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Analysis of Micropolar Fluid Flow Through a Porous Channel Driven by Suction/Injection with High Mass Transfer

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ABSTRACT
In this paper, the flow of a micropolar fluid conveyed through porous channel driven by suction or injection with high mass transfer is analyzed using the regular perturbation method to solve the coupled nonlinear ordinary equations arising from the mechanics of fluid. The developed analytical solutions are used to investigate the effects of flow and rotation parameters such as Reynolds number and microrotation parameters. The obtained analytical results when compared to results of the other methods in the existing works in literature are in good agreements. The results obtained from this paper can be used to further the study of the behavior of micropolar fluids in applications including as lubricants, blood flow, porous media, microchannels and flow in capillaries.

Keywords: *mass transfer, micropolar fluids, porous media, regular perturbation method,*

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INTRODUCTION

The theory of micropolar fluid was established by Eringen [1] in his bid to model the behavior of non-Newtonian flow whose microconstituents rotate during fluid flow. Moreover, in his work, he developed the constitutive relation to include more material parameters and microrotation vectors making the usual equations for Newtonian flow nonlinear. Also, in the study of micropolar fluids, Idris [2] studied the effect of non-uniform temperature gradient on micropolar fluids under convective heat transfer, while Yuan [3] investigated the behavior of micropolar fluids under laminar flow condition within a porous channel. Kelson [4, 5] presented the effect of surface conditions on micropolar fluid flow over a stretching sheet with strong suction and injection. The flow of viscous fluid was studied by Zaturska et al. [6] along a porous wall during suction. Power-law variations were adopted by Cheng [7] to study micropolar fluid from a vertical truncated cone under natural convection. Joneidi et al. [8] applied the differential transformation method (DTM) to heat transfer problems of nonlinear equations, while Hassan [9] adopted the DTM in solving eigenvalue problems. Magyari and Keller [10] studied boundary layer flows induced by permeable walls using exact solutions. Natural convective flow over horizontal plate was investigated by Murthy and Singh [11] presenting the thermal effects with surface mass flux on convection.

The relevance and importance of pertubation solutions to provide approximate analytical solutions have been proven beyond reasonable doubt in literature. However, owing to the problem of weak nonlinearites and small parameters, which are sometimes artificial, makes it necessarily to develop other analytical methods of solutions to overcome these limits [12–26]. Consequently, the use of other approximate analytical methods such as DTM, Homotopy Analysis Method (HAM), Optimal Homotopy Asymptotic method (OHAM), Variational Iteration method (VIM), Adomian Decomposition method (ADM) and some other approximation methods have been developed. Methods such as DTM, HAM and ADM, however, require the need to find an initial condition that will satisfy the boundary condition which theories have not been rigorously proven for all cases, making it necessary to use computational tools resulting to higher computational cost to provide problem solutions. Also, OHAM requires determining constants using auxilliary fuctions which may be too rigorous to determine for some nonlinear problems. Since the solutions reported for the other relatively sophisticated methods to nonlinear problems have good accuracy, but they are more complicated for applications than perturbation methods. Therefore, over the years, the relative simplicity and high accuracy, especially in the limit of small parameter, have made perturbation method an interesting tool among the most frequently used approximate analytical methods [27–30]. Therefore, in this paper, the flow and rotation of micropolar fluids transported through porous channels with high mass transfer are studied using the regular perturbation method. The effect of material and microrotation constituent on the flow process is investigated.

MODEL DEVELOPMENT AND ANALYTICAL SOLUTION

Consider the laminar, incompressible and isothermal flow of a micropolar fluid through a channel with porous walls where fluid undergoes suction or injection with speed q. The channel wall is parallel to the x-axis as described using Cartesian coordinate with a width of distance $2h$ and located at a reference $y = \pm h$. The formulation of the model development of the micropolar fluid is developed with respect to the above conditions following the assumptions that the fluid is incompressible, flow is steady and laminar. Also, radiation heat transfer is negligible.

Following the assumptions, the governing equations of the channel flow are given as

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

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial P}{\partial x} + (\mu+\kappa)\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \kappa\frac{\partial N}{\partial y} \tag{2}$$

$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial P}{\partial y} + (\mu+\kappa)\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \kappa\frac{\partial N}{\partial x} \tag{3}$$

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

The governing equations expressed in Equations (1)–(4) include microrotation or angular velocity and material parameters whose direction is in the *xy*-plane consistent with other micropolar fluid studies. In this study, material parameters are taken as independent and constant.

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

Fluid flow is assumed symmetric about y = 0.

