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Original Article

Effect of MHD on Two-Dimensional Flow of A Micropolar Fluid in A Porous Channel with High Mass Transfer

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Abstract - *An analysis is presented for the problem of the effect of MHD on two-dimensional flow of micropolar fluid in a porous channel with high mass transfer. An extrusion of Bernoulli's similarity transformation is used to reduce the governing partial differential equations to a set of non-linear coupled ordinary differential equations. By using quasilinearization technique, the non-linear ordinary differential equations are reduced to linear equations. The latter are solved for large mass transfer by using implicit finite difference method. Numerical results of velocity distribution of micropolar fluids are presented graphically for different flow parameters Reynolds number* Re, *micro-rotation/angular velocity* N, *microrotation boundary condition* s, *Magnetic Parameter* M.

Keywords *- Micropolar Fluid, Porous Channel, Mass Transfer, Magnetic Parameter, Reynolds number.*

1. Introduction

The earliest formulation of a general theory of fluid microcontinua was attributed to Eringen [4]. His theory of microfluids has opened up new areas in research in the physics of fluid flow. By Eringen's definition, a simple microfluid is a fluent medium whose properties and behaviour are affected by the local motions of the material particles contained in each of its volume elements; such a fluid possesses local inertia. Physically, they represent fluids consisting of randomly oriented particles suspended in a viscous medium studied by Lukaszewicz [10].

The basic idea of micropolar fluids has originated from the need to model the non-Newtonian flow of fluids containing rotating micro-constituents. Besides the usual equations for Newtonian flow, this theory introduces some new material parameters, an additional independent vector field-the microrotation-and new constitutive equations that must be solved simultaneously with the usual Newtonian flow equations. Subsequent studies showed that the model can be successfully applied to a wide range of applications including blood flow, lubricants, porous media, turbulent shear flows, and flow in capillaries, and microchannels.

The study of flow and heat transfer for an electrically conducting micropolar fluid past a porous plate under the influence of a magnetic field has attracted the interest of many investigators . In view of its applications in many engineering problems such as magneto hydrodynamic(MHD) generators, plasma studies, nuclear reactors, oil exploration, geothermal energy extractions and the boundary layer control in the field of aerodynamics. Soundalgekar and Thakar [15] studied forced and free convective flow past a semi infinite plate. Laminar flow in a channel with porous walls is studied by Berman. A.S[1]. A number of MHD studies have been carried out examining the effects of magnetic field on hydrodynamic flow in various configurations, for example, in channels and past plates and wedges, etc., Kumari [9], Kim [6].Thakar and Ram [16] studied free convection in hydromagnetic flows of a viscous heat generation fluid with wall temperature and hall currents.

Raptis [14] studied mathematically the case of unsteady two-dimensional natural convective heat transfer of an incompressible, electrically conducting viscous fluid via highly porous medium in the presence of magnetic field. El-Hakiem et al[3] studied the effect of viscous and joule heating on MHD free convection flow with variable plate temperature in a micropolar fluid in the presence of uniform transverse magnetic field using the Keller box implicit scheme. The effects of microstructure on the rheological properties of blood studied by Kang et al[5] and Migoun et al[12]. Migoun N.P.[11] studied parameters characterizing the microstructure of micropolar fluids. El-Amin [2] considered the MHD free convection and mass transfer flow in micropolar fluid over a stationary vertical plate with constant suction and solved numerically by means of the fourth-order Runge-Kutta method with shooting technique. Heat and mass transfer in MHD micropolar flow over a vertical moving porous plate in a porous medium studied by Kim Y.J et al [7]. The experimental determination of material micropolar fluid constants studied by Kolpaschikov et al[8].

Muhammad Ashraf and Muhammad Abu Bakar [17] studied the Micropolar fluidflow in a channel with shrinking walls. The flow of micro fluid through porous channel with expanding or contracting walls of different permeabilities studied by Xin-yiSi et al [18]. Ramachandran et al[13] studied heat transfer in boundary layer flow of a micropolar fluid past a curved surface with suction and injection, Ziabakshi and Domairry [19] studied the Micropolar flow in a porous channel with high mass transfer with Homotopy Analysis method, they neglected the influences of magnetic parameter.

