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Effects of MHD, Forchheimer and Heat Transfer in Annular Region between Porous and Impervious Concentric Cylinders - DTM Approach

T. C. Sushma[1]*, P. A. Dinesh[2], N. Nalinakshi[3], D. V. Jayalakshmamma[4] and B. P. Harichandra[5]

[1]*Department of Mathematics, Nitte Meenakshi Institute of Technology, Bengaluru – 560064, Karnataka, India; sushmadhuadekandi@gmail.com*

[2]*Department of Mathematics, M. S. Ramaiah Institute of Technology, Bengaluru – 560054, Karnataka, India; dineshdpa@msrit.edu*

[3]*Department of Mathematics, Atria Institute of Technology, Bengaluru – 560024, Karnataka, India; nalinigcm12@gmail.com*

[4]*Department of Mathematics, Vemana Institute of Technology, Bengaluru – 560034, Karnataka, India; jaya.dvj@gmail.com*

[5]*Department of Mechanical Engineering, M. S. Ramaiah Institute of Technology, Bengaluru – 560054, Karnataka, India; bpharichandra@msrit.edu*

Abstract

Significant increase of numerous applications in engineering, biological and industrial purpose as metallic extrusion motivated this communication. This paper proposes unique computational procedure is Method of Differential Transforms (DTM) to get an exact solution for electrified conducting fluid over a semi-porous cylinder in an impermeable cylinder with effects of Joule heating and convection term. A key finding of study reports the different dimensionless parameters influences the variations in velocity and heat transport on the fluid flow are presented graphically. The graph reveals an interesting result of Nusselt number, Skin-friction and stream lines elucidates the flow characteristics. A qualitative agreement is found in the present paper and are well matched with earlier work.

Keywords: *Convection Term, DTM, Joule Heating*

1.0 Introduction

Main reason for this present study on the semi porous cylinders has gained profound attention in Chemical industries in powerful process of chemical separation, filtration, extrusion of metals and oil mines. Enormous biological applications based on porous media has caught an attention of many research investigators like Kosari *et al.*[1]. studied one such fluid model for flow transport and thermal flow synthesis in a media of porous. Significant attention is paid by Verma and Verma[2] for the study of different permeability of a flow over a permeable layer enclosing the pervious sphere. The journal bearing which is of porous kind and attributes are interpreted using couple stress fluid flow model numerically solutions are approached by Shalini *et al.*[3]. Applications in engineering like copper wire tinning, annealing, extrusion of polymer sheet or metal, in growth of crystals, production of fiber

**Author for correspondence*

glass/paper, metallurgical and many more. Because of these list applications many research conducted and few are listed below like Chamkha[4] studied reaction of chemicals and absorption or generation of heat- mass transport phenomenon for the MHD flow past a pervious moving cylinder. This work basically on quiescent fluid to analyze the flow behavior with heat transfer and boundary layer flow is governed by owing stretched surfaces with velocity considered to be variable or constant.

Next to mention, theoretical study is conducted by Kalavathi *et al.*[5] to analyze the impact of MHD through porous and rough infinitely long journal bearing. Abbas *et al.*[6] conducted analysis to observe the radiation impact of thermal wave on flow of MHD past a cylinder is stretched and placed in a previous medium. Deo *et al.*[7] examined micro polar flow transfer which is made up of permeable cylinder encompassed by another unbounded porous medium. Convection is free and flow past a movable cylinder is installed vertically inside a pervious region to analyze impact of thermal radiation and mass transport on flow of MHD is investigated by Suneetha *et al.*[8].

A non Darcian model is considered by Aldoss[9] for the analysis of heat transport with variable boundary for convection is mixed kind with flow of MHD over a transversal cylinder situated inside a pervious region. Kalavathi *et al.*[10] conducted study on surface roughness effect inside a journal bearing which is porous and narrow in addition to heterogeneous no-slip or slip surfaces. Raghava *et al.*[11] studied numerically the mass and heat transport for the magneto hydrodynamics flow past a cylinder is of circular kind. Nalinakshi *et al.*[12] conducted the study to investigate the electrically conducting flow over a cylinder is solid in a previous region is cylindrical with applied magnetic field in transverse direction. Jayalakshmamma *et al.*[13] studied the variation of viscous flow with influence of magnetic effect over impervious region surrounded by a pervious region of a cylinder.

There are two distinct scales of microscopic/ macroscopic study on which the research can be conducted based fluid movements in pervious materials. Kumara *et al.* investigated research on convection with porosity in wall heating with macroscopic investigation focused on heat and fluid movement within porous materials using a macroscopic approach.

The study of flow model with concentric layered region of cylinders is analyzed by Umadevi *et al.*[14,15].

Most of the real-world situations are essentially non-linear in nature. The modeling of several physical systems mathematically give rise to differential equations of non-linear kind. In these, some of the equations are solved analytically and some are numerically solved. Techniques involved in analytical procedure are based on parameters that could be small or large of kind. For higher orders of non-linear differential equations, the Taylor series method is considered as traditional method is computationally very expensive in nature. To overcome such limitations or restrictions and difficulties involved in discretization or linearization. One such semi analytic computation procedure which does not require linearization, small parameters and no need of discretization is a (DTM) differential transform procedure that constructs the result in the polynomial form. Because of above listed restrictions and with unique problem solving procedure DTM method has caught a focus of many authors like in the year 1986 Zhou is the first to propose the DTM concept to solve initial value problems which are both non-linear and linear differential equations in the analysis of electrical circuits. DTM addresses an accurate value for the derivative of nth order provided flow model with various boundary conditions with semi-analytical fast computation manner and results in the form of high accurate series provided reference[16-25]. Sowbhagya[26] conducted study on maximum density outlook to onset of convection throghflow with Forchheimer-Bénard term. The study of perturbation approach by researchers[27] to examine the impact of electric modulation in a dielectric fluid saturating porous medium. A corrected Rayleigh number, which represents the computation of the system's stability is based on the functions as electric, thermal, and parameters for porosity as well as the frequency of the electric field modulation. There are two distinct scales of microscopic / macroscopic study on which the research can be conducted based fluid movements in pervious materials. Kumara *et al.*[28] investigated research on convection with porosity in wall heating with macroscopic investigation focused on heat and fluid movement within porous materials using a macroscopic approach.

As electricity directly running into the food materials to cause the release of heat inside the food particles in food processing. To achieve this joule heating is used in all electric heating equipment devices like stoves, soldering irons, heaters. The present communication addresses the differential transform method to understand the flow and investigate the solution of axisymmetric steady incompressible fluid by incorporating term of convection and fluid passage in to semi-pervious cylinder encompassed by a fluid filled partially and placed in a circular cylinder with joule heating influence with constant magnetic effect. The Joule effect considered in mass and heat flow transport with convection term are presented graphically.

2.0 Mathematical Formulation

The flow has been considered across a semi-pervious cylinder is a situated in a solid cylinder is filled partially

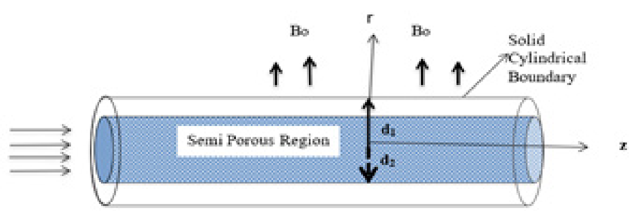

Figure 1. Physical configuration.

with two-dimensional, axi-symmetric, steady, and incompressible flow. The circular cylinder as radius is ‘d_1’ with fluid region enclosing a porous cylinder ‘d_2’as radius as given in Figure 1.