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

The value of s depicts various flow situations of the micropolar fluid. When s = 0, the microelement close to the porous wall surface is unable to rotate, while when s = 0.5, the microrotation is the same as the fluid vorticity at the boundary. Similarly, fluid injected or removed from the stream is depicted by the value of q. Given that suction is the condition when $q > 0$ and injection is the situation when $q < 0$. The governing equation is, therefore, simplified by including micropolar effects by assuming stream functions and micropolar to the Berman's similarity solution [26]:

$$\psi=-qxF(\eta) \tag{7}$$

$$N=\frac{qx}{h^2}G(\eta) \tag{8}$$

where

$$\eta=\frac{y}{h}, u=\frac{\partial \psi}{\partial y}=-\frac{qx}{h}F^{'}(\eta),$$
$$v=-\frac{\partial \psi}{\partial x}=qF(\eta) \tag{9}$$

Dimensionless micropolar parameters and non-zero crossflow Reynolds number are introduced as

$$N_1=\frac{\kappa}{\mu}, N_2=\frac{v_s}{\mu h^2},$$
$$N_3=\frac{j}{h^2}, \mathrm{Re}=\frac{\rho q}{\mu}h \tag{10}$$

With the aid of Equations (7)–(10), Equations (1)–(4) may be reduced to ordinary nonlinear differential equations as stated below:

$$(1+N_1)\frac{d^4F}{d\eta^4}-N_1\frac{d^2G}{d\eta^2}-$$
$$\mathrm{Re}\left(F\frac{d^3F}{d\eta^3}-\frac{dF}{d\eta}\frac{d^2F}{d\eta^2}\right)=0 \tag{11}$$

$$N_2\frac{d^2G}{d\eta^2}+N_1\left(\frac{d^2F}{d\eta^2}-2G\right)$$
$$-N_3\,\mathrm{Re}\left(F\frac{dG}{d\eta}-G\frac{dF}{d\eta}\right)=0 \tag{12}$$

With the appropriate boundary conditions defined as

$$F(\pm1)=1, F^{'}(\pm1)=0,$$
$$G(\pm1)=sF^{''}(\pm1) \tag{13}$$

Symmetry of fluid flow through the porous channel is assumed, therefore, boundary condition takes the following form:

$$F(0)=F^{''}(0)=F^{'}(1)=0,$$
$$F(1)=1, G(1)=sF^{''}(1) \tag{14}$$

The regular pertubation method, which is an analytical scheme for providing approximate solutions to the ordinary differential equations, is adopted in generating solutions to the coupled ordinary nonlinear differential equation. The flow and rotation series solution, where ε is the small pertubation parameter, may be presented in the following form:

$$F=F_0+\varepsilon F_1+\varepsilon^2F_2+O(\varepsilon^3) \tag{15}$$

$$G=G_0+\varepsilon G_1+\varepsilon^2G_2+O(\varepsilon^3) \tag{16}$$

Substituting Equations (15) and (16) into (11) and selecting at the the terms of the same orders yields

$$\varepsilon^0 : \frac{d^4F_0}{d\eta^4} \tag{17}$$

$$\varepsilon^1 : \quad \frac{d^4F_1}{d\eta^4} + N_1\frac{d^4F_0}{d\eta^4} + \mathrm{Re}\frac{dF_0}{d\eta}\frac{d^2F_0}{d\eta^2} - \frac{d^3F_0}{d\eta^3}F_0 - N_1\frac{d^2G_0}{d\eta^2} \tag{18}$$

$$\varepsilon^2 : \quad \frac{d^4F_2}{d\eta^4} + \mathrm{Re}\frac{dF_0}{d\eta}\frac{d^2F_1}{d\eta^2} + \frac{d^2F_0}{d\eta^2}\frac{dF_1}{d\eta} - \frac{d^3F_0}{d\eta^3}F_1 - \frac{d^3F_1}{d\eta^3}F_0 + N_1\frac{d^4F_1}{d\eta^4} - N_1\frac{d^2G_1}{d\eta^2} \tag{19}$$

Substituting Equations (15) and (16) into (12) and selecting at the various orders yields

$$\varepsilon^0 : \frac{d^2G_0}{d\eta^2} \tag{20}$$

$$\varepsilon^1 : \quad \frac{d^2G_1}{d\eta^2} + N_1\frac{d^2F_0}{d\eta^2} - 2\frac{G_0}{N_2}\eta + N_3\,\mathrm{Re}\frac{dF_0}{d\eta}G_0 - F_0\frac{dG_0}{d\eta}\frac{1}{N_2} \tag{21}$$

$$\varepsilon^2 : \quad \frac{d^2G_2}{d\eta^2} + N_1\frac{d^2F_1}{d\eta^2} - 2\frac{G_1}{N_2} + N_3\,\mathrm{Re}\,G_1\frac{dF_0}{d\eta} + G_0\frac{dF_1}{d\eta} - F_0\frac{dG_1}{d\eta} - F_1\frac{dG_0}{d\eta}\frac{1}{N_2} \tag{22}$$

The boundary conditions for the leading order equation is given as

$$F_0(0) = F_0^{''}(0) = F_0^{'}(1) = 0, \quad F_0(1) = 1, G_0(0) = G_0(1) = 0 \tag{23}$$