In this paper, we have studied the effect of magneto hydrodynamics on two dimensional micropolar flow in a porous channel with high mass transfer. A quasilinearization technique is first applied to replace the non-linear term, then the non-linear equations are changed to a set of coupled ordinary differential equations, which are solved by implicit finite difference method. The results have been compared with available results

2. Governing Equations

We consider steady, incompressible, laminar flow of a micropolar fluid along a two- dimensional channel with porous walls through which fluid is uniformly injected or removed with speed q. Using Cartesian coordinates, the channel walls are parallel to the $x-$axis and located at $y = \pm h$, where $2h$ is the channel width. The relevant equations governing the flow are (Ramachandran et al. [13]):

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}$$

$$u\frac{\partial u}{\partial x} + \upsilon\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \left(\nu + \frac{k}{\rho}\right)\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \frac{k}{\rho}\frac{\partial N}{\partial y} - \frac{\sigma B_0^{\ 2}}{\rho}u \tag{2}$$

$$u\frac{\partial \upsilon}{\partial x} + v\frac{\partial \upsilon}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + \left(\nu + \frac{k}{\rho}\right)\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{k}{\rho}\frac{\partial N}{\partial x} - \frac{\sigma B_0^{\ 2}}{\rho}\upsilon \tag{3}$$

$$u\frac{\partial N}{\partial x} + v\frac{\partial N}{\partial y} = -\frac{k}{\rho j}\left(2N + \frac{\partial u}{\partial y} - \frac{\partial v}{\partial x}\right) + \frac{v_s}{\rho j}\left(\frac{\partial^2 N}{\partial x^2} + \frac{\partial^2 N}{\partial y^2}\right), \tag{4}$$

Compared with Newtonian fluids, the governing equations include the microrotation or angular velocity N whose direction of rotation is in the $xy-$plane and the material parameters j, k and v_s. For consistency with other micropolar studies, all material parameters are taken as independent and constant. When these constants are zero, the governing equations reduce to those given by Berman [1]. The appropriate physical boundary conditions are

$$u(x, \pm h) = 0,\ v(x, \pm h) = \pm q,\ N(x, \pm h) = -s\left.\frac{\partial u}{\partial y}\right|_{(x,\pm h)} \tag{5}$$

and assuming that the flow is symmetric about $y = 0$,

$$\frac{\partial u}{\partial y}(x,0) = v(x,0) = 0, \tag{6}$$

Where $q > 0$ corresponds to suction, $q < 0$ to injection and s is a boundary parameter that is used to model the extent to which microelements are free to rotate in the vicinity of the channel walls. For example, the value $s = 0$ corresponds to the case where microelements close to a wall are unable to rotate, whereas the values $s = \mathbf{1/2}$correspond to the case where the microrotation is equal to the fluid vorticity at the boundary see Lukaszewicz [10]. To simplify the governing equations, we generalize Berman's similarity solution [1] to include micropolar effects by assuming a stream function and microrotation of the form

$$\psi = -qxF(\eta), \; N = \frac{qx}{h^2}G(\eta), \tag{7}$$

Where

$$\eta = \frac{y}{h}, \; u = \frac{\partial \psi}{\partial y} = -\frac{qx}{h}F'(\eta), \; v = -\frac{\partial \psi}{\partial x} = qF(\eta),$$

In addition, we introduce the dimensionless micropolar parameters and non-zero cross-flow Reynolds number

$$N_1 = \frac{k}{\rho v}, \; N_2 = \frac{v_s}{\rho v h^2}, \; N_3 = \frac{j}{h^2}, \; \text{and} \; \mathrm{Re} = \frac{qh}{v}, \tag{8}$$