The separations are found in domain of flow as clear fluid and porous. The basic model incorporated by terms of convection in Sharma *et al.*[24]. For a conducting fluid, equations governed to describe the flow under the assumptions made are equations Stokes’s modified along with mass transport equation.

Equation of mass

$$\nabla \cdot \vec{q} = 0 \tag{1}$$

Stokes equation of modified form

$$\rho(\vec{V}.\nabla)\vec{V} = -\nabla p + \mu\nabla^2 \vec{V} - \frac{\mu}{K}\vec{V} - \frac{\mu}{\sqrt{K\nu}}\left|\vec{V}\right|\vec{V} + \left(\vec{J}\times\vec{B}\right) \tag{2}$$

Equation of Energy:

$$\rho C_p(\vec{q}.\nabla)T = \kappa\nabla^2 T + \frac{\vec{j}^2}{\sigma} \tag{3}$$

We initiated work based the analysis on which the assumptions are made at that time, these momentum and heat equations for fluid in the region ($d_2 < r < d_1$) of annulus.

$$\mu\left(\frac{\partial^2 u_{rf}}{\partial r^2} + \frac{1}{r}\frac{\partial u_{rf}}{\partial r}\right) - \frac{\partial p}{\partial r} - \sigma B_0{}^2 u_{rf} = 0 \tag{4}$$

$$\rho C_p\left[u_{rf}.\frac{\partial T_{rf}}{\partial r}\right] - \kappa\left(\frac{\partial^2 T_{rf}}{\partial r^2} + \frac{1}{r}\frac{\partial T_{rf}}{\partial r}\right) - \sigma B_0{}^2 u_{rf}{}^2 = 0 \tag{5}$$

For region of pervious, motion and energy relation, where ($d_2 > r$) given by

$$\mu\left(\frac{\partial^2 u_{rp}}{\partial r^2} + \frac{1}{r}\frac{\partial u_{rp}}{\partial r}\right) - \frac{\partial p}{\partial r} - \sigma B_0{}^2 u_{rp}{}^2 - \frac{\mu}{K}u_{rp} - \frac{\mu C_d}{\sqrt{K\nu}}u_{rp}{}^2 = 0 \tag{6}$$

$$\rho C_p\left[u_{rp}.\frac{\partial T_{rp}}{\partial r}\right] - \kappa\left(\frac{\partial^2 T_{rp}}{\partial r^2} + \frac{1}{r}\frac{\partial T_{rp}}{\partial r}\right) - \sigma B_0{}^2 u_{rp}{}^2 = 0 \tag{7}$$

where, u_{rp} and u_{rp} are the fluid velocity in the impervious and region of porous. T_{rf}, T_{rp} are the temperature of the fluid in the annulus - pervious regions respectively.

The dimensionless parameters:

$$d_2^* = \frac{d_2}{d_1}, r^* = \frac{r}{d_1}, u_{rf}{}^* = \frac{u_{rf}}{u_0}, u_{rp}{}^* = \frac{u_{rp}}{u_0}, \mathrm{Re} = \frac{\rho u_0 d_1}{\mu}, G_p{}^* = \frac{\partial p}{\partial r}\Big/\frac{\rho u_0{}^2}{d_1}, Da = \frac{\mu}{K}$$

$$Br = \frac{G_p{}^2 d_2{}^4}{\mu\kappa(T_w - T_{wp})},\quad F = \frac{G_p d_1{}^4 C_d}{\mu\nu\sqrt{K}},\quad M = \sqrt{\frac{\sigma B_0{}^2 a^2}{\mu}},$$

$$\theta_{rf} = \frac{(T_{rf} - T_w)}{(T_{wp} - T_w)},\quad \theta_{rp} = \frac{(T_{rp} - T_w)}{(T_{wp} - T_w)}$$

where, the constant applied magnetics parameter is B_0, the C_p as specific heat at constantly applied pressure, the Hartmann number is M, the constant and dimensionless gradient of pressure as G_p, the Darcy term as Da, the Reynolds term is Re, the Forchheimer term is F and the Brinkman number as *Br*.

T_{rf} and T_{rp} be the temperature of the fluid in the non-porous and pervious regions. T_w be the notation of heat transport of the cylinder wall in addition to T_{wp} being the surface temperature at the porous cylinder.

With no loss in generality, the asterisks removal after dimensionless form attainment in equations [4-7] the pertinent to

$$r\frac{d^2u_{rfr}}{dr^2}+\frac{du_{rfr}}{dr}-\rho r\,\mathrm{Re}-M^2\ r u_{rf}=0 \quad (8)$$

$$r\frac{d^2\theta_{rf}}{dr^2}+\frac{d\theta_{rf}}{dr}+M^2\,Br\ r u_{rf}^{\ 2}-\alpha_1\ u_{rf}r\left(\frac{d\theta_{rf}}{dr}\right)=0 \quad (9)$$

$$r\frac{d^2u_{rp}}{dr^2}+\frac{du_{rp}}{dr}-G_p\ \mathrm{Re}\ r-\left(\frac{1}{Da}+M^2\right)r u_{rp}-\frac{F}{\mathrm{Re}}r u_{rp}^{\ 2}=0 \quad (10)$$

$$r\frac{d^2\theta_{rp}}{dr^2}+\frac{d\theta_{rp}}{dr}+M^2\ r\ Br\ u_{rp}^{\ 2}-\alpha_1\ r u_{rp}\left(\frac{d\theta_{rp}}{dr}\right)=0 \quad (11)$$

Where, $\alpha_1=\dfrac{\rho C_p u_0\,(T_{wp}-T_w)}{\kappa}$

The conditions applied on boundary are

$$\frac{\partial u_{rp}}{\partial r}=0,\quad \frac{\partial\theta_{rp}}{\partial r}=0\ \text{ at } r=0 \quad (12)$$

$$u_{rf}=0,\quad \theta_{rp}=0 \text{ at } r=1 \quad (13)$$

are the conditions of boundary at the interface of solid and porous are given by

3.0 Method of Solution

We have used unique procedure is a Differential Transform Method (DTM) for computing results to the equations which are governing the flow. The efficiency of DTM is provided in literature [17-20].

