199	0.17268	0.39049	0.16080	1.30954	1.55582
1.0	0.43340	0.19972	0.41141	0.17925	1.35912	1.77881
2.0	0.46130	0.20272	0.43041	0.18925	1.37617	1.98281

Table 2 shows the rate of heat transfer between the fluid and the plates. It is discovered that the magnetic field decreases the rate of heat transfer on both moving and stationary plates and the reverse trend is observed for an increase in the permeability of the porous materials. Furthermore, it is also seen that an increase in suction increases the rate of heat transfer on the moving plate and the reverse case was discovered on the stationary plate. In addition, it is also discovered that the rate of heat transfer decreases on the moving plate with growing injection and the reverse trend was observed on the stationary plate. This is due to the fact that, higher energetic fluid particles from the moving plate move down to the stationary plate which raises the temperature of the fluid near the stationary plate.

Table 2: Numerical values of rate of heat transfer Nu_0 and Nu_1

	$(M = 2.0, K = 0.5)$		$(M = 3.0, K = 0.5)$		$(M = 3.0, K = 1.0)$	
λ	Nu_0	Nu_1	Nu_0	Nu_1	Nu_0	Nu_1
-2.0	1.37301	1.24367	1.35663	1.23678	1.48152	1.52839
-1.0	1.37072	1.26600	1.34396	1.25871	1.45067	1.54777
0	1.31299	1.27568	1.30059	1.26080	1.42064	1.59582
1.0	1.29940	1.29372	1.27241	1.28325	1.40712	1.62881
2.0	1.27320	1.30331	1.26041	1.29932	1.37413	1.64583

Table 3 exhibits the numerical values of mass flux Q. It is clearly seen that growing magnetic field has the tendency to increase the mass flux. The table further shows that the permeability of the porous materials leads to increase mass flux. Finally, the mass flux increases with increase in injection and the reverse trend is observed in the case of suction.

Table 3: Numerical values of mass flux Q

	$(M = 2.0, K = 0.5)$	$(M = 3.0, K = 0.5)$	$(M = 3.0, K = 1.0)$
λ	Q	Q	Q
-2.0	0.46696	0.48752	0.52357
-1.0	0.48156	0.49211	0.54573
0	0.52976	0.54431	0.57005
1.0	0.54535	0.56991	0.59322
2.0	0.57535	0.58061	0.62222

VALIDATION

To validate our present problem, we compare our obtained results for velocity as well as temperature with the results of Jha and Ajibade (2010). When the magnetic field and suction/injection parameters are neglected, that is $M = \lambda = 0$ and making the permeability of the porous materials so large ($K = 10000$) an excellent agreement is obtained as can be seen in table 4.

Table 4: Validation of problem

	Jha and Ajibade (2010) $Gr = 10, y = 0.5$		Present Work $Gr = 10, \Pr = 0.71, \lambda = M = 0, K = 10000, y = 0.5$	
S	Velocity	Temperature	Velocity	Temperature
-1.0	1.197462	0.569730	1.196653	0.568548
-0.5	1.159338	0.533159	1.158743	0.533076
0.5	1.094048	0.470313	1.094021	0.470302
1.0	1.065983	0.443401	0.065832	0.443321

CONCLUSION

In this paper, the effects of magnetic field, suction/injection and permeability of porous materials on MHD free convection flow of viscous incompressible fluid in a porous channel formed by two infinite vertical parallel plates have been studied. The extension has excellent agreement with the work of Jha and Ajibade (2010). The results of this study can be summarized as;

- The velocity profile decelerates with an increase in the magnetic field parameter.
- The thermal Grashof number enhanced the fluid velocity.
- The effect of permeability parameter leads to an increase in the velocity profile.
- The skin friction decreases as magnetic field parameter M increases.
- The magnetic field decreases the rate of heat transfer on both heated and cold plates.
- The velocity and temperature distributions increase with increasing values of injection.
- The velocity and temperature distribution decrease with increase in suction.

