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Effect of Magnectic Field in a Forced Convective Saturated Porous Duct

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ABSTRACT

The main objective of the current work is to analyze the effect of magnetic field in a fully developed forced convection through a porous medium bounded by parallel plate channel, with the inclusion of boundary and inertial effects. The governing equations are discretized using finite difference method and resulting system of algebraic equation are solved using TDMA. The computation results have been validated and are found to be in good agreement with those available in the literature. The velocity and temperature plots are obtained for varying parameters like porous media shape parameter (s), Forchheimer number (F_s) and Magnetic number (M_n). The results show that nonlinear drag (F_s) have significant impact with porous media shape parameter (s) and less significant with magnetic field.

Keywords - Forced convection, Porous media, Magnetic field, Finite difference method

1. INTRODUCTION

The investigation of fluid flow in porous media has been of considerable interest for engineers and scientists for several decades. Various applications, such as fluid flow and heat transfer in compact heat exchangers, packed beds, aerosol transport, geo physics, oil recovery technique, thermal insulation and heat storage and blood flow in vessels, are all dependent on the behavior of the flow in the porous media.. From the forgoing literature review it is clear that most of the prior studies on forced convective heat transfer in a porous medium have never include the magnetic effect. Forced convective heat transfer flows through the porous medium under the influence of magnetic field contain much research potential. Since experimental process is very expensive and complex too. On the other hand, as the computational resources are becoming cheaper and faster, there is a lot of scope for computational work. In computational work, there is a need to validate the results with available literature. A number of theoretical and experimental investigations have been reported concerning to heat transfer flows through the porous medium under the influence of magnetic field. **A. Ghofrani[1]** ***el al.***, experimentally investigated the laminar forced convection heat transfer of an aqueous ferrofluid flow passing through a circular copper tube in the presence of an alternating magnetic field and find out that when applying an alternating magnetic field can enhance the convective heat transfer rate. **Hajit *et al[2].***, studied the heat transfer in rectangular passages with prescribed wall heat flux, filled with saturated porous materials and their solution uses the Green's function that can accommodate the inclusion of heat flux over the entire surface area or over isolated sections of the boundary. **Hooma.K[3]** theoretically investigated the temperature dependent viscosity effect on forced convection in a circular tube filled with a porous medium and found that the effect of the variation impacts the Nusselt number significantly while the pressure drop was not influenced that much. **Hooman.K***et.al*[4]., also analytically investigated the effects of viscous dissipation on thermal entrance heat transfer in a parallel plate channel filled with a saturated porous medium and validated the results of analytical and numerical which were compatible

Hooman.K*et al***[5].,** analyzed the effects of viscous dissipation and boundary condition on forced convention in a journal occupied by a saturated porous medium. **Rashmi *et al[8].*,** focused on numerical simulations of natural convection heat transfer in Al_2O_3-water nanofluids using computational fluid dynamics approach and their numerical result simulated shows decrease in heat transfer with increase in particle volume fraction. **Sheikholeslami *et a[9]*** simulated Fe_3O_4 -water nano fluid mixed convection heat transfer in a lid-driven semi annulus in the presence of a non-uniform magnetic field and their results show that the Nusselt number has a direct relationship with Richardson number and nanoparticle volume fraction, while it has a reverse relationship with Hartmann number and magnetic number. **Vafai. K *et al[10]*** have proved that for a high-permeability porous medium the thickness of the momentum boundary layer depends on both the Darcy number and the inertia parameter, while that for a low-permeability porous medium depends only on the Darcy number. The objective of present study is to identify the effect of magnetic field in a forced convective saturated porous duct which is not carried out in literature [6]. The result will be validated numerically using FORTRAN.

2. MATHEMATICAL FORMULATION

For the steady-state fully developed, forced convection situation in the presence of magnetic field, there exists a unidirectional flow in the X*-direction inside a channel with impermeable walls at y*= ± H, as illustrated in Fig. 1. For x*>0, the heat flux at the tube wall is held constant at the value q” and magnetic flux is introduced in the duct.

