THE MAGNETOCONVECTIVE FLOW IN AN INCLINED MICRO-POROUS CHANNEL WITH A SOURCE OR A SINK

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Abstract :

To investigate the effects of source or sink in an inclined micro-porous channel field with conducting fluid. The basic equations governing the flow generate the second-order ordinary differential equations and hence closed-form solutions are obtained. The velocity and temperature fields are computed for the flow governing parameters such as rare fraction parameter, fluid-wall interaction parameter, suction/injection parameter, angle of inclination and heat source or sink parameter. It is found that the sink parameter suppress the velocity whereas source parameter enhance the velocity for all values of temperature difference ratio. Further, the volume flow rate increases as the sink parameter increases for $\xi = 1$ whereas it decreases for $\xi = 0, -1$.The skin friction at the left wall increases for the value of $\xi = -1$ and decrease for $\xi = 0,1$ whereas the skin friction at the right wall increases for all values of ξ.

Keyword: **Heat Source or Sink, Inclined micro-porous channel, MHD, Convective flow, Velocity slip.**

1. INTRODUCTION

Recent studies have focused on the convective flow in fluid saturated porous media. Understanding the convective transport mechanisms in porous materials has become more crucial due to the advancement of geothermal energy technology, high-performance insulation for buildings and cold storage, energy efficient drying techniques, and numerous other industries. Additionally, the nuclear sector is intrigued by it, particularly for the evaluation of heat removal following a fictitious accident in a nuclear reactor and for effective insulation. In comparison to other forms of convection, free convection is the most cost effective. This energy transfer method's distinctive features include its dependability and lack of sound. In some cases, when the characteristic dimensions of the cavity are significant or a temperature is observed.[1] studied the effect of viscous dissipation on fully developed natural vertical microchannel. [2]also discussed the entropy production in MHD mixed convection micropolar fluid flow over an inclined porous stretching sheet.[3]analyzed by the an infinite vertical plate immersed in a porous material is the subject of a heat transfer investigation in the unsteady MHD natural convection flow of a viscous fluid under uniform heat flux and radiation.

Numerous studies of magneto-hydrodynamic flow under different physical conditions have been conducted. Basically, there are various applications for inclined geometry in heat transfer technologies, such as solar collectors. [4] investigate the effects of thermal radiation and heat production on a naturally occurring, fully developed, constant hydromagnetic convection flow. The unsteady MHD slip flow with radiative heat and mass transfer over an inclined plate embedded in a porous medium was discussed by[5]. [6] studied the influence of radiation and ohmic heating on the dissipative flow of micropolar and hybrid nanofluids within an inclined channel under the convective boundary conditions. They observed that the magnetic field and radiation parameters mitigated the fluid temperature.[7]examined the study on magneto convective flow on a porous medium with hall and thermal radiation effects. They discovered that increasing hall parameter result in a strong secondary flow field. [8] studied the impact of chemical and soret on the radioactive MHD flow from an infinite vertical plate. Venkateswarlu et al.[9] looked into the impacts of thermal radiation and heat generation on steady hydro magnetic flow in a vertical micro-porous channel with suction or injection. Hussein.[10] considered the new investigation of asymmetric wall temperature and fluid-wall interaction on radioactive stability of fully developed natural convection in vertical micro-porous-channel.[11]discussed the entropy production in MHD mixed convection micropolar fluid. [12]investigated the magnetohydrodynamic convective flow in an inclined micro-porous channel. They found that the convective current in the micro-porous channel is improved by lowering the inclination angle and consequently raising fluid velocity. [13]examined the study across a porous inclined vertical plate with Maxwell fluid flow under the impact of heat generation and MHD.