With the aid of the boundary conditions, Equation (23), it could be expressed easily that Equations (17) and (20) can be shown as follows:

$$F_0 = -\frac{\left(\eta\left(\eta^2-3\right)\right)}{2} \tag{24}$$

Equations (24), (27)and (30) are substituted back into the series solution, Equation (15). The flow profile solution is expressed in its final form as

$$G_0 = 0 \tag{25}$$

$$F_1(0) = F_1^{''}(0) = F_1^{'}(1) = 0, \quad F_1(1) = 1, G_1(0) = G_1(1) = 0 \tag{26}$$

With the aid of the boundary conditions in Equation (26), the solutions of Equations (18) and (21) can be shown as

$$F_1 = -\frac{\left(\mathrm{Re}\,\eta\left(\eta^2-1\right)^2\left(\eta^2+2\right)\right)}{280} \tag{27}$$

$$G_1 = \frac{N_1\eta(\eta^2-1)}{2N_2} \tag{28}$$

The boundary conditions for the second-order equation are given as

$$F_2(0) = F_2^{''}(0) = F_2^{'}(1) = 0, \quad F_2(1) = 1, G_2(0) = G_2(1) = 0 \tag{29}$$

Using the boundary conditions in Equation (29), it can be easily shown that the solutions of Equations (19) and (22) are

$$F_2 = \frac{\left(\mathrm{Re}\,\eta(\eta^2-1)^2\begin{pmatrix}9240N_1 - 703\mathrm{Re} + 4620N_1\eta^2 \\ -530\mathrm{Re}\,\eta^2 - 357\mathrm{Re}\,\eta^4 + 14\mathrm{Re}\,\eta^6\end{pmatrix}\right)}{1293600} + \frac{N_1(\eta^2-1)}{40N_2} \tag{30}$$

$$G_2 = \frac{N_1\eta(\eta^2-1)\begin{pmatrix}3N_1\eta^2 - 7N_1 + 3N_3 \\ +\mathrm{Re} + 3N_3\,\mathrm{Re}\,\eta^2\end{pmatrix}}{60N_2^2} + \frac{N_1\,\mathrm{Re}(\eta^2-1)^2(\eta^2+2)}{280N_2} \tag{31}$$

Substituting Equations (24), (27) and (30) into the series solution equation (15). The rotation profile solution is expressed in its final form as

$$F=-\frac{\left(\eta\left(\eta^2-3\right)\right)}{2}-\frac{\left(\mathrm{Re}\,\eta\left(\eta^2-1\right)^2\left(\eta^2+2\right)\right)}{280}+\frac{N_1(\eta^2-1)}{40N_2}+\frac{\left\{(\mathrm{Re}\,\eta(\eta^2-1)^2\begin{pmatrix}9240N_1-703\,\mathrm{Re}+4620N_1\eta^2\\-530\,\mathrm{Re}\,\eta^2-357\,\mathrm{Re}\,\eta^4+14\,\mathrm{Re}\,\eta^6\end{pmatrix}\right\}}{1293600} \tag{32}$$

Also, after substituting Equations (25), (28) and (31) into the series solution equation (16). The rotation profile solution is expressed in its final form as

$$G=\frac{N_1\eta(\eta^2-1)}{2N_2}+\frac{N_1\eta(\eta^2-1)\begin{pmatrix}3N_1\eta^2-7N_1+3N_3\\+\mathrm{Re}+3N_3\,\mathrm{Re}\,\eta^2\end{pmatrix}}{60N_2^2}+\frac{N_1\,\mathrm{Re}(\eta^2-1)^2(\eta^2+2)}{280N_2} \tag{33}$$

RESULTS AND DISCUSSION

The result obtained from the analytical solutions is discussed here, where the effect of parameters on flow and rotation is reported graphically. The effect of micropolar fluid parameters at various values on the velocity and rotation profile is presented. Figure 1 shows the effect of the Reynolds number (Re) on velocity profile. It can be depicted that the velocity distribution decreases as Re increases when fluid is undergoing suction, and during injection, the velocity profile increases for increasing values of Re (Table 1).

Figure 2 shows the effect of microrotation parameter (N_1). From the figure, increasing values of N_1 parameter decreases the velocity profile slightly, which is as a result of an increase in rate of shear at the wall causing a decrease in boundary layer thickness. Effect of the microrotation parameter (N_2) on the velocity profile is depicted in Figure 3. The result shows a slight increase in velocity distribution at increasing values of N_2 parameter due to increase in momentum boundary layer thickness near the porous wall.

Table 1. *Comparison of numerical and regular perturbation solution when $N_1 = N_2 = 1$, $N_3 = 0.1$ and $\mathrm{Re} = -1$.*