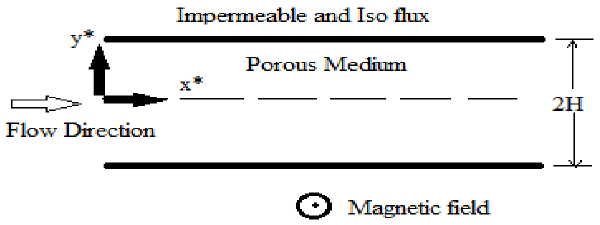

Figure 1. Layout of the duct

The Brinkman-Forchheimer momentum equation is

$$\mu_{eff}\frac{d^2u^*}{dy^{*2}}-\frac{\mu}{K}u^*-\frac{C_F\rho u^{*2}}{\sqrt{K}}+G-\frac{\sigma B_0^2}{\rho}u^*=0 \qquad \text{....(1)}$$

where μ_{eff} is an effective viscosity, μ is the fluid viscosity, K is the permeability, ρ is the permeability, c_F is the inertial coefficient, and G is the negative of the pressure gradient.

The dimensionless variables are defined as

$$x=\frac{x^*}{PeH},\ y=\frac{y^*}{H},\ u=\frac{\mu u^*}{GH^2} \qquad \text{....(2)}$$

here the Peclet number Pe is defined by

$$Pe=\frac{\rho c_p HU}{k} \qquad \text{....(3)}$$

The dimensionless form of Eq.(1) is then

$$M\frac{d^2u}{dy^2}-\frac{u}{Da}-\frac{MFu^2}{\sqrt{Da}}+1-M_nu=0 \qquad \text{...(4)}$$

The viscosity ratio M, the Darcy number Da, the Forchheimer number F, and the magnetic parameter M_n are defined by

$$M=\frac{\mu_{eff}}{\mu},\ Da=\frac{K}{H^2},$$
$$F=\frac{C_F\rho GH^3}{\mu_{eff}\,\mu},\ M_n=\frac{\sigma B_0^2H^2}{\rho\mu}. \qquad \text{... (5)}$$

Eq.(4) can be rewritten as

$$\frac{d^2u}{dy^2}-s^2u-Fsu^2\sqrt{m}+\frac{1}{M}-\frac{M_n}{M}u=0 \qquad \text{.....(6)}$$

where the porous media shape parameter is defined as

$$s=\left(\frac{1}{MDa}\right)^{1/2} \qquad \text{.....(7)}$$

Eq.(6) is to be solved subject to no-slip boundary condition, i.e., u=0 at y=1, and the symmetry condition or ${du}/{dy}=0$ at y=0.

The mean velocity U and the bulk mean temperature T_m are defined by

$$U=\frac{1}{H}\int_0^H u^*dy^*,\ T_m=\frac{1}{HU}\int_0^H u^*T^*dy^*. \qquad \text{...(8)}$$

Further dimensionless variables are introduced as

$$\hat{u} = \frac{u^*}{U} \quad \text{.... (9)}$$

and

$$\theta = \frac{T^* - T_w}{T_m - T_w} \quad \text{...(10)}$$

The Nusselt number Nu is

$$Nu = \frac{2Hq''}{k(T_w - T_m)} \quad \text{...(11)}$$

Local thermal equilibrium and homogeneity is assumed. the steady-state thermal energy equation in the absence of heat source, axial conduction ,and thermal dispersion is then

$$\rho c_p u^* \frac{\partial T^*}{\partial x^*} = k \frac{\partial}{\partial y^*}\left(\frac{\partial T^*}{\partial y^*}\right) \quad \text{.....(12)}$$

It follows from the First Low of Thermodynamics that

$$\frac{\partial T^*}{\partial x^*} = \frac{q''}{\rho c_p HU} \quad \text{........(13)}$$

Though the local temperature T^* is a function of both axial and radial coordinates the dimensionless temperature profile in the fully developed region, θ is a function of the coordinate (y^*) only, while the bulk mean temperature is a function of the axial coordinate (x^*) only.

In non-dimensional form Eq(12) becomes (when Eqs.(8)-(11)are used)

$$2\frac{d^2\theta}{dy^2} + \hat{u}\, Nu = 0 \quad \text{.....(14)}$$

where the boundary conditions are as follows

$\frac{d\theta}{dy} = 0\ at\ y = 0$ and $\theta = 0\ at\ y = 1$.

Nusselt number is a qualitative measure of heat transfer.