In light of several physical issues, the impact of heat source or sink on heat transport is another significant consideration. In systems like semiconductors, electronics, and nuclear reactors, heat creation or absorption may alter the heat distribution in the fluid, which in turn alters the rate at which particles deposit. Alsaberyet.al[14] investigated how a heat source or sink significantly affected natural convection flow in a cylindrical hollow. [15] discussed the CFD simulation of the heat sink's performance for decreasing junction temperature. [16]examined how the chemical processes taking place between two parallel plates were affected by MHD micro-polar fluid flow. [17] studied the effects of viscous dissipation, suction or injection, for a steady MHD natural convection coquette flow that generates and absorbs heat. The impact of Hall current and thermal diffusion on the radioactive hydro magnetic flow of a spinning fluid in the presence of heat absorption was discussed by [18]. [19]investigated how a heat source and sink affected the beginning of a natural gas engine in an annulus with boundaries that are both isothermal and is of flux. The effect of a heat source or sink on MHD flow between vertical alternate conducting walls with hall effect was examined by [20].[21]found that a heat source or sink in a tube had an effect on how diffusion thermographs affected the erratic spontaneous convection of a chemically reactive fluid. Mixed convection flow of an electrically conducting fluid in a vertical channel using robin boundary conditions with heat source or sink was studied by. [22]examined the flow was promoted with increasing heat generation parameter. [23] worked on heat source or sink, viscous dissipation, using third-kind boundary condition on mixed convective flow and heat transfer of couple stress fluid in a vertical channel. They came to the conclusion that raising the heat generation parameter raised the velocity, temperature, mass flow rate, and Nusselt number, whereas raising the heat absorption parameter had the opposite effect. Recently,

[24] exercised on the magneto micropolar nanofluid layer flow through a wedge surface carrying ion slip and hall currents with heat source and sink. It was determined that copper nanoparticles suspended in motor oil and iron oxide nanoparticles dropped in water produced the best rate of heat transmission. [25] investigated the impacts of the heat source on the moving vertical porous plates in the presence of MHD chemical reactions. [26]discussed the experimental heat transfer performance employing heat sinks of various shapes for electrical applications.

Keeping in view the engineering and technological applications of flow through micro-channels, it is therefore significant to investigate heat transfer and flow formation having an external magnetic field's effect and suction or injection in the attendance of a heat source or sink through inclined micro-porous channel. Analytical solutions to the governing equations are provided, and graphs are then shown to show the impacts of the different governing parameters.

2. METHODOLOGY

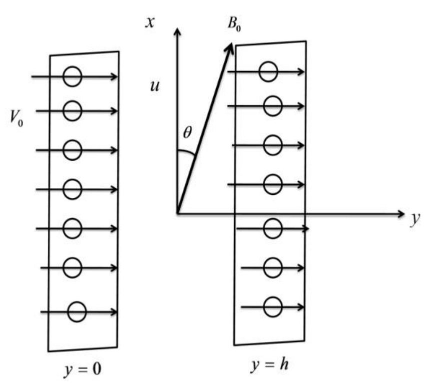

Fig.1:Physical model

The flow under study is a fully developed free convection flow influenced by a transverse magnetic field in an inclined micro-porous channel filled with a viscous, incompressible, electrically conducting fluid. Under the influence of a transverse magnetic field fluid flows naturally and continuously in an inclined micro-porous channel. Figure 1 depicts the system under study and the chosen coordinate axes. Porous channel walls are spaced apart from the fluid define its perimeter as b. Magnetic field is considered to be applied in a path that is perpendicular to the flow direction. The magnetic Reynolds number is assumed to be very low which correlates to an induced magnetic field that is very weak compared to the external magnetic field. To maintain the mass of the fluid in the channel, fluid is injected into the flow zone by a cold porous plate and fluid is removed from the flow zone through a heated porous plate at the same rate. In addition, the heating of the plates is asymmetrical through one plate being maintained at a particular temperature T_1 while the other is heated to a different temperature T_2. Temperature differences between the plates create spontaneous convection flow in the channel.

According to Boussinesq' approximation, the governing equations for motion and energy dimensionless form become:

$$\frac{d^2U}{dY^2} - S\frac{dU}{dY} - M^2U + Gr\sin\phi = 0 \tag{1}$$

$$\frac{d^2\theta}{dY^2} - S\Pr\frac{d\theta}{dY} \pm \psi\theta = 0 \tag{2}$$

The following dimensionless quantities are used:

where

$$\left.\begin{aligned} &Y=\frac{y}{b},\quad \theta=\frac{T-T_0}{T_1-T_0},\quad S=\frac{V_0 b}{v},\quad U=\frac{u}{U_0}, \\ &M^2=\frac{\sigma B_0{}^2 b^2}{\rho v},\quad Gr=\frac{\rho g\beta\left(T_1-T_0\right)b^2}{vU_0}, \\ &\psi=\frac{Qb^2}{K},\quad \Pr=\frac{v}{\alpha} \end{aligned}\right\} (3)$$

Temperature jumps and velocity slip at the fluid-wall interaction are defined by the boundary conditions.