	G(η)			
η	**NM [13]**	**Present work**	**NM [13]**	**Present work**
0	0.0000	0.0000	0.0000	0.0000
0.05	0.0752	0.0749	-0.0202	-0.0214
0.1	0.1500	0.1495	-0.0401	-0.0424
0.15	0.2240	0.2232	-0.0595	-0.0629
0.2	0.2969	0.2959	-0.0780	-0.0824
0.25	0.3683	0.3671	-0.0954	-0.1006
0.3	0.4378	0.4365	-0.1113	-0.1172
0.35	0.5051	0.5035	-0.1256	-0.1319
0.4	0.5696	0.5680	-0.1378	-0.1445
0.45	0.6311	0.6295	-0.1477	-0.1544
0.5	0.6892	0.6876	-0.1550	-0.1615
0.55	0.7435	0.7420	-0.1592	-0.1654
0.6	0.7937	0.7922	-0.1601	-0.1658
0.65	0.8392	0.8379	-0.1572	-0.1623
0.7	0.8798	0.8787	-0.1503	-0.1545
0.75	0.9152	0.9143	-0.1388	-0.1423
0.8	0.9448	0.9442	-0.1225	-0.1251
0.85	0.9685	0.9681	-0.1009	-0.1027
0.9	0.9858	0.9856	-0.0736	-0.0746
0.95	0.9964	0.9963	-0.0401	-0.0405
1.00	1.0000	1.0000	0.0000	0.0000

Figure 4 shows the effect of Reynolds number (Re) on rotation profile. It could be seen from the figure that, at increasing values of Re, rotation distribution decreases up till point η = 0.6 (not accurately determined) for suction, thereafter rotation distribution increases for increasing values of Re during injection. This can be physically explained that, at increasing Re, the minimum point of micropolar fluid rotation is still retained at the origin. As microrotation parameter N_1 increases for suction flow, the rotation profile decreases till η = 0.56 (not accurately determined), then the reverse is the case for injection as depicted in Figure 5, illustrating there is an increase from suction to injection. During suction flow at increasing values of microrotation parameter N_2, it is shown from Figure 6 that rotation profile increases for suction, and thereafter reduces during injection. Also, the effect of microrotation parameter N_3 on rotation profile is seen in Figure 7. As it is observed, increasing values of N_3 parameter show an increasing rotation distribution for suction till point η = 0.6 (not accurately determined). Thereafter rotation distribution decreases for injection flow.

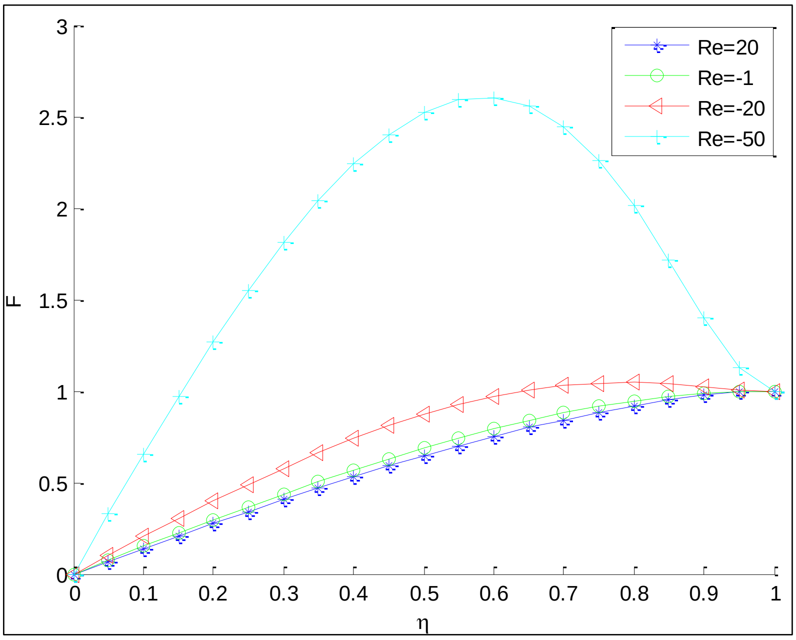

Fig. 1. *Effect of Reynolds number (Re) on velocity profile when* $Re = N_2 = 1$ *and* $N_3 = 0.01$.

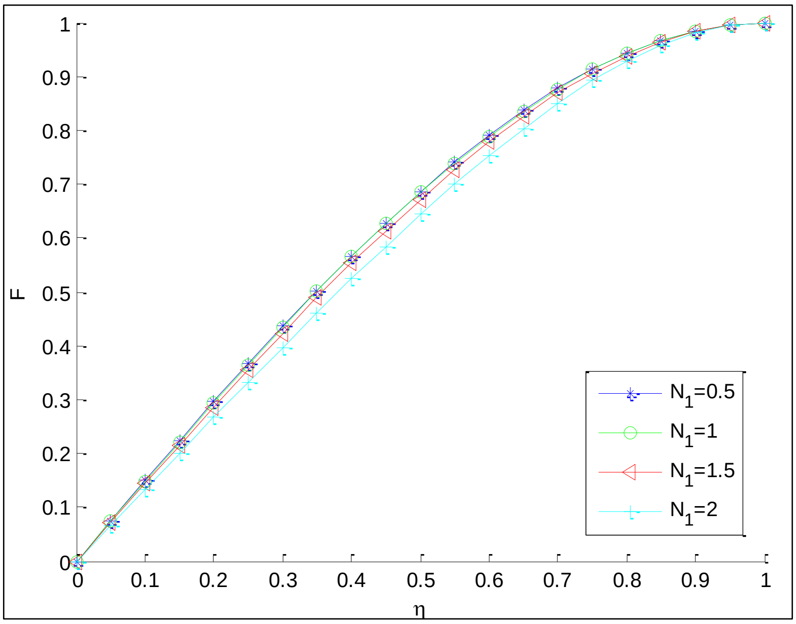

Fig. 2. *Effect of microrotation parameter,* N_1, *on velocity profile when* $N_1 = N_2 = 1$ *and* $N_3 = 0.01$.