Table 1. The basic mathematical operations with DTM

Function	Differential Transform
$u(y)=g(y)\pm h(y)$	$U(k)=G(k)\pm H(k)$
$u(y)=\lambda h(y)$	$U(k)=\lambda H(k)$
$u(y)=\dfrac{\partial h(y)}{\partial y}$	$U(k)=(k+1)H(k+1)$
$u(y)=\dfrac{\partial^m h(y)}{\partial y^m}$	$U(k)=(k+1)$.................. ...$(k+m).H(k+1)$
$u(y)=y^n$	$U(k)=\delta(k-n)=\begin{cases}1 & at\ \ k=n\\ 0 & otherwise\end{cases}$
$u(y)=g(y)h(y)$	$U(k)=\sum_{r=0}^{k}G(r)H(k-r)$
$u(y)=g_1(y)g_2(y)$.. ....$g_m(y)$	$U(k)=\sum_{k_1}^{k}\ldots\sum_{k_{m-1}=0}^{k_2}G_1(k_1)G_2(k_2-k_1)$.. .....$G_m(k-k_{m-1})$

U(k) as derivative form $\left(\frac{d^k u(y)}{dy^k}\right)$ (14)

Is given by

$$\frac{1}{k!}\left[\frac{d^k u(y)}{dy^k}\right]_{y=yi} = U(k) \quad (15)$$

Then inversely differential transform applied on U(k)

$$u(y) = \sum_{k=0}^{\infty} U(k)(y-y_0)^k \quad (16)$$

DTM is applied on (8), we get the recurrence relations is in the form

$$\sum_{l=0}^{k}\begin{bmatrix}\delta(l-1)(k-l+2)(k-l+1)U_{rf}(k-l+2)\\ +(k+1)U_{rf}(k+1)\end{bmatrix} - G_p \operatorname{Re}\delta(k-1) - M^2 B_r \sum_{l=0}^{k}\left[\delta(l-1)U_{rf}(k-l)\right] \quad (17)$$

Here, $u_{rf}(r)$ term differential transform is $U_{rf}(k)$ as r = 0. Where $u_{rf}(r)$ is determined by condition of boundary as $U_{rf}(0)$ = a (constant).

$U_{rf}(1) = 0$, $U_{rf}(3) = 0$, $U_{rf}(5) = 0$

$$U_{rf}(2) = \frac{1}{4}\left(G_p \operatorname{Re} + M^2 a\right) \qquad U_{rf}(4) = \frac{M^2}{64}\left(G_p \operatorname{Re} + M^2 a\right)$$

$$U_{rf}(6) = \frac{M^2}{2304}\left(M^2 a + G_p \operatorname{Re}\right) \quad (18)$$

Applying (18) in $U_{fr}(k)$, the inverse differential transform of velocity profile as

$$u_{rf}(r) = a + U_{rf}(1).r + U_{rf}(2).r^2 + U_{rf}(3).r^3 + U_{rf}(4).r^4 + U_{rf}(5).r^5 + U_{rf}(6).r^6 \quad (19)$$

to find 'a', invoking the conditions of boundary. At r = 0, a is given by

$$a = \frac{-\left(\frac{1}{4} + \frac{M^2}{64} + \frac{M^4}{2304}\right)G_p \operatorname{Re}}{\left(1 + \frac{M^2}{4} + \frac{M^4}{64} + \frac{M^6}{2304}\right)} \quad (20)$$

Back substituting 'a' in (19), we get the compact solution at region of annulus for velocity.

In the permeable region, the velocity profile is obtained by applying DTM on (10), the recurrence relations are:

$$\sum_{l=0}^{k}\left[\delta(l-1)(k-l+2)(k-l+1)U_{rp}(k-l+2) + (k+1)U_{rp}(k+1)\right] - G_p \operatorname{Re}\delta(k-1) - \left(\frac{1}{Da} + M^2 B_r\right)\sum_{l=0}^{k}\left[\delta(l-1)U_{rp}(k-l)\right] - \frac{F}{\operatorname{Re}}\sum_{l=0}^{k}\sum_{i=0}^{l}\left[\delta(i-1)U_{rp}(l-i)U_{rp}(k-l)\right] = 0 \quad (21)$$

At r = 0, $U_{rp}(k)$ is applied DTM to get $u_{rp}(r)$. Here $u_{rp}(r)$ is computed with aid of $U_{rp}(0)$ = b (constant).

$U_{rp}(1) = 0$, $U_{rp}(3) = 0$, $U_{rp}(5) = 0$,

$$U_{rp}(2) = \frac{1}{2^2}\left(G_p \operatorname{Re} + \left(\frac{1}{Da} + M^2\right)b + \frac{F}{\operatorname{Re}}b^2\right), \quad (22)$$

Like this Six consecutive terms are calculated in equation (22) inverse differential transform is computed using (22) and We get

$$u_{rp}(r) = b + U_{rp}(1).r + U_{rp}(2).r^2 + U_{rp}(3).r^3 + U_{rp}(4).r^4 + U_{rp}(5).r^5 + U_{rp}(6).r^6, \quad (23)$$

Boundary condition at interface $r = d_1 \rightarrow u_{ff} = u_p$ a polynomial is obtained is of the form the fourth degree term in 'b'. Mathematica programming is used in evaluating a polynomial in 'b' and substitution of this 'b' value in (23) we arrive at velocity profile solution for region of both pervious and fluid clear flow are presented graphically.

Energy profile:

In the region of annulus, the energy equation recurrence relation by DTM approach on (9) and given by

$$\sum_{l=0}^{k}\begin{bmatrix}\delta(l-1)(k-l+2)(k-l+1)\theta_{rf}(k-l+2)\\ +(k+1)\theta_{rf}(k+1)\end{bmatrix} - M^2 B_r \sum_{l=0}^{k}\sum_{i=0}^{l}\left[\delta(i-1)U_{rf}(l-i)U_{rf}(k-l)\right] - \alpha_1 \sum_{l=0}^{k}\sum_{i=0}^{l}\begin{bmatrix}\delta(i-1)U_{rf}(l-i)\\ .(k-l+1)\theta_{rf}(k-l+1)\end{bmatrix} = 0 \quad (24)$$

At r = 0, the $\theta_{rf}(r)$ term differential transform as $\theta_{rf}(k)$ calculated and $\theta_{rf}(0)$ = c (constant).

$$\theta_{rf}(1) = 0, \quad \theta_{rf}(2) = -\frac{M^2 Br\left[U_{rf}(0)\right]^2}{4},$$

$$\theta_{rf}(3) = \frac{2\alpha_1\, a\, \theta_{rf}(2)}{9}, \quad (25)$$

Similarly, five consecutive terms are computed in equation (25). All the above (25) values are applied to (24) and inverse differential transform of (25) is

$$\theta_{rf}(r) = c + \theta_{rf}(1).r + \theta_{rf}(2).r^2 + \theta_{rf}(3).r^3 + \theta_{rf}(4).r^4 + \theta_{rf}(5).r^5, \quad (26)$$

With condition $\theta_{rf}(1) = 0$, the 'c' computed as

$$c = -(\theta_{rf}(1) + \theta_{rf}(2) + \theta_{rf}(3) + \theta_{rf}(4) + \theta_{rf}(5), \quad (27)$$

the results of energy equation in (26) as in the region of permeable is calculated by

$$\sum_{l=0}^{k}\begin{bmatrix}\delta(l-1)(k-l+2)(k-l+1)\theta_{rp}(k-l+2) \\ +(k+1)\theta_{rp}(k+1)\end{bmatrix} - M^2 B_r \sum_{l=0}^{k}\sum_{i=0}^{l}\left[\delta(i-1)U_{rp}(l-i)U_{rp}(k-l)\right] - \alpha_1 \sum_{l=0}^{k}\sum_{i=0}^{l}\left[\delta(i-1)U_{rp}(l-i)(k-l+1)\theta_{rp}(k-l+1)\right] = 0 \quad (28)$$

The differential transform of $\theta_{rp}(k)$ is $\theta_{rp}(r)$ and computed at r = 0 by $\theta_{rp}(0) = \alpha$ (arbitrary constant).