Where $\mathrm{Re} > 0$ corresponds to suction, and $\mathrm{Re} < 0$ to injection. Substituting (7) and (8) into (1-4) reduce the governing equations to $\frac{\partial^2 p}{\partial x \partial \eta} = 0$,

$$\mathrm{Re}[FF''' - F'F''] - MF'' = (1 + N_1)F^{1V} - N_1 G'' \tag{9}$$

and $$N_3 \,\mathrm{Re}(FG' - F'G) = N_1(F'' - 2G) + N_2 G'' \tag{10}$$

where prime denotes differentiation w.r.t η. The boundary conditions are:

$$F(\pm 1) = 1, \; F'(\pm 1) = 0, \qquad G(\pm 1) = sF''(\pm 1) \tag{11}$$

Assuming symmetric flow in the channel, then the above boundary conditions are:

$$F(0) = F''(0) = F'(1) = 0, \; F(1) = 1, \qquad G(0) = 0, \quad G(1) = 0 \tag{12}$$

For a given cross-flow Reynolds number Re, the problem as defined contains four additional micropolar parameters $s, N_{1,2,3}$ in general, the parameters may depend on the concentration and shape of the microelements, and a determination of the parameters values is a difficult matter [5]. The experimental works of Migoun [11], Kolpashchikov et al. [8], Migoun & Prokhorenko [12] suggests that $N_1 = O(1)$ for water in capillary tubes, whereas N_2 and N_3 must be non-negative for micropolar fluids [4]. For comparison with existing studies, in this work we set $s = 0, N_{1,2} = 1, N_3 = 10^{-1}$ and investigate solution behaviour as Re is varied.

3. Results and Discussion

The Numerical values obtained for F, F' and G for $s = 0, N_1 = N_2 = 1, N_3 = 0.1$ for different values of Re and M . Fig.1 computed profiles for $F(\eta)$ for the different values of Re. Due to the symmetry the profiles are shown over half of the channel width only. It is observed that the velocity profile $F(\eta)$ decreases with the increase of Re. Fig.2 shows computed profiles for $F(\eta)$ for the different values of M .From fig 2, it is observed that the velocity profile $F(\eta)$ decreases with increase of M .From fig.3 we can notice that the computed profiles for $F'(\eta)$ approach leading order profile has the mass transfer through the channel walls increases. It is seen that the velocity $F'(\eta)$ decrease with the increase of Re .

From fig.4. it is observed that the velocity profiles $F'(\eta)$ increases with increase of magnetic parameter M. It is observed that from fig.5 with the increase of Re, the $G(\eta)$ decreases for $N_1 = N_2 = 1, N_3 = 0.1, s = 0$ .From fig.6 we observe that with the increase of magnetic parameter $G(\eta)$ decreases.The numerical solution is obtained without difficulty via quasilinearization scheme, and very good agreement between the solution obtained from the perturbation analysis and computation was observed for strong injection which is seen in tables.1&2

Table 1. Values of F(η) and $F'(\eta)$ for Re=-1.

$F(\eta)$			$F'(\eta)$	
η	**Ziabakshand Domairry.**	**Present**	**Ziabakshand Domairry.**	**Present**
0	0	0	1.51323034	1.51322035
0.25	0.37011817	0.37011616	1.41503487	1.41503549
0.5	0.69134071	0.69135074	1.12291190	1.12291896
0.75	0.91609699	0.91610959	0.64536199	0.64540986
1	1	1	0	0

Table 2. Values of F(η) and $F'(\eta)$ for Re=-20.

$F(\eta)$			$F'(\eta)$	
η	**Ziabakshi and Domairry.**	**Present**	**Ziabakshi and Domairry**	**Present**
0	0	0	1.54237954	1.54247952
0.25	0.37664029	0.37664021	1.43504617	1.43504616
0.5	0.70004200	0.70004302	1.11867229	1.11872192
0.75	0.92072593	0.92072497	0.62044938	0.62044927
1	1	1	0	0