$$\left.\begin{aligned} &U\left(0\right)=\beta_v Kn\left.\frac{dU}{dY}\right|_{Y=0},U\left(1\right)=-\beta_v Kn\left.\frac{dU}{dY}\right|_{Y=1}, \\ &\theta\left(0\right)=\xi+\beta_v KnIn\left.\frac{d\theta}{dY}\right|_{Y=0},\theta\left(1\right)=1-\beta_v KnIn\left.\frac{d\theta}{dY}\right|_{Y=1} \end{aligned}\right\}\left(4\right)$$

$$\beta_v=\frac{2-f_v}{f_v},\beta_t=\frac{2-f_t}{f_t}\frac{2y_s}{y_s+1}\frac{1}{Pr},Kn=\frac{\lambda}{b},$$

where

$$In=\frac{\beta_t}{\beta_v},\xi=\frac{T_2-T_0}{T_1-T_0}$$

Here, f_v and f_t are the thermal and tangential momentum coefficients respectively, and ranges from 0 to 1. γ_s be the ratio of exact temperature, T_0 is the reference temperature which indicates free path for molecules, where ξ is the variation between the barrage and the ambient heat, and In is the variable for fluid-wall interaction. Using the principles of f_v and f_t for many technical applications, the value β_v of β_t is close to 1.667, whereas the value ranges from close to unity to more than 100. This corresponds toward f_v = 1, f_t = 1, y_s = 1.4, and Pr = 0.71.

Equations (1) and (2) have the following precise solutions, subject to boundary conditions (4).

$$\theta(Y)=C_1\exp\left(D_1Y\right)+C_2\exp(D_2Y) \qquad (5)$$

$$U\left(Y\right)=C_3\exp\left(D_3Y\right)+C_4\exp(D_4Y)+ l_1\exp\left(D_1Y\right)+l_2\exp\left(D_2Y\right) \qquad (6)$$

where

$$l_1=\frac{-GrC_1Sin\phi}{F_1},\ l_2=\frac{-GrC_2Sin\phi}{F_2},$$
$$F_1=D_1{}^2-SD_1+M^2,\ F_2=D^2{}_2-SD_2+M^2$$

The volume flow rate and the heat transfer rate are two critical variables for buoyancy-induced micro-flow and micro-heat transfer, respectively. The flow rate of the dimensionless volume flow rate is:

$$Q=\frac{m}{bU_0}\int_0^1 Udy \qquad (7)$$

Equation (6) is substituted for equation (7) to produce

$$\begin{aligned} Q=&\frac{C_3\exp\left(D_3\right)}{D_3}+\frac{C_4\exp\left(D_4\right)}{D_4}+\frac{l_1\exp\left(D_1\right)}{D_1}+ \\ &\frac{l_2\exp\left(D_2\right)}{D_2}-\frac{C_3}{D_3}-\frac{C_4}{D_4}-\frac{l_1}{D_1}-\frac{l_2}{D_2} \end{aligned} \qquad (8)$$

The Nusselt number is the rate of heat transmission

$$\begin{aligned} Nu&=\frac{qb}{\left(T_1-T_0\right)}k=\frac{d\theta\left(Y\right)}{dy} \\ &=C_1\exp\left(D_1Y\right)D_1+C_2\exp\left(D_2Y\right)D_2 \end{aligned} \qquad (9)$$

Therefore $Nu_0=\left.\frac{d\theta}{dY}\right|_{Y=0}=C_1D_1+C_2D_2$ (10)

$$Nu_1=\left.\frac{d\theta}{dY}\right|_{Y=1}=C_1D_1\exp\left(D_1\right)+C_2D_2\exp\left(D_2\right) \qquad (11)$$

The skin -friction (τ) on the channel plates is calculated using expression (6) as follows:

$$\tau_0 = \left.\frac{dU}{dY}\right|_{Y=0} = C_3D_3 + C_4D_4 + l_1D_1 + l_2D_2 \quad (12)$$

$$\tau_1 = \left.\frac{dU}{dY}\right|_{Y=1} = C_3D_3\exp(D_3) + C_4D_4\exp(D_4) + l_1\exp(D_1)D_1 + l_2\exp(D_2)D_2 \quad (13)$$

where

$$D_1 = \frac{S\,\mathrm{Pr} + \sqrt{(S\,\mathrm{Pr})^2 - 4\psi}}{2},\; D_2 = \frac{S\,\mathrm{Pr} - \sqrt{(S\,\mathrm{Pr})^2 - 4\psi}}{2},$$

$$D_3 = \frac{S + \sqrt{S^2 + 4M^2}}{2},\; D_4 = \frac{S - \sqrt{S^2 + 4M^2}}{2}$$