$$\theta_{rp}(1) = 0, \; \theta_{rp}(2) = -\frac{M^2\, Br\left[U_{rp}(0)\right]^2}{4}, \quad \theta_{rp}(3) = \frac{2\alpha_1\, b\, \theta_{rp}(2)}{9}, \quad (29)$$

Same way the next two terms are obtained in (29). Differential transform is used inversely on recurrence equation (28) as

$$\theta_{rp}(r) = \alpha + \theta_{rp}(1).r + \theta_{rp}(2).r^2 + \theta_{rp}(3).r^3 + \theta_{rp}(4).r^4 + \theta_{rp}(5).r^5, \quad (30)$$

Boundary condition is used at the interface $r = d_2 \rightarrow, \; \theta_{rp} = \theta_p$ the value of α calculated.

$$\alpha = c + (\theta_{rp}(2) - \theta_{rf}(2)).r^2 + (\theta_{rp}(3) - \theta_{rf}(3)).r^3 + (\theta_{rp}(4) - \theta_{rf}(4)).r^4 + (\theta_{rp}(5) - \theta_{rf}(5)).r^5, \quad (31)$$

Back substituting 'c' and 'α', the profile of temperature is computed from (26) and (30) for impermeable and pervious. Using programming of Mathematica graphs are presented. Skin friction is a shearing stress at the wall of cylindrical outer region is given as

$$C_{fr} = \frac{\mu \frac{\partial u_{rf}}{\partial r}}{\rho u_0^2}$$

$$C_{fr} = \frac{1}{\text{Re}}\left(\frac{\partial u_{rf}}{\partial r}\right)_{r=d_1} \quad (32)$$

At the surface of porous cylinder:

$$C_{pr} = \frac{1}{\text{Re}}\left(\frac{\partial u_{rp}}{\partial r}\right)_{r=d} \quad (33)$$

Nusselt number is a coefficient transfer of heat at the inner wall of cylinder is of circular kind as

$$Nu = -\left(\frac{\partial \theta_{rf}}{\partial r}\right)_{r=d_1} \quad (34)$$

At the surface of porous cylinder. The skin friction and Nusselt number are calculated and graphs are interpreted using codes in Mathematica.

4.0 Results and Discussion

Graphical analysis of the velocity and energy profile has been done based on the results of electrically conducting,

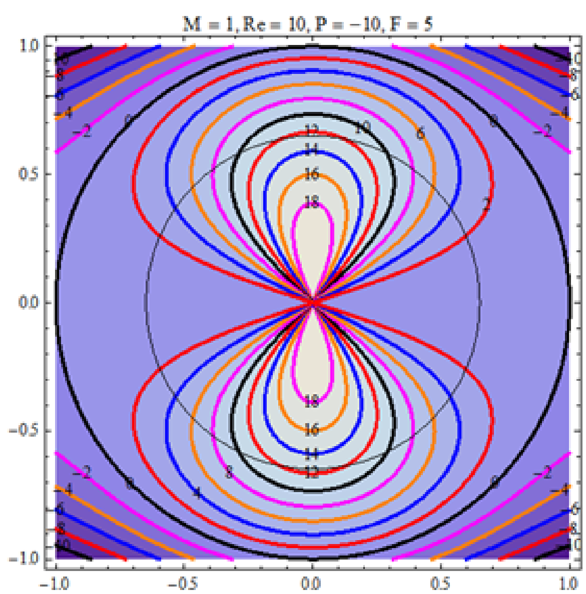

Figure 2 Variations in Magnetic field M =1 for stream lines with fixed parameters of Reynolds number Re, Pressure gradient P and Forchheimer number F

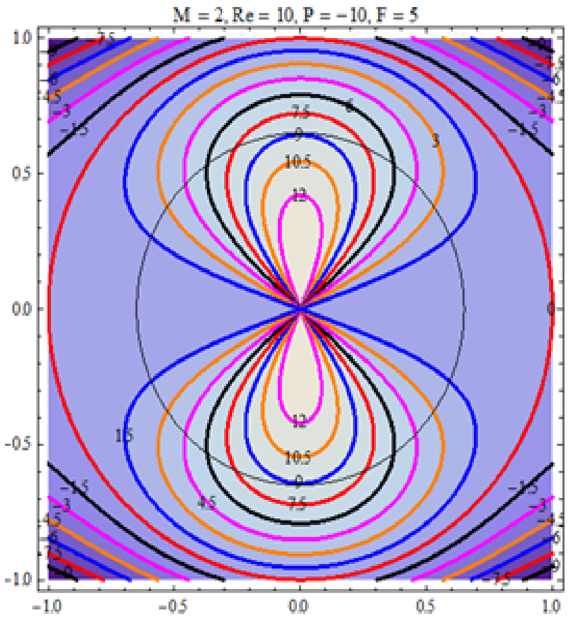

Figure 3 Variations in Magnetic field M = 2 for stream lines with fixed parameters of Reynolds number Re, Pressure gradient P and Forchheimer number F

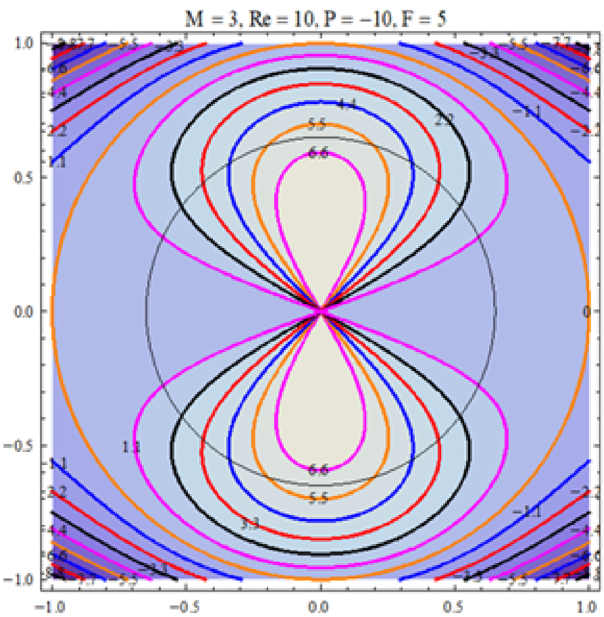

Figure 4 Variations in Magnetic field M =3 for stream lines with fixed parameters of Reynolds number Re, Pressure gradient P and Forchheimer number F

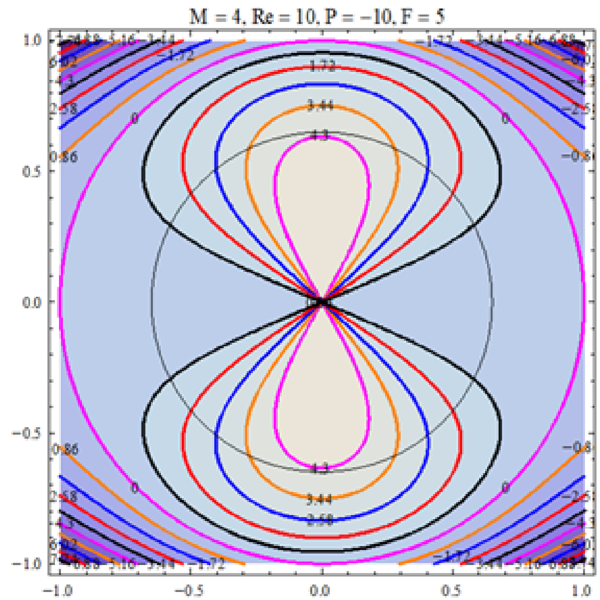

Figure 5 Variations in Magnetic field M =4 for stream lines with fixed parameters of Reynolds number Re, Pressure gradient P and Forchheimer number F

