Original Article
ISSN (Online): 2582-7472

ShodhKosh: Journal of Visual and Performing Arts
April 2024 5(4), 1013–1019

FREE CONVECTION PROBLEMS OF NON-NEWTONIAN FLUID IN A VERTICAL CHANNEL WITH WALL TEMPERATURE IN THE PRESENCE OF HEAT SOURCE

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DOI
10.29121/shodhkosh.v5.i4.2024.3662

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

A The natural convection heat transfer of liquid metals in a confined enclosure is considered an important problem to passive cooling system. Natural convection in an enclose field with fluid-saturated porous medium.

Keywords: Non Newtonian

1. INTRODUCTION

Micropolar fluids have been shown to accurately simulate the flow characteristics of poly- meric additives, geomorphological sediments, colloidal suspensions, hematological suspensions, liquid crystals, lubricants, etc. The main advantage of using a micropolar fluid model compared to other non-Newtonian fluids is that it takes care of the rotation of fluid par- ticles by means of an independent kinematic vector called the microrotation vector. The mathematical theory of equations of micropolar fluids and applications of these fluids in the theory of lubrication and porous media is presented by Lukaszewicz

The heat and mass transfer in micropolar fluids is also important in the context of chemical engineering, aerospace engineering, and also industrial manufacturing processes. The problem of free convection heat and mass transfer in the boundary layer flow along a vertical surface submerged in a micropolar fluid has been studied by a number of investigators. The boundary layer flow of a micropolar fluid over a semi-infinite plate .

The aim of the present paper is to study the free convection heat and mass transfer along a vertical plate with uniform wall temperature and concentration embedded in a stable, micropolar fluid with thermal and mass stratification.

Fluids with additive/suspension are considered non-Newtonian, which can be fully described by the theory of micropolar fluids first developed by Eringen [1]. Chamkha et al. [2] was the first to study the fully developed free convection of a micropolar fluid in a vertical channel. This study was further extended by Cheng [3] to include mass transfer, Natural convection in an enclose field with fluid-saturated porous medium. The purpose of this article is to extend the work of Cheng [3] by taking the vertical channel. The solution of the boundary value problem will be obtained by using exact method. In this work we aim to study the fully developed heat and mass transfer by natural convection of as micropolar fluid inside a plane vertical channel for asymmetric wall temperature in presence of heat source. The closed form exact solutions are derived and the effect of the vortex viscosity parameter on the flow, heat transfer and mass transfer characteristics such as the velocity, microrotaion, volume, flow rates ,total heat rate added to the fluid and the total species rate added to the fluid are examined.

2. PROBLEM FORMULATION AND MATHEMATICAL SOLUTION

Let us consider the laminar flow of viscous incompressible fluid past a flat and impressible elastic sheet. By applying two equal and opposite forces along thex-axis the sheet is stretched with a speed $u_w(x)$ proportional to the distance from the origin x=0. The resulting motion of the otherwise quiescent fluid is caused by the moving sheet, and the flow is governed by the constant property Navier-stokes equations for steady two-dimensional flow. The viscous fluid is only partially adhering to the stretching sheet, and the fluid motion is thus subjected to the slip-flow condition and the condition far away from the stretching sheet which are expressed as

$u(x,y)-u_w(x)=L\dfrac{\partial u}{\partial y}$ at y = 0 and v=-v0 , and $u \to 0$ as $y \to \infty$ (.1)

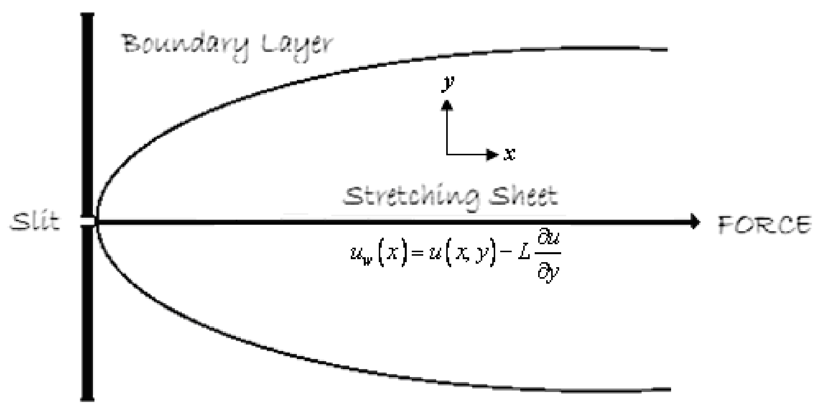

Fig.1. Schematic diagram of stretching sheet.