REFERENCES

Ahmed, S. F., Das, M. K., and Ali, L. E. (2015). Analytical study on unsteady MHD free convection and mass transfer flow past a vertical porous channel. *American Journal of Applied Mathematics. 3(2): 64-74.*

Ajibade, A. O., and Ayuba, U. M. (2014). Combined effect of Diffusion-Thermo and chemical reaction on the unsteady MHD double diffusive flow between two inclined parallel plates with heat and radiation absorption. *International Journal of Energy and Technology. 6(20): 1-11.*

Ajibade, A. O., and Tafida, M. K. (2018). Transient Natural Convection Flow of Heat Generating Fluid Between Vertical Parallel Plates in the Presence of Suction/Injection with Isothermal and Adiabatic Condition. *The Journal of Mathematical Association of Nigeria. 45(1): 12-23.*

Ajibade, A. O., and Tafida, M. K. (2020). The combined effect of variable viscosity and variable thermal conductivity on natural convection Couette flow. *International Journal of Thermofluids. 5-6: 100036.*

Anas, S. M. (2018). The effects of radiation and radial magnetic field on steady free convection flow in a vertical porous concentric annular due to convective surface boundary condition. *International Journal of Engineering and Mathematical Intellegence. 5(1,2): 2276 – 8815.*

Fahad M. B., Samad, M. A., and Hossain, M. R. (2017). Combined effect of viscous dissipation and radiation on unsteady free convective Non-Newtonian fluid along a continuously moving vertically stretched surface with No-Slip phenomena. *American Journal of Computational and Applied Mathematics. 7(3): 71-79.*

Jat, R. N., and Gopi, C. (2013). MHD flow and heat transfer over an exponentially stretching sheet with viscous dissipation and radiation effects. *Applied Mathematical Sciences 7(4): 167-180.*

Jha, B. K. and Ajibade., A. O. (2010). Unsteady free convective Couette flow of heat generating/absorbing fluid. *International Journal of Energy and Technology., 2(12): 1-9.*

Kabir, K. H., Alim, M. A., and Andallah, L. S. (2013). Effects of viscous dissipation on MHD natural convection flow along a vertical wavy surface with heat generation. *American Journal of Computational Mathematics. 3: 91-98.*

Kalyani, C., Reddy, K. M.C and Kishan, N. (2015). MHD mixed convection flow past a vertical porous plate in a porous medium with heat source/sink and soret effects. *American Chemical Science Journal. 7(3): 150-159.*

Machiraddy, G. R., Padma, P., and Shakar, B. (2015). Effects of viscous dissipation and heat source on unsteady MHD flow over a stretching sheet. *Ain Shams Engineering Journal. 6: 1195-1201.*

Madhu, AB. R., and Srivasa. G. (2015). Joule heating effect on MHD free convective heat absorbing/generating viscous dissipative Newtonian fluid with variable temperature. *International Journal of Research Granthaalayah. 4: 71-21.*

Madhasudhana, B. R., Viswanatha, R., Varm, S. V. K., and Raju, M. C. (2013). MHD transient free convection and chemically reactive flow past a porous vertical plate with radiation and temperature gradient dependent heat source in slip flow regime. *IOSR Journal of Applied Physics. 3(6): 22-32.*

Manjunatha, S., and Gireesha, B. J. (2016). Effects of variable viscosity and thermal conductivity
On MHD flow and heat transfer of a dusty fluid. *Ain Shams Engineering Journal. 7: 505 - 515.*

Naikoti, K., Dessie, H. (2014). MHD effects on heat transfer over stretching sheet embedded in porous medium with variable viscosity, viscous dissipation and heat source/sink. *Ain Shams Engineering Journal. 5: 967-977.*

Raju, M. C., Varma, S. VK., and Seshaiah, B. (2015). Heat transfer effects on a viscous dissipative fluid flow past a vertical plate in the presence of induced magnetic field. *Ain Shams Engineering Journal. 6: 333-339.*

Reddy, D. Y., Srinivasa, R. V., and Anand, B. L. (2017). MHD boundary layer flow of nanofluid and heat transfer over a porous exponentially stretching sheet in presence of thermal radiation and chemical reaction with suction. *International Journal of Mathematics Trends and Technology. 47(2): 87-100.*

Sinha, A., Ahmed, N., and Agarwalla, S. (2017). MHD free convective flow through a porous medium past a vertical plate with ramped wall temperature. *Applied Mathematical Sciences. 11(20): 963-974.*

Veena, P. H., Pravin, V. K., and Kumar, K. A. (2011). MHD flow and heat transfer with temperature gradient dependent heat sink in a porous medium past a stretching surface. *International Journal of Chemical Engineering. 4(2): 133-146.*