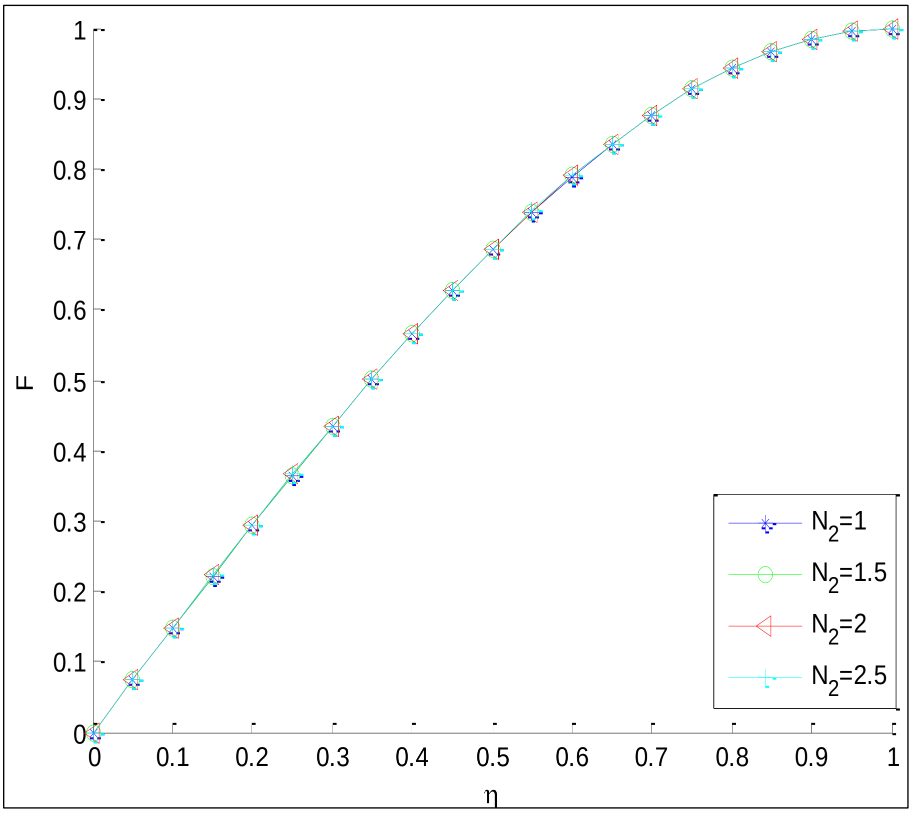

Fig. 3. *Effect of micro rotation parameter, N_2 on velocity profile when $Re = N_1 = 1$ and $N_3 = 0.01$.*

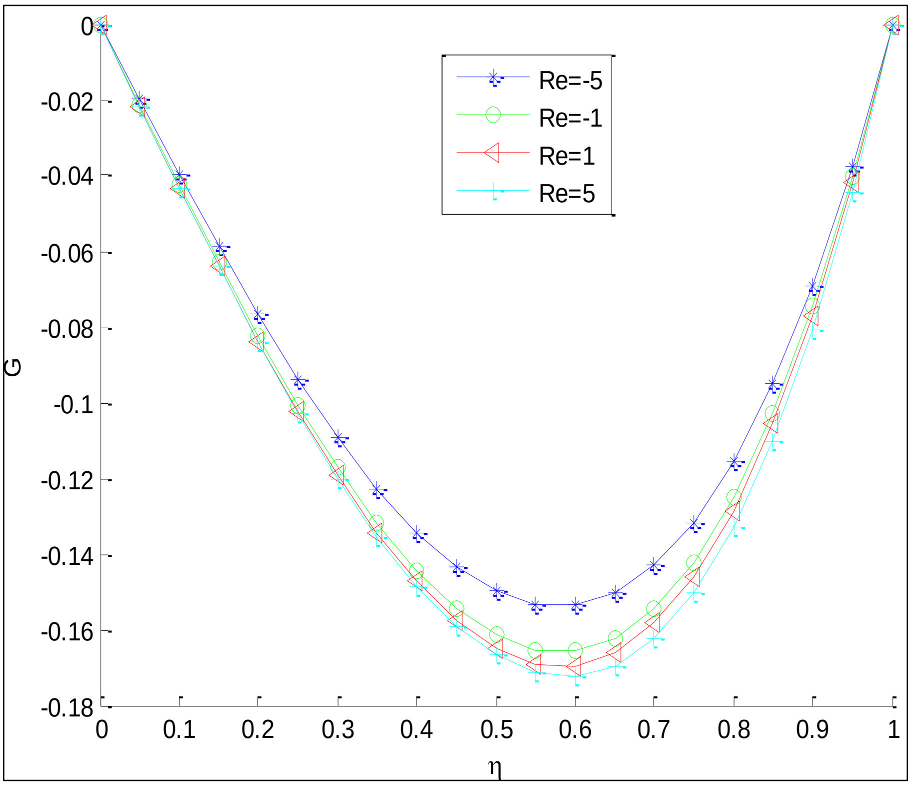

Fig. 4. *Effect of Reynolds number, Re on rotation profile whenN_1=N_2=1 and N_3=0.01.*