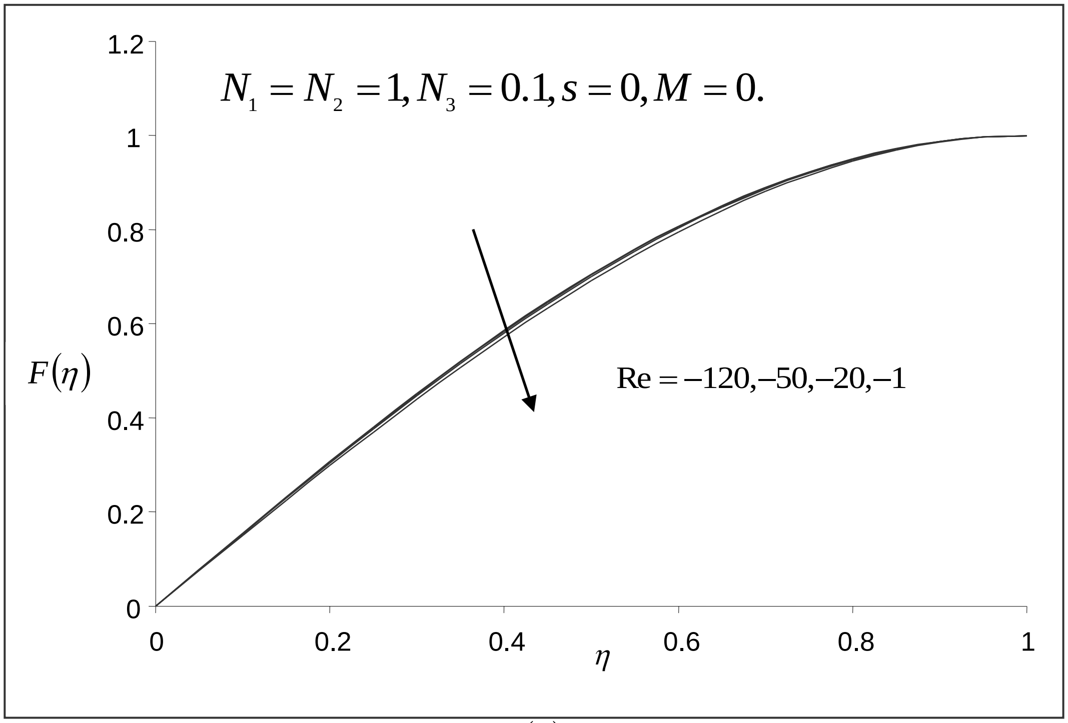

Fig. 1 $F(\eta)$ with Re

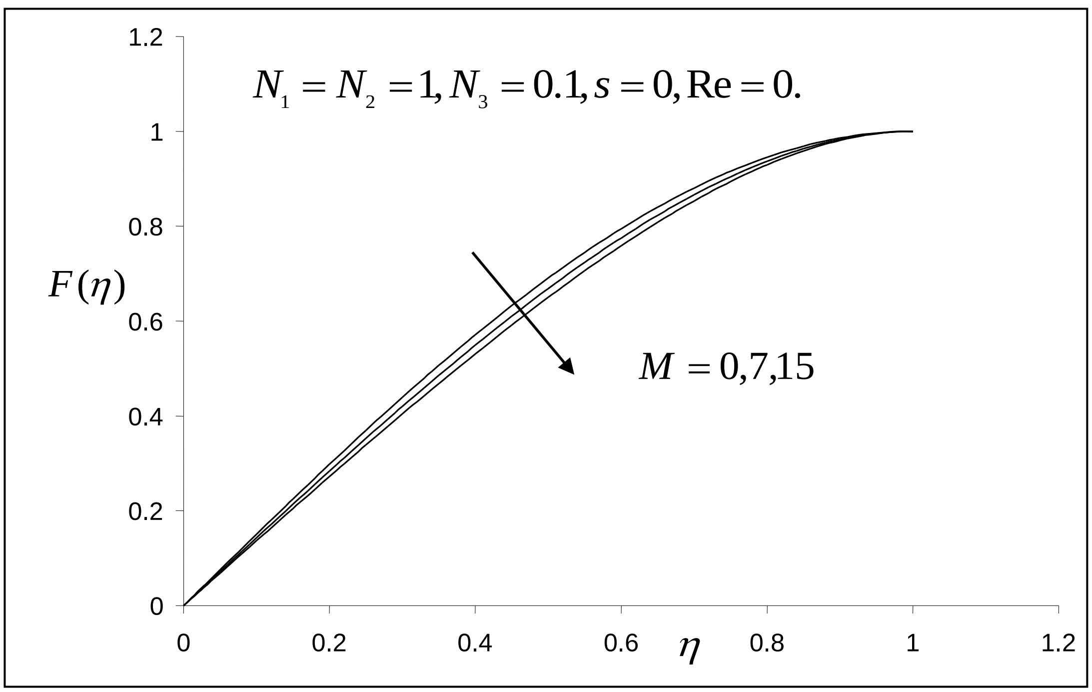