2.1. NUMERICAL PROCEDURE AND VALIDATION

The governing equations are discretized using central difference scheme finite difference method and resulting system of algebraic equation are solved using Tri Diagonal Matrix Algorithm (TDMA) with the help of FORTRAN software. The computation results have been validated with the literature "A perturbation solution for forced convection in a porous-saturated duct" by Hooman and are found to be in good agreement with this literature, convergence criteria is less than 10^{-5} error and is given by

$$\frac{\Sigma(\phi_i^m - \phi_i^{m-1})}{\Sigma\phi_i^m} \le 10^{-5}$$

Magnetic number (Mn)	Forchheimer number (Fs)	Porous media shape parameter (S)	Nusselt number (Nu)
0	1	1	4.199
		10	5.15
		100	5.9
0	2	100	5.902
		1000	5.983
		1000	5.984
10	2	100	5.902
		1000	5.983
		1000	5.984

3. RESULT AND DISCUSSION

Fully developed forced convection in a porous-saturated parallel plate channel, with the inclusion of boundary, magnetic and inertial effects, was solved numerically by using finite difference method. The most important observations are as follows:

From Fig. 2, the velocity profile depends strongly on the parameters F_s and s, when s is very small compared to unity. It is worth noting that, within the range of our approximations, these two parameters affect the velocity profile in a similar way.

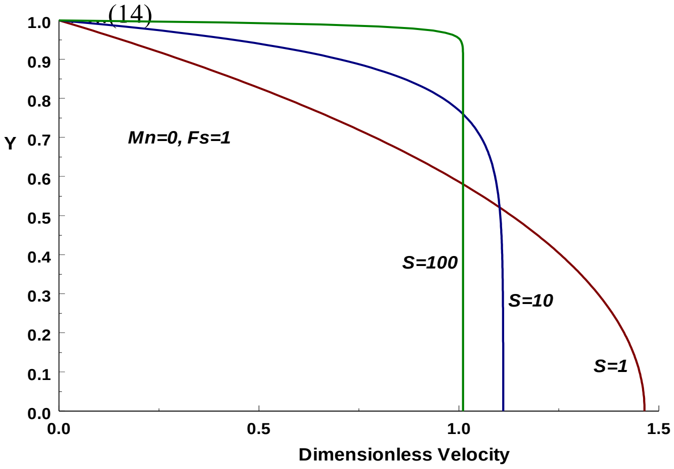

Fig.2. Dimensionless velocity profiles for some values of s (Fs=1,Mn=0).

As s increases, the central region containing a relatively uniform velocity distribution spreads further toward the walls and the effects of form drag becomes less significant. At larges, the velocity profile is confined to a very thin layer adjacent to the walls and as s →∞ the limiting slug flow is observed.

The temperature distribution is shown in Fig. 3 for some values of s. The results show that the centerline temperature increases with increase in s. The value of the Nusselt number increases with an increase in either s or F_s. For small values of s the Nusselt number tends to be higher for higher F_s values, however, for large values of s no change is inspected in Nu as the value of F_s varied.

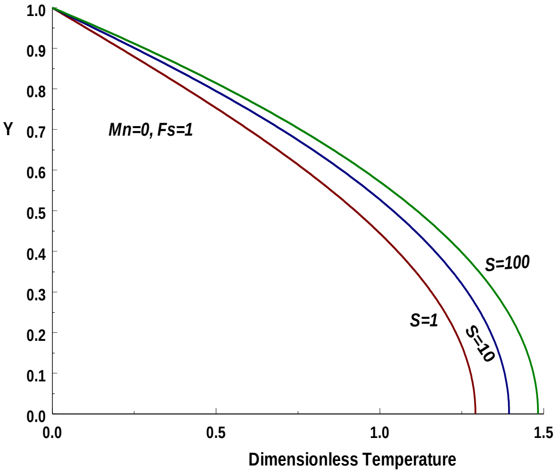

Fig.3. Dimensionless temperature distribution for some values of s (Fs=1,Mn=0)

The table shape of the temperature profile does not change significantly with s or F_n but the centerline temperature enhances as s increases. If Mn = 0 means the velocity and temperature profiles are match with Reference base paper.

Fig.4 to 7 shows the profiles of velocity and temperature with change in magnetic field and keeping F_s and S as like previous case . Further the magnetic number value increases from 10 to 1000 the plot remains same. It is clearly noted that the impact of magnetic field is less significant in this type of flow.

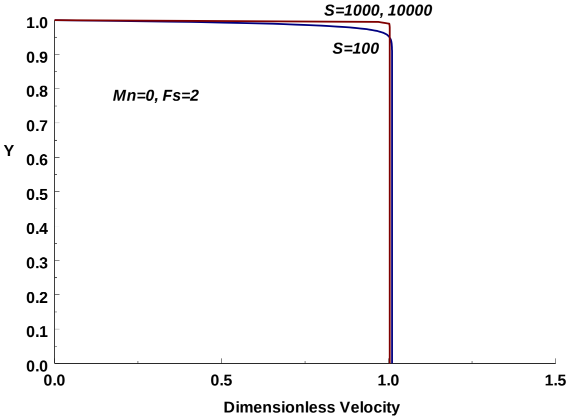

Fig.4. Dimensionless velocity profiles for some values of s (Fs=2,Mn=0).