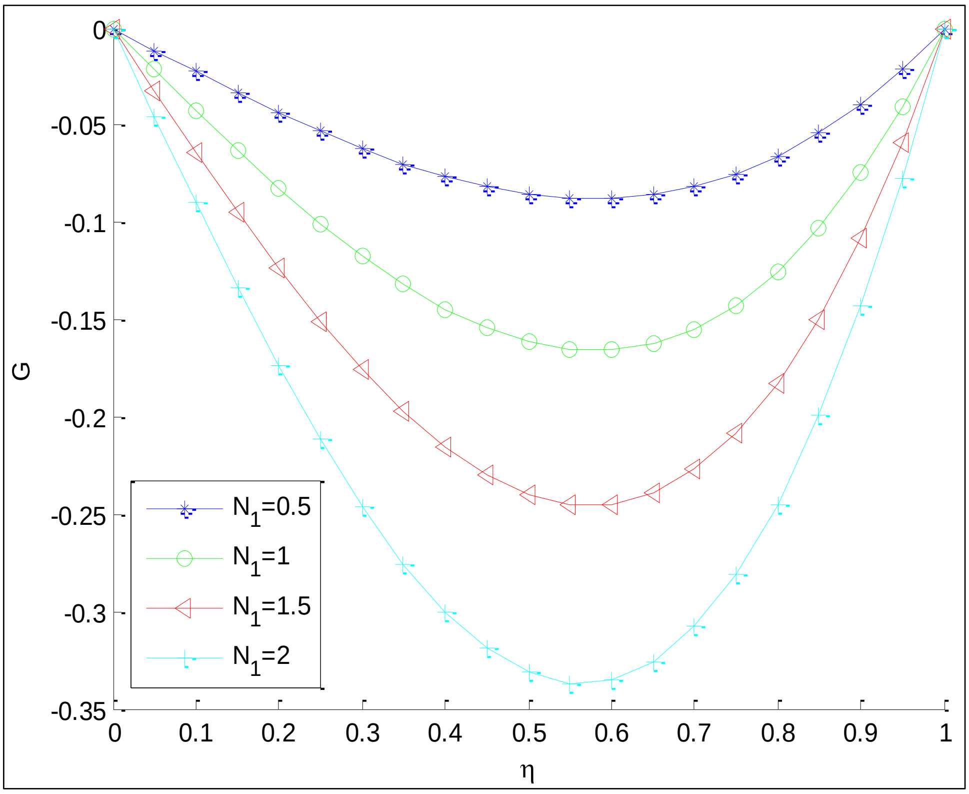

Fig. 5. *Effect of micro rotation parameter, N_1 on rotation profile when $Re = N_2 = 1$ and $N_3 = 0.01$.*