Fig. 2 $F(\eta)$ with Melocity $F(\eta)$

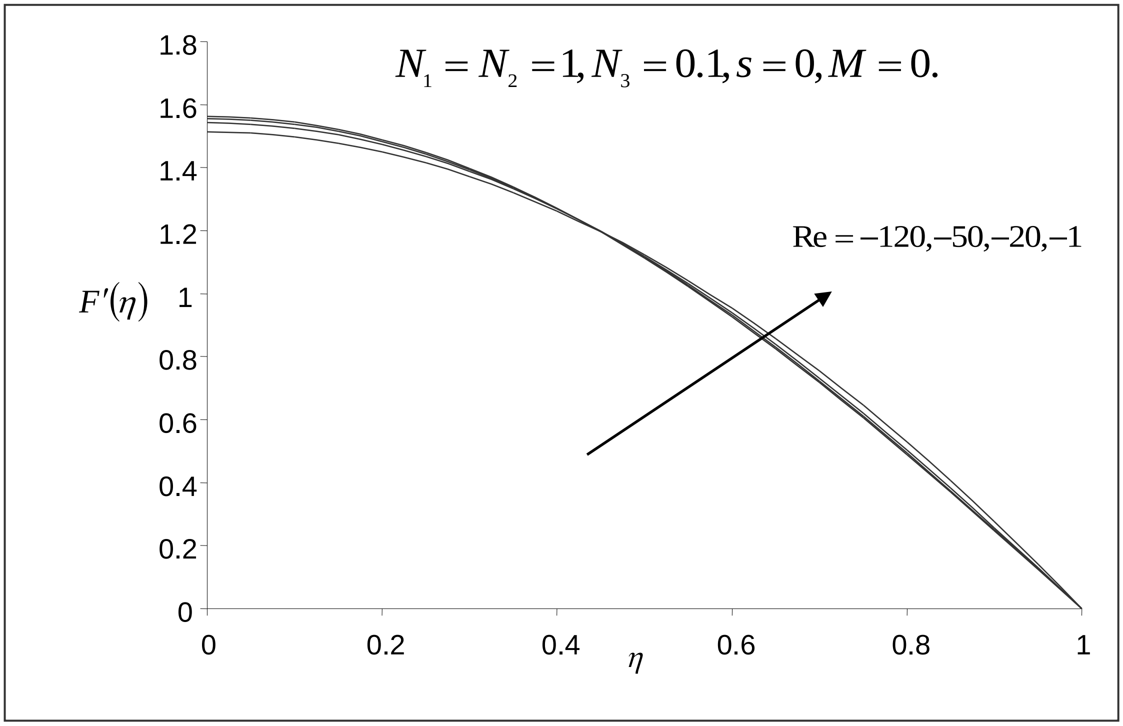

Fig. 3 $F'(\eta)$ with Re .