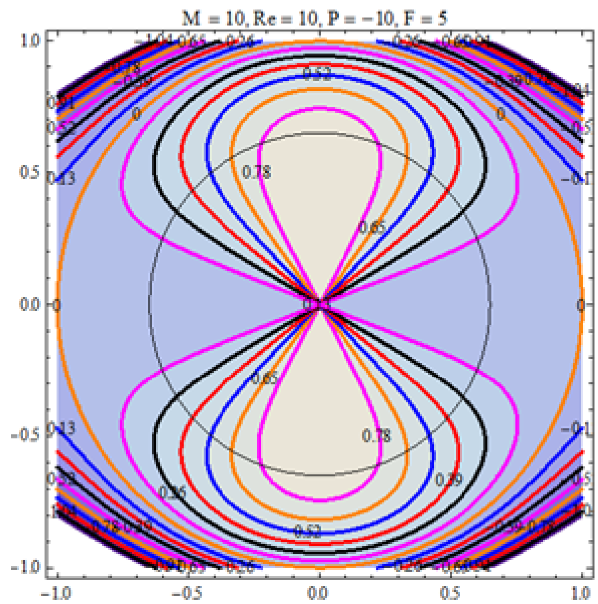

Figure 6. Variations in Magnetic field M = 10 for stream lines with fixed parameters of Reynolds number Re, Pressure gradient P and Forchheimer number F

axisymmetric and incompressible steady flow of fluid over a pervious cylinder bounded partially the fluid is filled in impermeable cylinder. The differential transformation is a technique utilized to retrieve the results of mass transport and variations in temperature of the flow in the clear and porous regions, respectively. To analyze the state of flow, the stream lines are plotted. Stream lines helps in investigating the condition of the flow for further if any

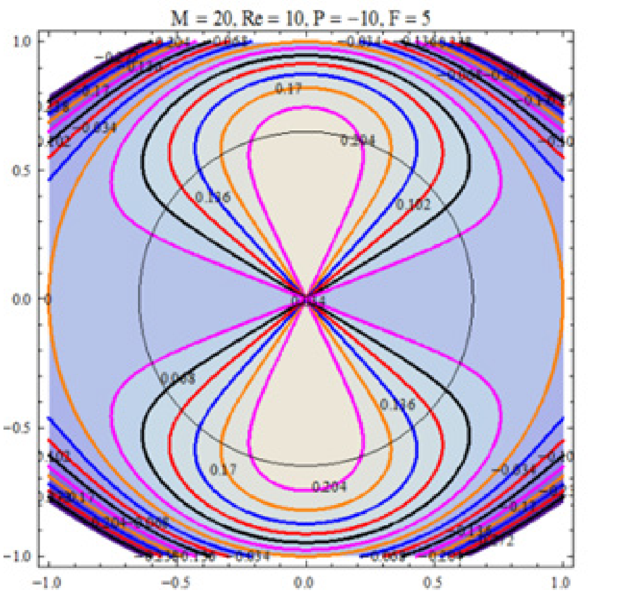

Figure 7. Variations in Magnetic field M = 20 for stream lines with fixed parameters of Reynolds number Re, Pressure gradient P and Forchheimer number F

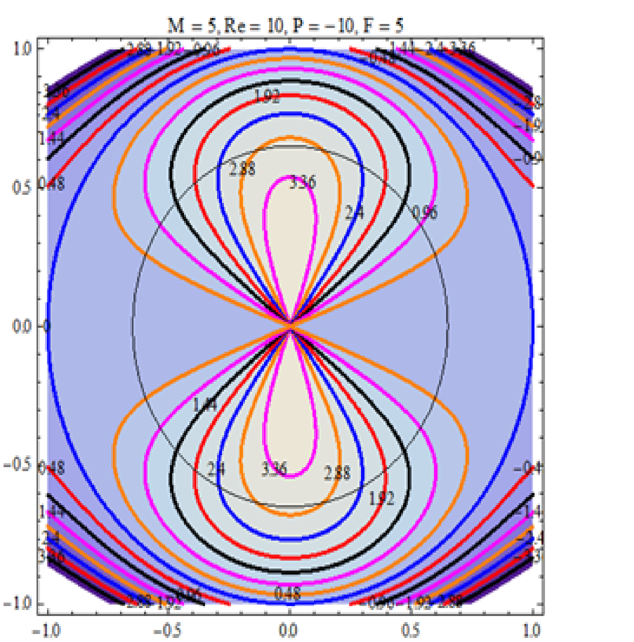

Figure 8. Variations in Magnetic field M = 5 for stream lines with fixed parameters of Reynolds number Re, Pressure gradient P and Forchheimer number F

corrections are required to get the compact solution for the flow field.

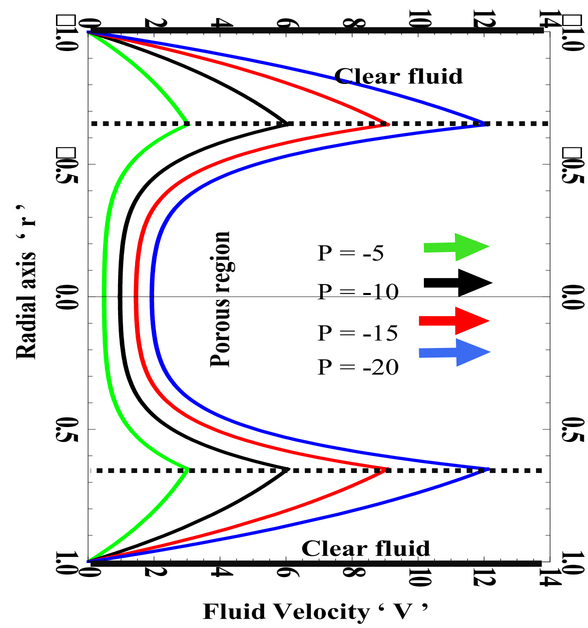

Figure 9. Effect of Pressure Gradient 'P' on fluid flow with fixed parameters of M=3, Re=10, Da=0.01, Br=0.01 and F=5

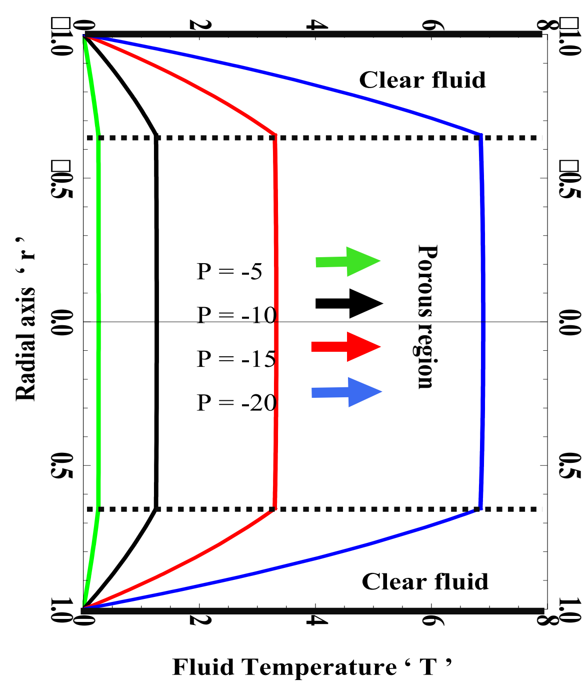

Figure 10. Effect of Pressure Gradient 'P' on fluid temperature with fixed parameters of M=3, Re=10, Da=0.01, Br=0.01 and F=5