It is noteworthy that in the present problem the fluid is dragged by the moving sheet. The Navier Stokes equations of motion for steady viscous incompressible fluid are given by

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=0, \qquad (.2)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\upsilon\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 y}{\partial y^2}\right) \qquad (.3)$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\upsilon\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \qquad (.4)$$

Where υ is the kinematic viscosity, ρ is the density, p is the fluid pressure.

Let $u=cxf'(\eta)$, $\quad v=-\left(\dfrac{c\mu}{\rho}\right)^{\frac{1}{2}}f(\eta)$, $\quad \eta=\left(\dfrac{c\rho}{\mu}\right)^{\frac{1}{2}}y$

$$p = p_w - \frac{1}{2} c \mu g(\eta) \qquad (5)$$

Introducing similarity transformation (.5) equations (.1), (2), (.3) & (.4) takes the form,

$$(f')^2 - ff'' = f''', \qquad (6)$$

$$f(0) = s,$$
$$f'(0) = 1 + \gamma f''(0), \qquad (7)$$
$$g(0) = 0,$$

and $f' \to 0 \quad as \quad \eta \to \infty$ (.8)

Here prime denotes differentiation with respect to η.
Assuming,

$$g(\eta) = f^2 + 2f' - 2\beta^2, \qquad (9)$$

The shear stress coefficient is given by

$$c_f = \frac{\mu \frac{du}{dy} / y=0}{\frac{pu_w^{\,2}}{2}} = \frac{2f''(0)}{\mathrm{Re}_x^{\frac{1}{2}}} = -2\beta \mathrm{Re}_x^{-\frac{1}{2}} \qquad (10)$$

Where the local Reynolds number is defined as $\mathrm{Re}_x = U_w \frac{x}{v}$ .The velocity component v does not contribute to shear stress at the sheet as that using the boundary layer assumption.

3. HEAT TRANSFER ANALYSIS

The governing boundary layer heat transport equation for the two-dimensional flow problem under consideration is given by

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho C_p}\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right] \qquad (11)$$

Where ρ is the density, Cp is the specific heat at constant pressure.

The solution of equation (11) is obtained using two different types of heating processes namely,
(i) Constant surface Temperature (CST)
(ii) Prescribed surface Temperature (PST) conditions as described below.

Constant Surface Temperature (CST)

The boundary conditions in case of CST is given by

$$T = T_w \quad at \quad y = 0$$
$$T \to T_\infty \quad as \quad y \to \infty \qquad (12)$$

Where T_w is the temperature of the sheet and T_∞ is the temperature of the fluid far away from the sheet.

Defining the non-dimensional temperature $\theta(\eta)$ as

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \qquad (13)$$

Where $T-T_\infty=\left(T_w-T_\infty\right)\theta(\eta)$ *and* T_w-T_∞ is a constant

Using equation (13), equation (4.3.1) can be written in the form

$$\theta''(\eta)+Prf(\eta)\theta'(\eta)=0 \tag{14}$$

Where $Pr=\frac{\mu Cp}{k}$ is the Prandtl number, consequently the boundary conditions (4.3.1.1) take the form

$$\begin{aligned}&\theta(\eta)=1 \quad at \quad \eta=0\\&\theta(\eta)\to 0 \quad as \quad \eta\to\infty\end{aligned} \tag{15}$$

Introducing the new independent variable

$$\xi=-\Pr e^{-\beta\eta} \tag{16}$$

Substituting in (4.3.1.3) we obtain

$$\xi\frac{d^2\theta}{d\xi^2}+\left(1-\Pr-\xi\right)\frac{d\theta}{d\xi}=0 \tag{17}$$

The corresponding boundary conditions are

$$\begin{aligned}&\theta(\xi)=1 \quad at \quad \xi=-\Pr\\&\theta(\xi)\to 0 \quad as \quad \xi\to 0\end{aligned} \tag{18}$$

The heat transfer rate, characterized by the Nusselt number, at the sheet is given by

$$Nu=\frac{k\frac{\partial T}{\partial y}}{k\left(T_w-T_\infty\right)}x=-\left(\frac{cx^2}{v}\right)^{\frac{1}{2}}\quad\theta'(0)=\mathrm{Re}_x^{\frac{1}{2}}\theta'(0) \tag{19}$$

$$\theta'(0)=\frac{\frac{\Pr-1}{\Pr+1}\Pr\beta M\left(\Pr,\Pr+2,-\Pr\right)}{M\left(\Pr-1,\Pr+1,-\Pr\right)}-\Pr\beta \tag{20}$$

4. RESULTS AND DISCUSSION

An analysis has been carried out, to study the behaviour of a viscous incompressible fluid taking into consideration of partial slip condition. Analytical solution is obtained for the flow and Heat transfer in the present investigation. Analytical solution for the heat transport equations are sought in terms of hypergeomeric Kummer's functions. The effect of governing parameters like, slip parameter γ, suction parameter $-v_0$, Prandtl number *Pr*, are shown graphically from fig.2 to fig6. Before discussing the results of the present investigation we mention the following:

Far away from the stretching surface the velocity u parallel to the sheet decays and eventually goes to zero. The velocity component v perpendicular to the sheet, on the other hand, tends to constant negative values. Since f approaches β sufficiently far off the sheet.