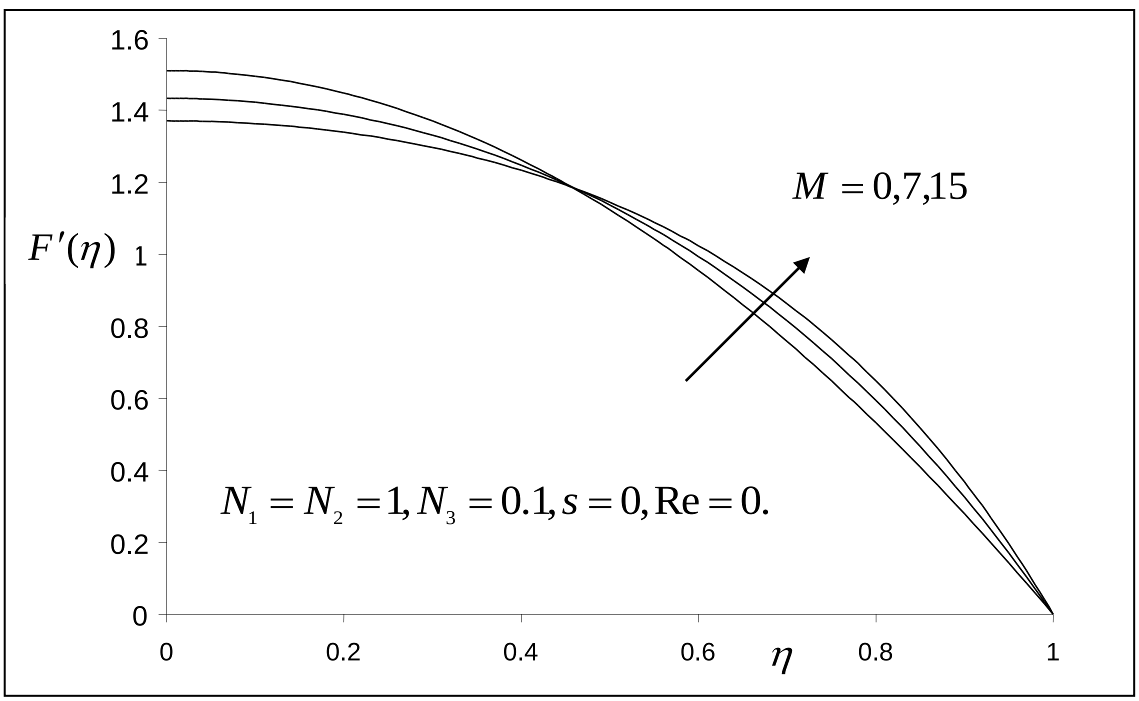

Fig. 4 $F'(\eta)$ with M

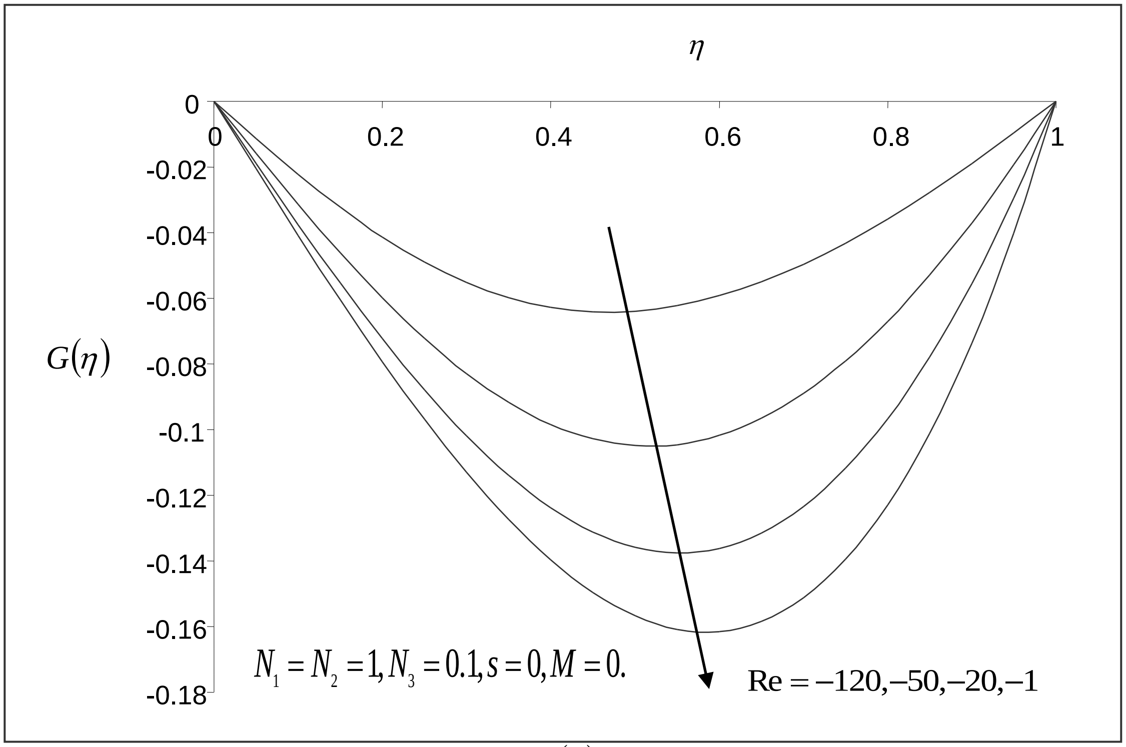

Fig. 5 $G(\eta)$ with Re