2. RESULTS AND DISCUSSION

The velocity, volume flow rate and skin friction are computed for the variations of rarefaction parameter $(\beta_v Kn)$, Harman number (M), fluid-wall interaction parameter (In), inclination of angle (ϕ), suction/injection parameter (S), heat source or sink parameter (ψ) and are presented graphically in Figs 2-9. The values chosen are $0 \le \beta_v Kn \le 0.1$, $0 \le In \le 10$, $-1 \le \psi \le -10$ with reference values $\beta_v Kn = 0.05$, $M = 2.0$, $In = 1.667$, $S = 0.5$, $\phi = 45^0$, $\psi = -2$.

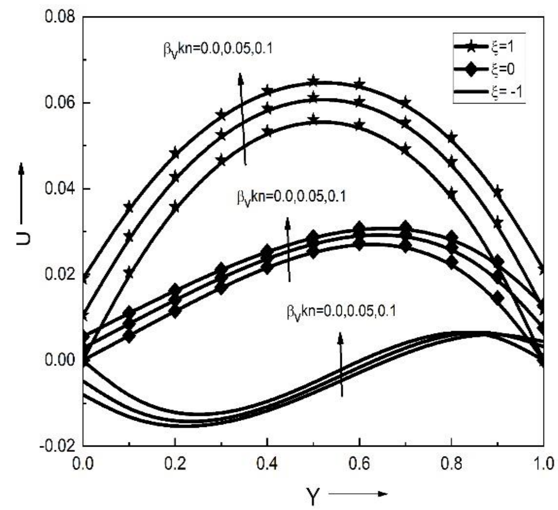

Fig .2. Effect of $\beta_v Kn$ on velocity