A regular pattern in stream lines are commonly observed in literature, whereas circular type of patterns is rarely seen. If we observe physically also in the

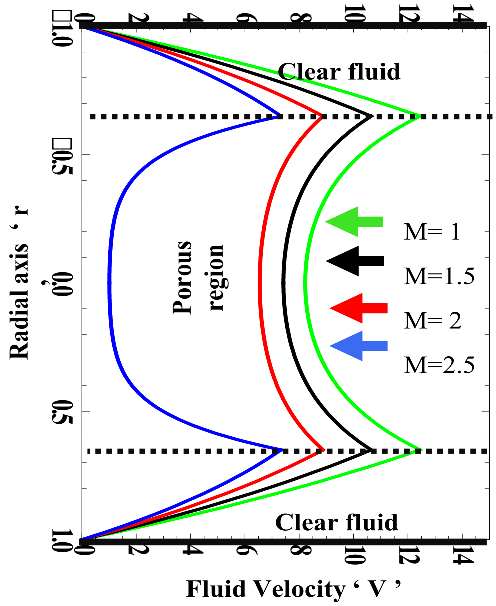

Figure 11. Effect of Hartman number M on fluid flow with fixed values of Re=10, P=-10, Da=0.1, F=5 and Br=0.01

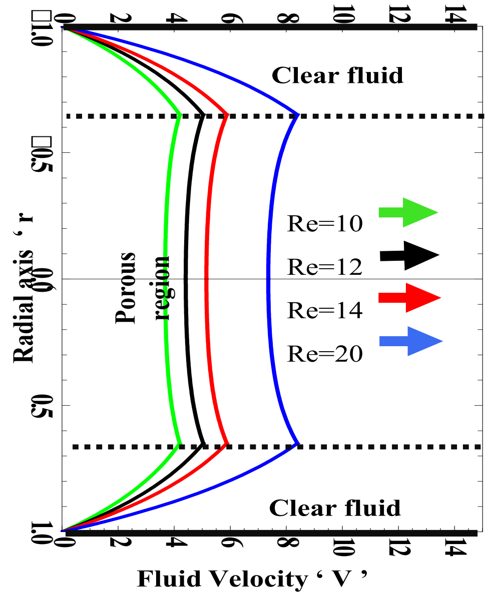

Figure 13. Effect of Reynolds number Re on fluid temperature with fixed values of M=4, P=-10, Da=0.1, F=5 and Br=0.1

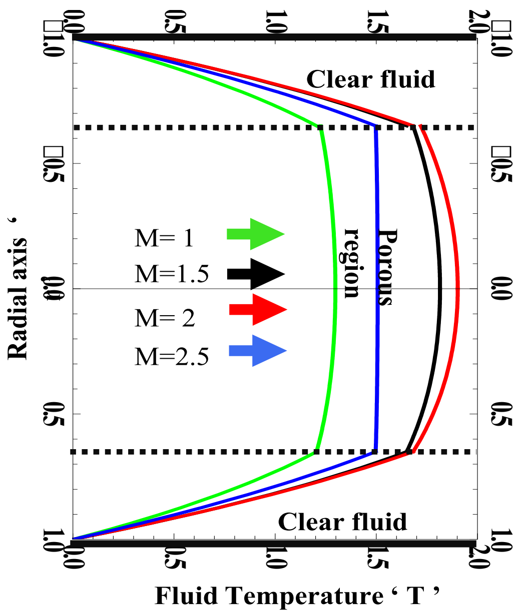

Figure 12. Effect of Hartman number M on fluid temperature with fixed values of Re=10, P=-10, Da=0.1, F=5 and Br=0.01

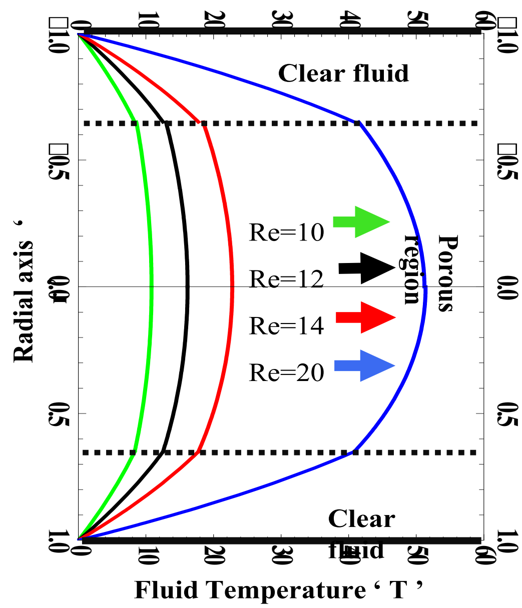

Figure 14. Effect of Reynolds number Re on fluid temperature with fixed values of M=4,P=-10, Da=0.1, F=5 and Br=0.1

present paper refer Figures 2-5, we can find the flow is continuous. Here, the flow near the porous cylinder it is of vorticity kind. Here the fluid which moves near the pervious region it is circulating, as per our knowledge we never come across such a pattern of fluid flow before. Whereas the fluid which are moving away from the permeable region that moves away in a regular pattern and the flow is continuous. To refer the graphs of stream

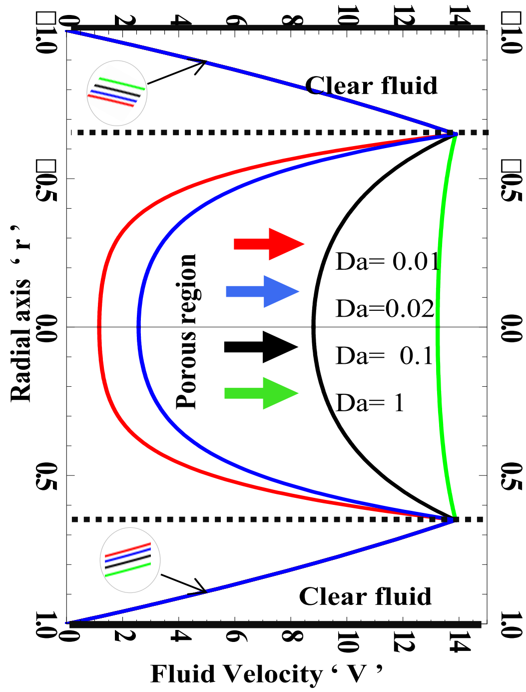

Figure 15. Effect of Darcy number Da on fluid velocity with fixed values of M=1, Re=10, P=-10, Da=0.1, F=5 and Br=0.01