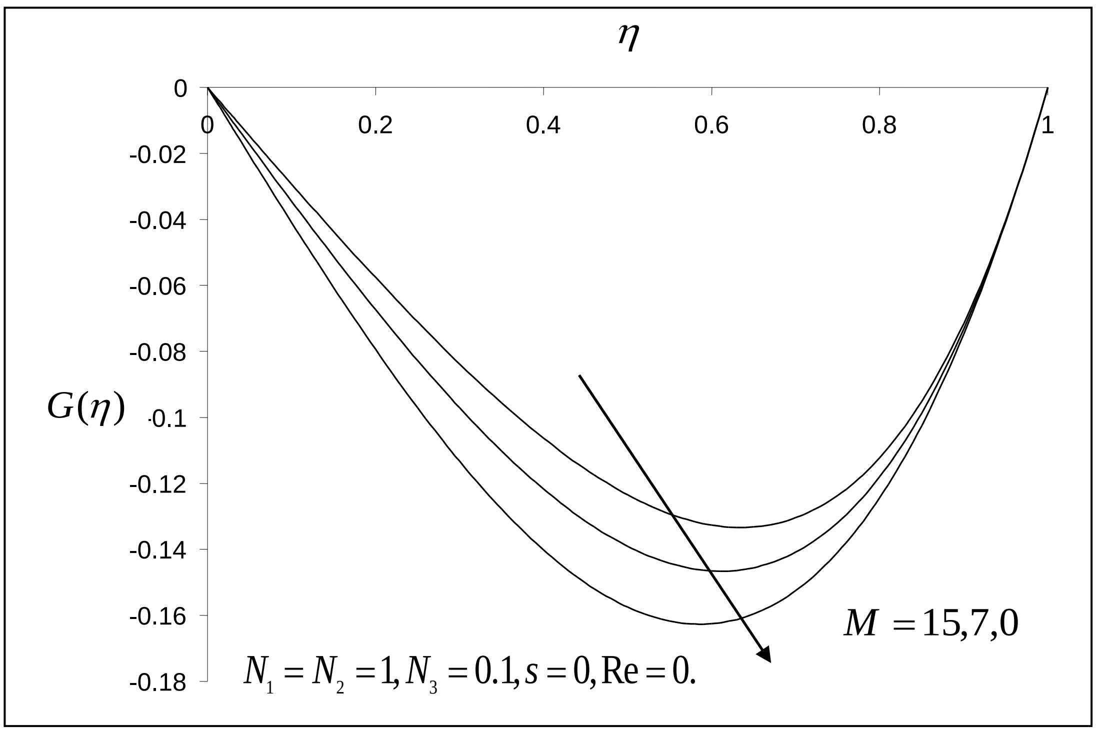

Fig. 6 $G(\eta)$ with Me

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