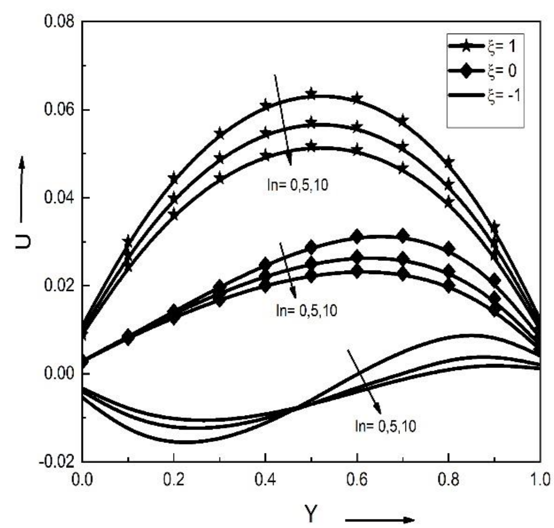

Fig .3. Profile of velocity for various In

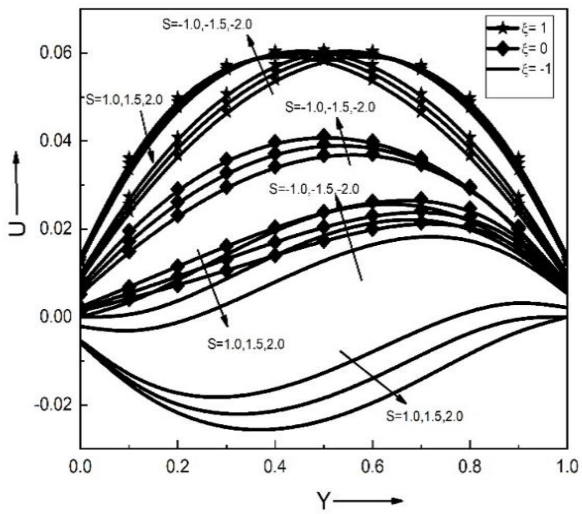

Fig .4. Profile of velocity for various S

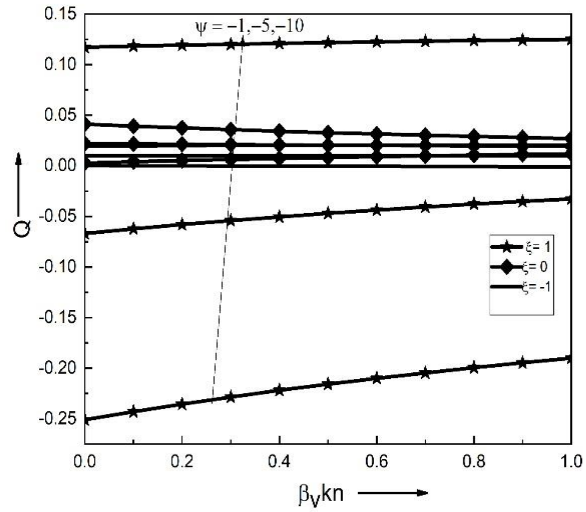

Fig .6. Impact of Q on ψ

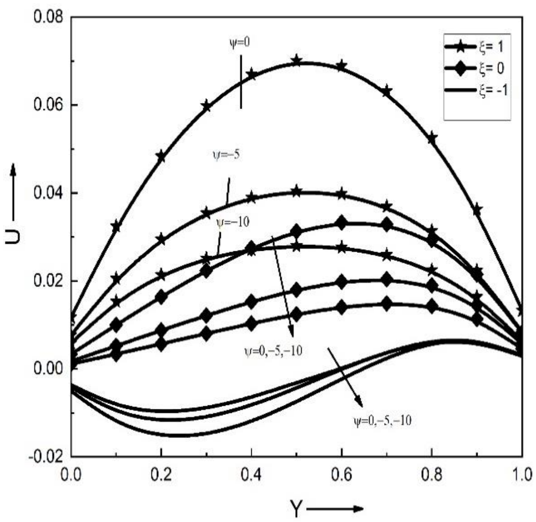

Fig .5. Impact of (ψ) on velocity

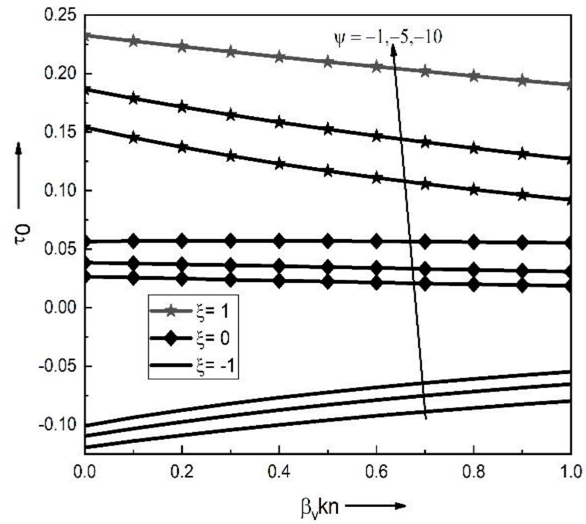

Fig .7. Impact of Skin friction at the left wall on ψ

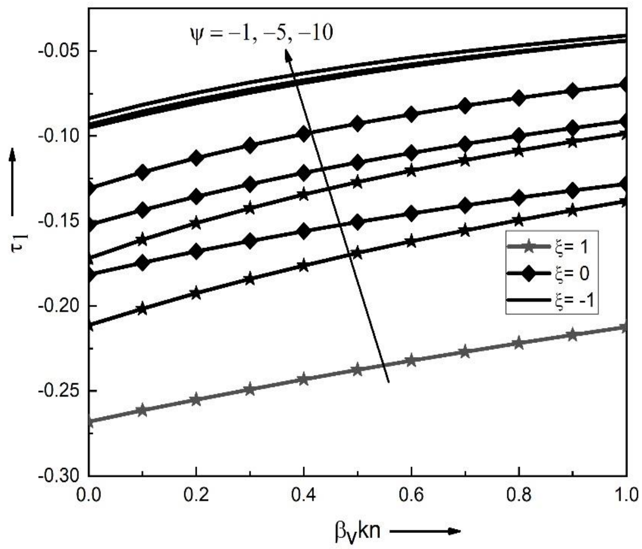

Fig .8. Effect of Skin friction on the right wall on ψ

Table 1: displays a comparison of the skin friction's numerical values at an inclined micro-porous channel walls for $Gr = 1, \phi = 90^0$ with the work.[12]