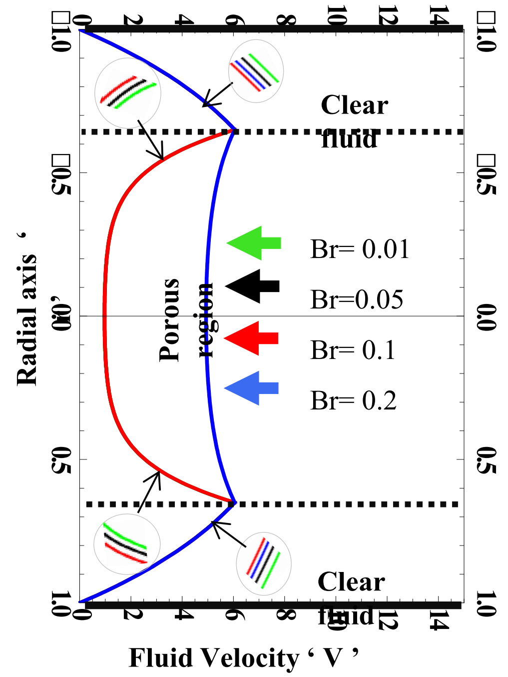

Figure 17. Effect of Forchheimer number F on fluid velocity with fixed values of M=3, Re=10, P=-10, Br=0.01and Da=0.1

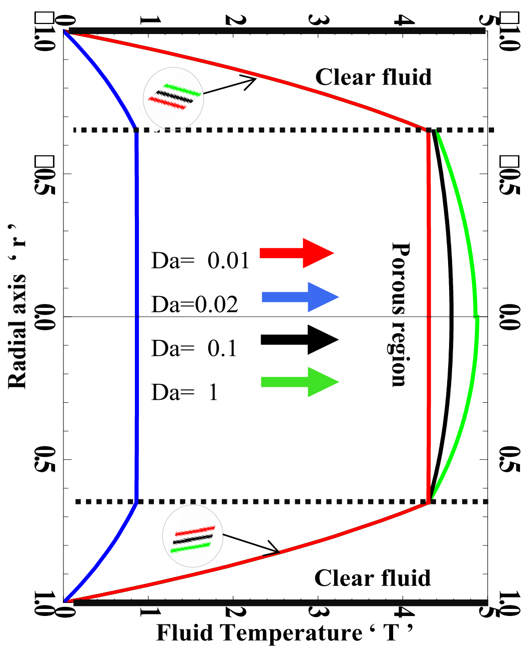

Figure 16. Effect of Darcy number Da on fluid temperature with fixed values of M=1, Re=10, P=-10, Da=0.1, F=5 and Br=0.01

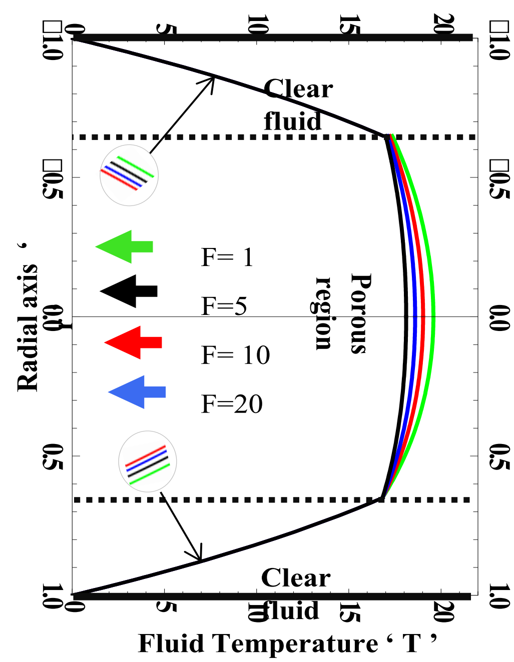

Figure 18. Effect of Forchheimer number F on fluid temperature with fixed values of M=3, Re=10, P=-10, Br=0.01and Da=0.1

lines showcases the key impact of magnetic field with added feature of Joule heating, for the detailed view refer Figures 6-8 narrates how the flow is slowly started to move away and slides over the previous cylinder as

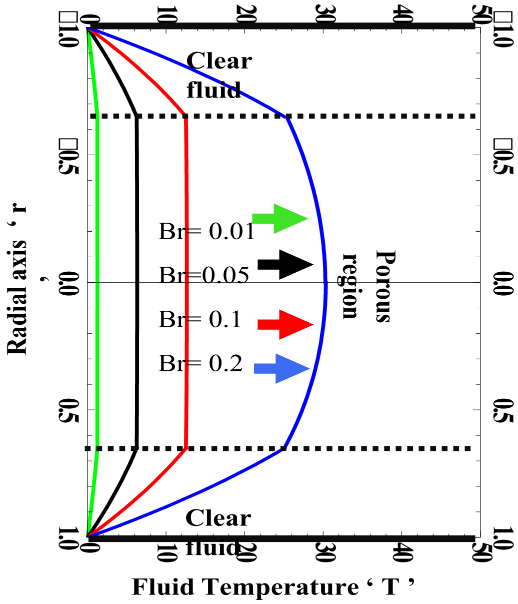

Figure 19. Effect of Brinkmann number Br on fluid velocity with fixed values of M=3, Re=10, P=-10, F=5 and Da=0.1

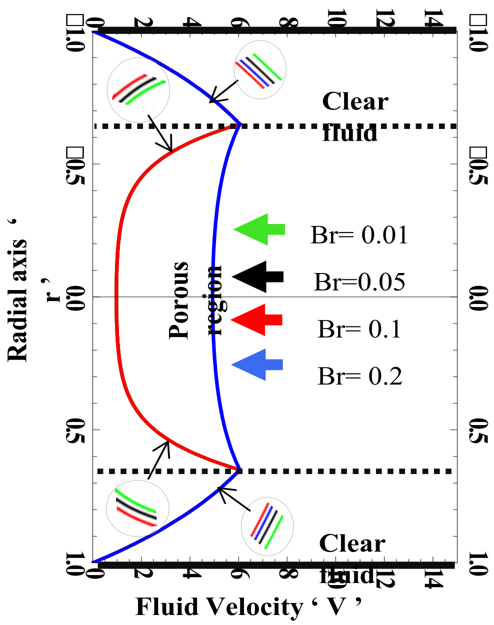

Figure 20. Effect of Brinkmann number Br on fluid temperature with fixed values of M=3, Re=10, P=-10, F=5 and Da=0.1

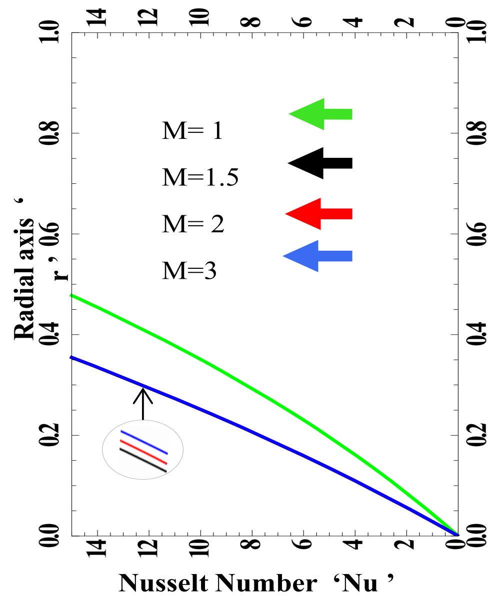

Figure 21. Nusselt number at the surface of the outer wall 'Nu' with fixed values of Re=10, P=-10, F=5, Br=0.01and Da=0.1