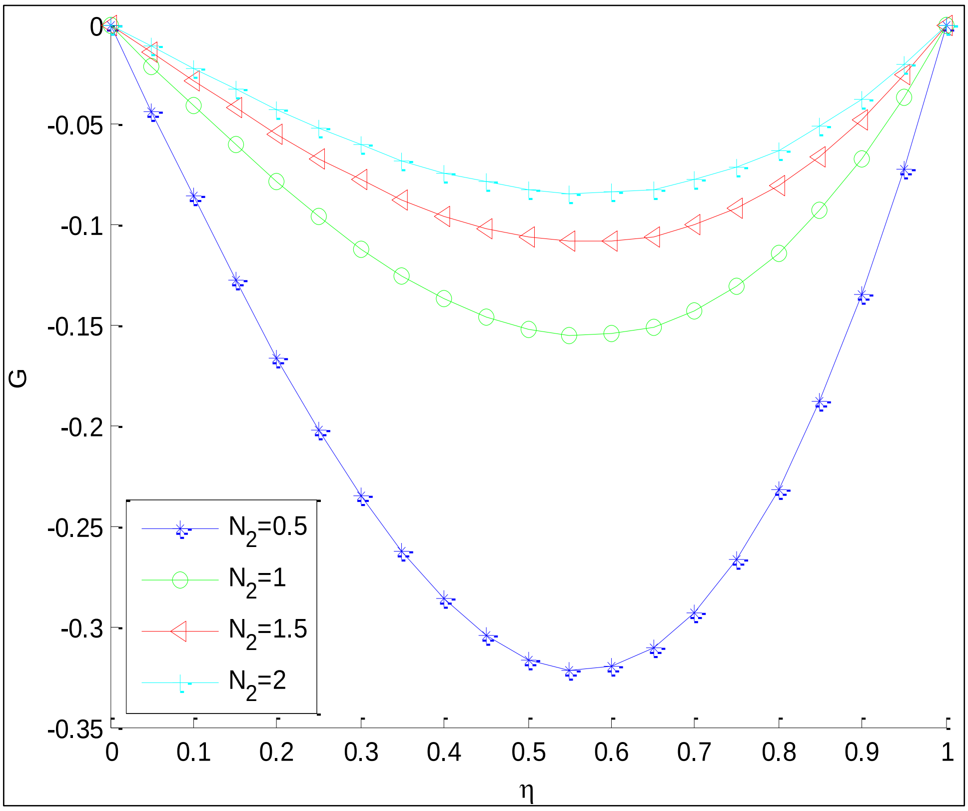

Fig. 6. *Effect of micro rotation parameter, N_2 on rotation profile when $Re = N_1 = 1$ and $N_3 = 0.01$.*

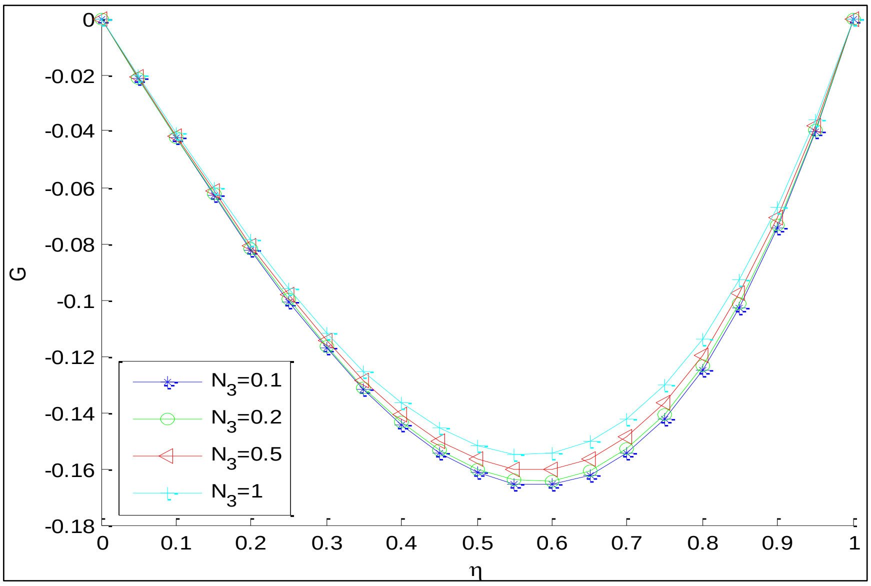

Fig. 7. *Effect of microrotation parameter, N_3, on rotation profile when Re = $N_1 = N_2 = 1$.*

CONCLUSION

In this work, the flow of a micropolar fluid conveyed through porous channel driven by suction or injection with high mass transfer has been analyzed using the regular perturbation method. The developed analytical solutions are used to investigate the effects of flow and rotation parameters such as Reynolds number and microrotation parameters. The results obtained can be used to advance the study of micropolar fluid in processes such as blood flow, turbulent shear flow, microchannel and porous channel.

Nomenclature

F dimensionless stream function
G dimensionless microrotation
H width of channel (m)
j micro-inertia density
N microrotation/angular velocity (S^{-1})
$N_{1,2,3}$ dimensionless parameter
p embedding parameter
q mass transfer parameter(ms^{-1})
Re Reynolds number
s microrotation boundary condition
u,v Cartesian velocity components (ms^{-1})
x,y Cartesian coordinate parallel and normal to channel (m)

Greek symbols

η dimensionless normal distance
μ dynamic viscosity($kgm^{-1}s^{-1}$)
κ coupling coefficient($kgm^{-1}s^{-1}$)
ρ fluid density(kgm^{-3})
ψ stream function(m^2s^{-1})
ν_s microrotation/spin gradient viscosity (m kg s^{-})

REFERENCES

[1] Eringen AC. Theory of micropolar fluids. *J Math Mech*. 1966; 16: 1–18p.
[2] Idris R, Othman H, Hashim I. On the effect of non-uniform basic temperature gradient on Benard–Marangoni convection in micropolar fluids. *Int Commun Heat Mass Transf*. 2009; 36(3): 203–209p.
[3] Yuan SW. Further investigation of laminar flow in channels with porous wall. *J Appl Phys*. 1956; 27: 267–269p.
[4] Kelson NA, Desseaux A. Effect of surface conditions on flow of a micropolar fluid driven by a stretching sheet. *Int J Eng Sci*. 2001; 39(16): 1881–1897p.
[5] Kelson NA, Farrell TW. Micropolar