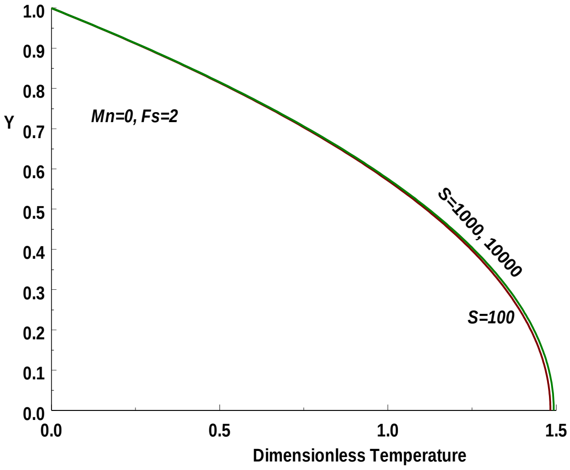

Fig.5. Dimension temperature distribution for some values of s (Fs=2,Mn=0).

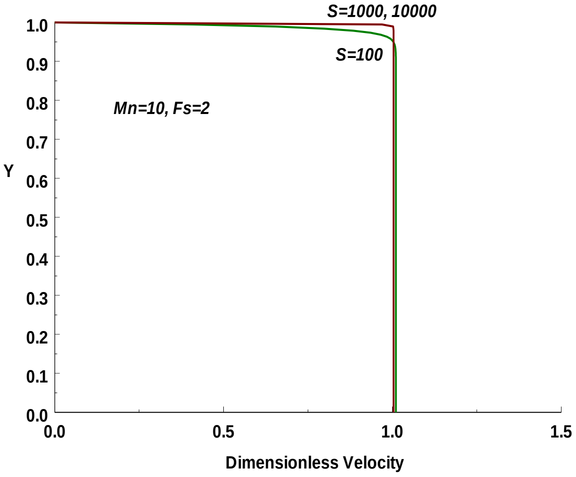

Fig.6. Dimensionless velocity profiles for some values of s (Fs=2,Mn= 10).

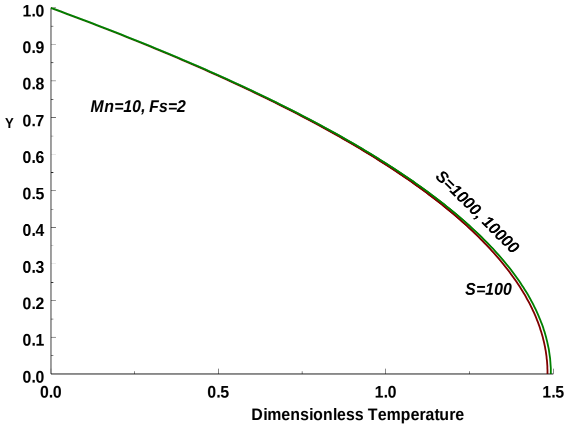

Fig.7. Dimensionless temperature distribution for some values of s (Fs=2, Mn=10).

4. CONCLUSION

Fully developed forced convection in a porous-saturated parallel plate channel, with the inclusion of boundary, magnetic and inertial effects, was solved numerically using finite difference method. The most important observations are as follows:

- The velocity profile depends strongly on the parameters Fs and s, when s is very small compared to unity. It is worth noting that, within the range of our approximations, these two parameters affect the velocity profile in a similar way.
- As s increases, the central region containing a relatively uniform velocity distribution spreads further toward the walls and the effects of form drag becomes less significant. At larges, the velocity profile is confined to a very thin layer adjacent to the walls and as $s \to \infty$the limiting slug flow is observed.
- The value of the Nusselt number increases with an increase in either s or Fs. For small values of s the Nusselt number tends to be higher for higher Fs values, however, for large values of s no change is inspected in Nu as the value of F varied.
- The shape of the temperature profile does not change significantly with s or Fs but the centerline temperature enhances as s increases
- From table 1, it is clear that Nu increases significantly with increases in Fs and s but no change with increase in magnetic number (Mn).

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