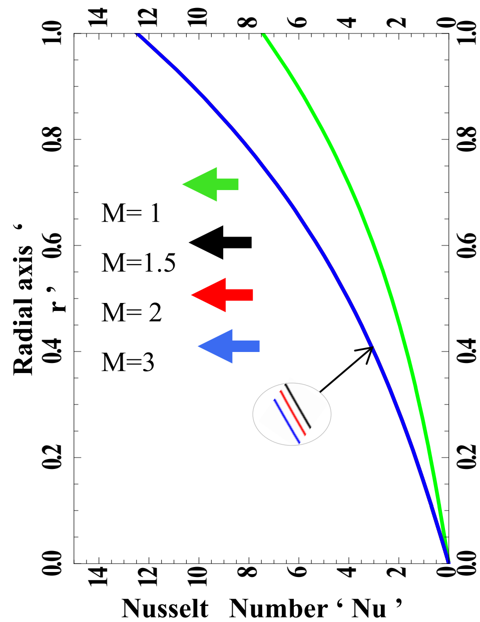

Figure 22. Nusselt number at the surface of the porous cylinder 'Nu' with fixed values of Re=10, P=-10, F=5, Br=0.01and Da=0.1

we increase the M values from 5 to 20. Figure 9 depicts the favorably the flow is varied due to a negative value of increments in gradient of pressure and can be seen in Figure 10 the enhancing of distribution of temperature in the flow field caused by a pressure term of negative kind.

Effective controlling of shear forces in the domain of flow is influenced by insertion of parameter 'M' the

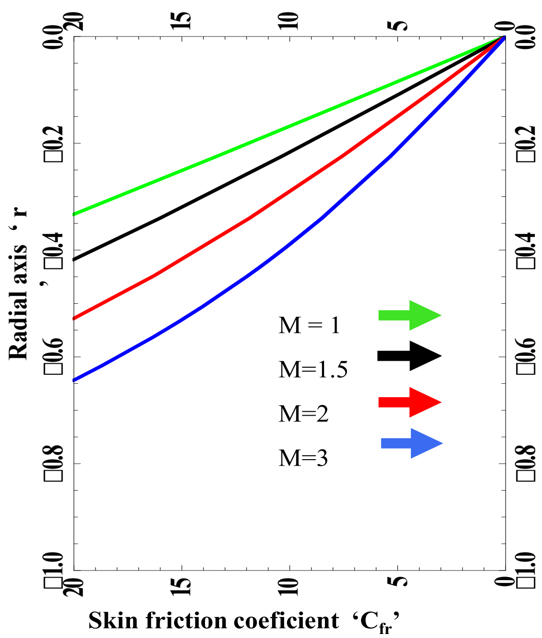

Figure 23. Skin friction co-efficient at the surface of the outer wall 'C_{fr}' with fixed values of Re=10, P=-10, Br=0.01and Da=0.1

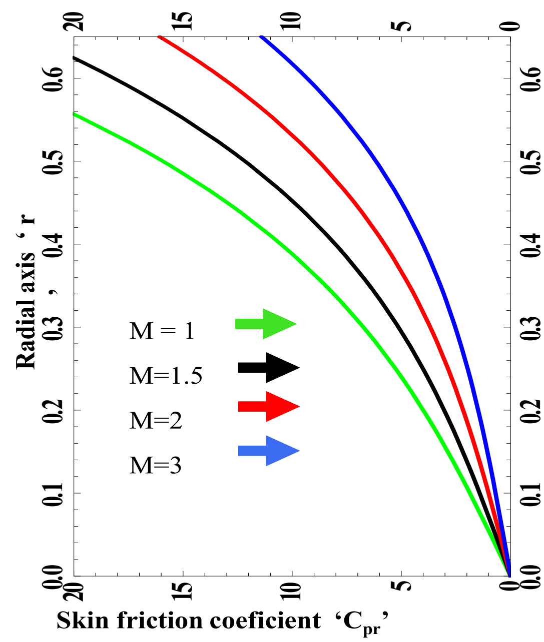

Figure 24. Skin friction co-efficient at the surface of the porous cylinder 'C_{pr}' with fixed values of Re=10, P=-10, Br=0.01and Da=0.1

Hartman number on field of flow and this effect is enacted due to M is vertically applied to the direction of flow which is more likely behaves as drag force. Then complete process of magnetic parameter domination over the flow field that results to suppress the flow is demonstrated through graphs as in Figure 11. This effect magnetic parameter suppresses the rate of flow which leads to formation sub-layers in the patterns of viscous flow and it is observed that the conditions at the boundaries causes meandering in the flow pattern at the clear-porous interface. Figure 12 gives the study of parametric way of observation for maximum transfer of heat distribution for gradual rise in the magnetic parameter effect.

Reynolds number 'Re' impact on the flow is observed for the various values like 10 - 14 leads to increase the flow rate gradually but as increase in the value of Re to 20 a jump drastically in flow pattern is noticed in the velocity field is in Figure 13. Similar effect is seen in the graphs of heat transfer is in Figure 14.

As we consider the impact of 'Da' Darcy number on slight variation in its values, then there is easy flow occurs in velocity profile maintains uniform path can be seen in Figure 15 and rise in the temperature seen in Figure 16. Immensely influence of Forchheimer coefficient 'F' over flow motion is narrated through graphs as in Figures 17 and 18 and it show casing variations of the velocity of a fluid and temperature also controlled effectively by variations in the values of Forchheimer number. That helps to rise the rate of flow near surface of the inner wall of outer cylinder if impervious kind and decreases in immediate vicinity to the peripheral permeable region. But opposite effects are noticed in flow temperature. The effect of Brinkman term 'Br' is demonstrated through Figures 19 and 20.

'Nu' Nusselt number, a dimensionless parameter that impacts on rapid increase in rate of heat transfer for wall of outer solid cover cylinder and the inner layer of porous cylinder. This impact is elucidated through Figures 21 and 22. The parametric analysis of non-dimensional parameter that is a skin friction coefficient is seen in Figures 23 and 24.

Parametric analysis of non-dimensional parameter that is a skin friction coefficient is seen in Figures 23 and 24.

5.0 Conclusions

The essence of the state of fluid is observed in fluid motion and transport of heat in the present fluid model is to understand the flow field with aid of effect of Joule heating accompanied with incorporated convection term. The present flow model is to analyze the behavior of flow in semi-pervious region inside a cylindrical impervious medium with annular is filled partially by a fluid that relay on applications in numerous field such as sound proofing of acoustic devices, goil refineries, geology of petroleum, construction engineering, filtration, rock/soil mechanics, bioremediation, geophysics, extrusion of metallics and process of metal working. In consideration to the above list of applications, the present work is carried out. Pressure gradient is of negative kind influences immensely the flow field.

- The major findings in present study are:
- The parameter of magnetic effect dominates the fluid results in suppressing the flow rate.
- Enhancement in heat distribution in flow due to Hartmann number variation effect.
- Reynolds number higher values facilitates in drastic change of the flow patterns observed in the velocity graph.
- Heat transfer enhanced with slight variation in Darcy number values are seen in flow field profile.
- Forcheimer number gradual increase causes suppression in the pattern of flow.

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