Closed form analytical solutions like are generally rare in fluid mechanics. Even though a solution exist for a given case subjected to the conventional no slip boundary condition, generalization of that case to account for partial slip normally prohibits the existence of an analytical solution. Equations (9) & (.10) is an exact solution of the Navier-stokes equation and is formally valid for any Reynolds number.

Fig (2) represents the effect of suction parameter on flow velocity $f'(\eta)$ and it is noticed that as suction parameter s increases velocity profile $f'(\eta)$ decreases.

Fig.(3) represents the effect of slip parameter γ on flow velocity $f'(\eta)$ and it is noticed that as slip parameter γ increases velocity profile $f'(\eta)$ decreases. Fig.(4) and Fig.(5) represents the effect of slip parameter γ on heat transfer in CST and PST cases respectively. The increasing values of slip parameter γ results in increase of temperature of fluid. Fig. (6) and Fig. (7) represents the effect of Prandtl number *Pr* on the heat transfer in CST and PST cases respectively. From these plots it is evident that large values of Prandtl number results in decrease in temperature of the flow field.Since it is well known that the thermal boundary layer thickness is inversely proportional to the square root of Prandtl number, the decrease of temperature profile with Pr is straightforward in oth cases.

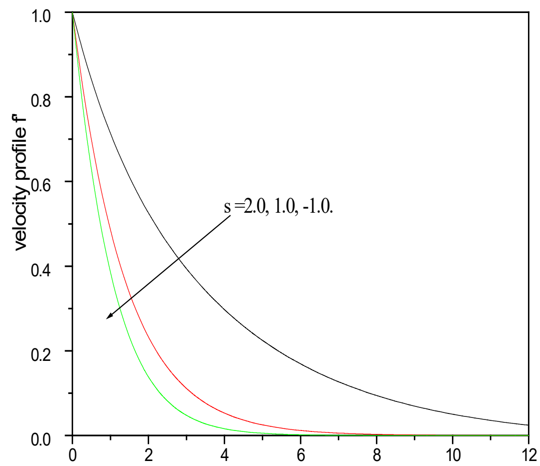

Fig 2 A graph of dimensionless velocity profile f' versus similarity variable η

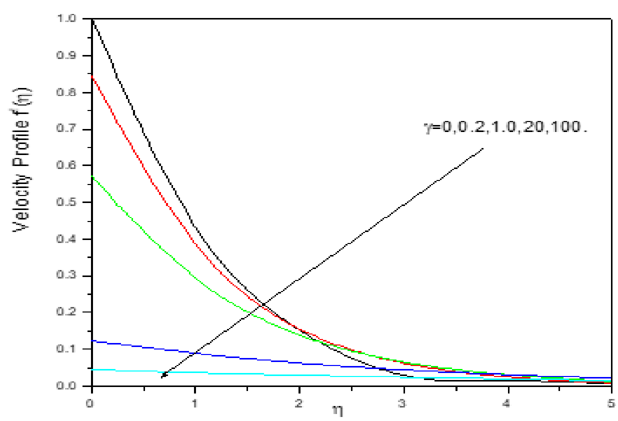

Fig.3.Dimensionalless velocity profiles f(η) for different values of the slip factor γ