flow over a porous stretching sheet with strong suction or injection. *Int Commun Heat Mass Transf*. 2001; 28(4): 479–488p.
[6] Zaturska MB, Drazin PG, Banks WHH. On the flow of a viscous fluid driven along a channel by suction at porous walls. *Fluid Dyn Res*. 1988; 4: 151–178p.
[7] Ching-Yang C. Natural convection of micropolar fluid from a vertical truncated cone with power-law variation in surface temperature. *Int Commun Heat Mass Transf*. 2008; 35(1): 39–46p.
[8] Yuan SW. Further Investigation of laminar flow in channels with porous walls. *J Appl Phys*. 1956; 27: 267–269p.
[9] Abdel-Halim IH. On solving some eigen-value problems by using a differential transformation. *Appl Math Comput*. 2002; 127: 1–22p.
[10] Magyari E, Keller B. Exact solutions for self-similar boundary layer flows induced by permeable stretching wall. *Eur J Mech*. 2000; 19: 109–122p.
[11] Murthy PSVN, Singh P. Thermal dispersion effects on non-Darcy natural convection over horizontal plate with surface mass flux. *Arch Appl Mech*. 1997; 67: 487–495p.
[12] He JH. Homotopy pertubation method for bifurication of non-linear problems. *Int J Nonlinear Sci Numer Simul*. 2005; 6: 207–218p.
[13] Joneidi AA, Ganji DD, Babaelahi M. Micropolar flow in a porous channel with high mass transfer. *Int Commun Heat Mass Transf*. 2009; 36: 1082–1088p.
[14] Golbabai A, Ahmadian D. Homotopypade method for solving linear and nonlinear integral equations. *Int J Nonlinear Dyn Eng Sci*. 2009; 1(1): 59–66p.
[15] Joneidi AA, Domairry G, Babalaehi M, Mozaffari M. Analytical treatment of magnetohydrodynamic (MHD) flow and heat transfer due to a stretching hollow cylinder. *Int J Numer Methods Fluids*. Doi: 10.1002/2087.
[16] Ramachandran PS, Mathur MN, Ohja SK. Heat transfer in boundary layer flow of a micropolar fluid past a curved surface with suction and injection. *Int J Eng Sci*. 1979; 17: 625–639p.
[17] Marinca V, Herisanu N, Constantin B, Marinca B. An optimal homotopy asymptotic method applied to steady flow of a fourth grade fluid past a porous plate. *Appl Math Lett.* 2009; 22: 245–251p.
[18] Marinca V, Herisanu N. Application of optimal homotopy asymptotic method for solving nonlinear equations arising in heat transfer. *Int Commun Heat Mass Transf*. 2008; 35: 710–715p.
[19] Marinca V, Herisanu N. Optimal asymptotic method with application to thin film flow. *Central Eur J Phys.* 2009; 6: 1608–1644p.
[20] Robinson WA. The existence of multiple solutions for the laminar flow in a uniformly porous channel with suction at both walls. *J Eng Math*. 1976; 10: 23–40p.
[21] Sheikholeslami M, Ashorynejad HR, Domairry G, Hashim I. Flow and heat transfer of Cu-water nanofluid between a stretching sheet and a porous surface in rotating system. *J Appl Math*. Article ID: 421320.
[22] Sheikholeslami M, Gorji-Bandpy M, Soleimani S. Two phase simulation of nanofluid flow and heat transfer using heat analysis. *Int Commun Heat Mass Transf*. 2013; 47: 73–81p.
[23] Hatami M, Sheikholeslami M, Ganji DD. Nanofluid flow and heat transfer in asymmetrical porous channel with expanding or contracting wall. *J Mol*

Liq. 2014; 195: 230–239p.
[24] Hatami M, Shikholeslami M, Ganji DD. Laminar flow and heat transfer of nanofluid between contracting and rotating disks by least square method. *Powder Technol*. 2014; 253: 769–779p.
[25] Sheikholeslami M, Rashidi MM, Alsaad DM, Firouzi F, Rokni HB, Domairry G. Steady nanofluid flow between parallel plates considering thermophoresis and Brownian effect. *J King Saud*. 2015; 06.003.
[26] Berman AS. Laminar flow in a channel with porous wall. *J Appl Phys*. 1953; 27: 1232–1235p.
[27] Roman L. Analysis of strongly non-linear free vibration of beams using perturbation method. *Civ Environ Rep*. 2017.
[28] Filobello-Niño U, Vazquez-Leal H, Boubaker K, Khan Y, Perez-Sesma A, Sarmiento Reyes A, Jimenez-Fernandez VM, Diaz-Sanchez A, Herrera-May A, Sanchez-Orea J, Pereyra-Castro K. Perturbation method as a powerful tool to solve highly nonlinear problems: the case of Gelfand’s equation. *Asian J Math Stat*. Doi: 10.3923 /ajms.2013.
[29] Hu H. A classical perturbation technique which is valid for large parameters. *J Sound Vibr*. 2014; 269: 409–412p.
[30] Filobello-Niño U, Vazquez-Leal H, Khan Y, Yildirim A, Jimenez-Fernandez VM, Herrera May AM, Castañeda-Sheissa R, Cervantes Perez J. Perturbation method and Laplace-Padé approximation to solve nonlinear problems. *Miskolc Math Notes*. 2013; 14(1): 89–101p.

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