ξ	$\beta_v kn$	**Previous work** τ_0 Aina and Malgwi.[12]	**Present work** τ_0 at $\psi = 0$	**Present work** τ_0 at $\psi = -10$	**Previous work** τ_1 Aina and Malgwi.[12]	**Present work** τ_1 at $\psi = 0$	**Present work** τ_1 at $\psi = -10$
1	0.0	0.3551	0.3551	0.15422	-0.4151	-0.4151	-0.17189
	0.05	0.3429	0.3429	0.11680	-0.3944	-0.3944	-0.12702
	0.1	0.3313	0.3313	0.09211	-0.3760	-0.3760	-0.09844
0	0.0	0.0963	0.0963	0.02666	-0.2677	-0.2677	-0.13075
	0.05	0.1032	0.1032	0.02225	-0.2366	-0.2366	-0.09263
	0.1	0.1065	0.1065	0.01868	-0.2136	-0.2136	-0.06960
-1	0.0	-0.1624	-0.1624	-0.10088	-0.1203	-0.1203	-0.08961
	0.5	-0.1365	-0.1365	-0.07229	-0.0788	-0.0788	-0.05824
	0.1	-0.1183	-0.1183	-0.05474	-0.05111	-0.05111	-0.04077

Figure 2 display the impact of $\beta_v\, Kn$ and ξ on the velocity field. As $\beta_v\, Kn$ increases the velocity slips at both the walls enhances for all values of ξ. Which reduce the retarding effect of the wall. This shows the enhancement of fluid velocity. Further the impact of $\xi = 1$ is more influential on the velocity in comparison with $\xi = -1\ and\ 0$. For $\xi = -1$, flow reversal occurs closer to the right plate and there is no flow reversal for $\xi = 0\ and\ 1$. However, the profiles for $\xi = 0$ (symmetric heating) lies in between $\xi = \pm 1$ (asymmetric heating).

Figure 3 show the impact of In on the velocity distribution. For both symmetric and asymmetric heating. As the interaction parameter rises, there is a drop in slip velocity at the left wall while it increases at the right plate wall when $\xi = -1$. Furthermore as In increases the velocity decreases at left and right walls for $\xi = 0, -1$.

Figure 4 show the influence of injection $(S > 0)$ and suction $(S < 0)$ parameters distribution on the velocity for symmetric and asymmetric heating. This figure shows that as the injection parameters increases velocity decreases for all values of ξ. This is knowing to the fact that cold fluid particles are injected in to the micro-porous- channel to the cold porous wall while fluid particles that or heated on the hot wall removed out of the channel. This decreases temperature in the channel thus weakening the convection current. This leads to a decreasing in velocity. This figure also informs that the velocity slip becomes significant as ξ decreases. The influence of suction $(S < 0)$ on the velocity slip is exactly opposite to that of injection. Also this figure shows that the velocity slip becomes significant as the wall–ambient temperature difference ratio decreases. It means that the magnitude of increase in velocity increases as ξ decreases.

Figure 5 display the impact of heat source or sink parameter on the velocity fields. For the values of $\psi = 0, -1, -5$, velocity whereas decreases for both symmetric and asymmetric wall heating parameter. Additionally, as ξ increases velocity also increases for all values of ψ.

Figure 6 display the impact of the volumetric flow rate on the heat sink parameter for both symmetric and asymmetric wall heating. As ψ decreases, volumetric flow rate decreases for all values of ξ. As $\beta_v kn$ increases flow rate increases for $\xi = 1$ whereas it decreases for $\xi = -1, 0$.

Figure 7 and 8 reveal the effect of ψ and ξ on the skin friction at the left and right walls. As ψ 9increases skin friction decreases at both the plates for all values of ξ. As $\beta_v kn$ increases τ_0 increases for $\xi = -1$, whereas it decreases for $\xi = 0, 1$. The skin friction at the right wall increases as $\beta_v kn$ increases for all values of ξ. The magnitude of increase is more for $\xi = 1$ in comparison with $\xi = -1, 0$.

4. CONCLUSIONS

The current study examines the effect of heat sink in an inclined micro-porous channel. Analytical solutions are found for the governing equations. Following are the key findings.

1. As $\beta_v kn$ parameter increases, velocity increases for symmetric and asymmetric heating, whereas velocity decreases as In increases.

2. The suction parameter increases the velocity whereas injection parameter decreases the velocity for symmetric and asymmetric wall heating.
3. The heat sink parameter decreases the velocity for symmetric and asymmetric heating.
4. The volumetric flow rate parameter and skin friction at both plates are suppressed with heat sink parameter.

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