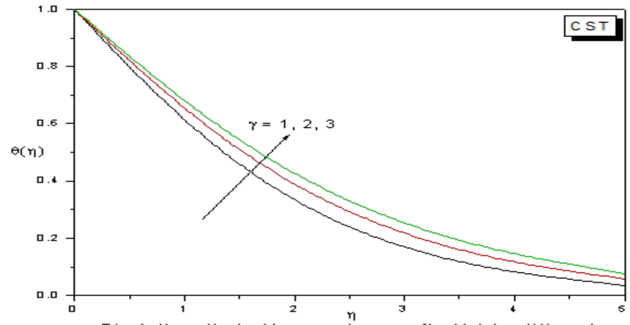

Fig.4. the effect of temperature profile θ(η) for different γ

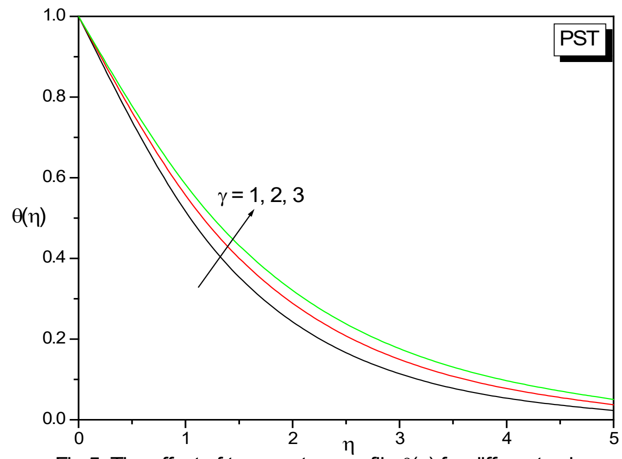

Fig.5. The effect of temperature profile θ(η) for different values of γ

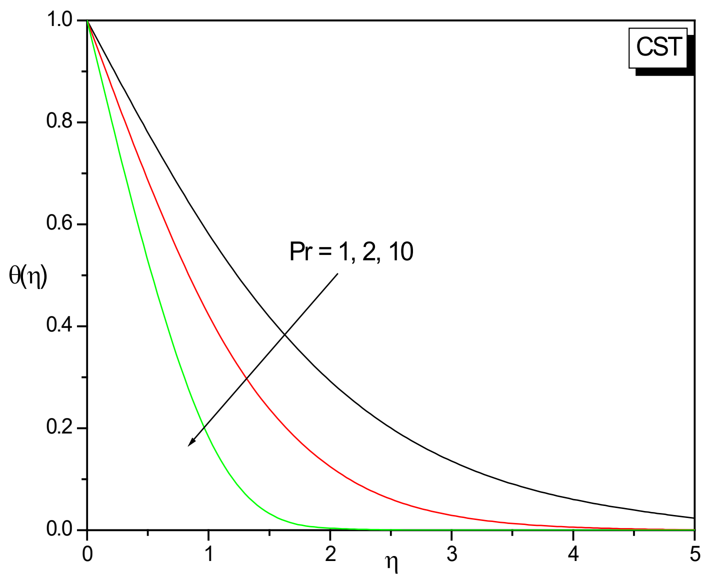

Fig.6. The effect of temperature profile θ(η) for different Pr

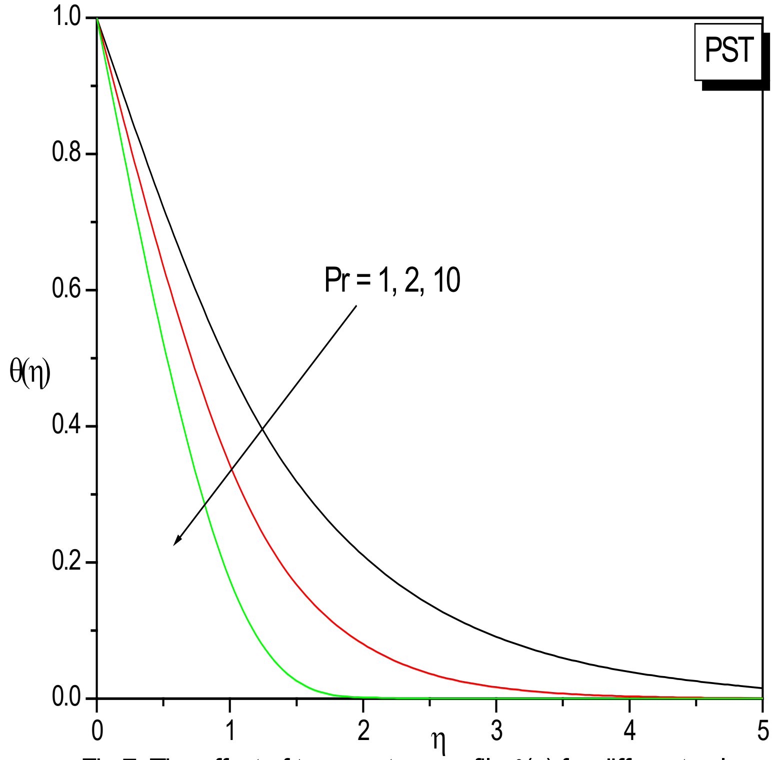

Fig.7. The effect of temperature profile θ(η) for different values of Pr

ACKNOWLEDGEMENT

None.

CONFLICT OF INTERES

None.

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