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Review

Steady flow and heat transfer analysis of third grade fluid with porous medium and heat generation

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A R T I C L E I N F O

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A B S T R A C T

In this study, flow and heat transfer of a non Newtonian third grade fluid with porous medium and internal heat source conveyed through parallel plates held horizontally against each other are investigated. The nonlinear ordinary equations arising due to visco-elastic effects from the mechanics of the fluid are analysed using the adomian decomposition method (ADM) adopting Vogel's temperature dependent model based viscosity. Thermal fluidic parameters effects such as pressure gradient, heat generation parameter and porosity term are examined on the flow and heat transfer. Increasing porosity term shows slight decreasing effect on velocity distribution, as increasing heat generation term demonstrates significant increase on temperature distribution towards the upper plate. Obtained solutions in this paper may be used to advance studies in thin film flow, energy conservation, coal-water mixture, polymer solution and oil recovery application. Also Results from analyses compared against the fourth order Runge kutta numerical solution proves to be in satisfactory agreement.

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1. Introduction

In many industrial and technological applications the flow and heat transfer of non-Newtonian fluid of the third grade has received much attention owing to its vast importance in the field of engineering, science and technology. It is also of relevance in reservoir engineering, porous industrial materials, fluid beds, ceramic processing, polymer solution and oil recovery amongst others. The physical behavior of non-Newtonian fluids depends on forces acting on it per time, unlike Newtonian fluids which can be completely described by temperature and pressure effects. In such classification the third grade fluid, a sub category of non-Newtonian fluid which capture's the non-Newtonian effects such as shear thinning, shear thickening as well as normal stresses, even in cases of rigid boundary. It also exhibits viscous elastic fluid characteristics.

Several researchers have studied the third grade fluid owing to its practical relevance in modern science. In the light of these efforts, Fosdick and Rajagopal [11] studied the stability of the third grade fluid while [22] presented numerical solutions utilizing the finite difference scheme to study the effect of variable viscosity on third grade fluid in a pipe. Hayat et al. [19] investigated the effect of third grade fluid over stretching sheets. Effects of slip boundary condition were showed by Ellahi et al. [7] on nonlinear

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Nomenclature

Λ_1	non-Newtonian material parameter	k_{th}	thermal conductivity
Λ_2	porosity parameter	u	dimensionless velocity (x component)
Λ_3	pressure gradient	v	dimensionless velocity (y component)
β	activation energy	T_o	initial temperature term
φ	porosity of porous space	δ	heat generation parameter
k	permeability	θ	dimensionless temperature
C_0	initial concentration term	Q	heat source term
Γ	viscous dissipation	E	fluid energy term
??	dimensionless viscosity	A_0	area of flow
A	dimensionless Vogel's constant		
B	dimensionless Vogel's constant		

flows. Abbasbandy [1] used Numerical solutions to investigate flows between two porous walls of the third grade fluid. Similarity solutions were analyzed for the third grade fluid for special channel coordinate systems by Muhammet [23] while Ogunsola and Peter [27] studied effect of radiation with Arrhenius reaction on third grade flow. Akinshilo and Sobamowo [3] studied third grade fluid as blood utilizing gold nanoparticles. Aksoy and Pakdemirli [4] adopted the perturbation solution in the study of third grade fluid through various flow channels.

Many models have been used in recent past to describe viscous fluid flow for non Newtonian fluids through various flow channels. These models illustrates the effect of nonlinear relationship between stress-strain. Hence higher order nonlinear differential type fluid have been given considerable research attention [8,24,26,20,15,17,30,29,25,32].

Approximate analytical methods of solutions applied by researchers in study of the heat transfer includes the pertubation method (PM), homotopy analysis method (HAM), homotopy pertubation method (HPM), variational iteration method (VIM), differential transformation method (DTM), and methods of weighted residuals [10,21,6,9,18,31,28,13,14,16,15,17,12,2,30,29,5]. Methods such as PM are limited owing to the problems of weak nonlinearities and artificial pertubation parameter which are non existence in real life. The need to find an initial condition to satisfy the boundary condition makes methods such as HPM, VIM, DTM, HAM requires computational tools in handling a solution of large parameters resulting to large computational cost and time. Whereas the methods of weighted residuals which includes the collocation method (CM), Garlerkin method (GM) and least square method (LSM) involves the need to determine weighing residuals to satisfy weighing functions which may be arbitrary. The solution method of decomposing nonlinear coupled equations into linear and nonlinear terms makes the adomian decomposition method (ADM) a powerful yet relatively simplistic method which is not limited by any artificial parameter or initial guess term. This makes ADM an interesting scheme in providing analytical solutions to nonlinear problems in science and engineering as often employed by researchers.

In the light of the above research, this paper aim to investigate the flow and heat transfer of the third grade fluid with porous medium and internal heat source, utilizing the adomian decomposition method (ADM).

2. Model development and analytical solution

The fluid under consideration is a non-Newtonian fluid of grade three with porous medium which flows steadily between two plates placed horizontally against each other as described in the physical model of the problem Fig. 1. The fluid flows under non-slip condition connoting fluid particles close to the plate walls sticks to walls surface and no temperature jump connoting fluid particles close to the plate walls have equal temperature with inner plate surface. The formulation of the model development of the flow with porous medium and internal heat source is developed assuming fluid is incompressible since it is liquid, body forces acting on fluid as well as radiation effect is negligible because of flow geometry. Fluid is in thermal equilibrium i.e. fluid is thermodynamically stable.

Following the model proposed by Aksoy and Pakdermirli [4] introducing an internal heat source term. The momentum and energy equations can be reduced to ordinary pairs of nonlinear second order differential equations. This is introduced as:

$$\frac{d\mu}{dy}\frac{du}{dy}+\mu\frac{d^2u}{dy^2}+6\Lambda_1\left(\frac{du}{dy}\right)^2\frac{d^2u}{dy^2}-\Lambda_2 u\left[\mu+2\Lambda_1\left(\frac{du}{dy}\right)^2\right]=\Lambda_3 \tag{1}$$

$$\frac{d^2\theta}{dy^2}+\mu\Gamma\left(\frac{du}{dy}\right)^2+2\Gamma\Lambda_1\left(\frac{du}{dy}\right)^4+\delta\theta=0 \tag{2}$$

The appropriate boundary condition can be introduced as:

$$\begin{aligned} &u=0,\ \theta=0 \quad \text{at } y=0 \\ &u=0,\ \theta=1 \end{aligned} \tag{3}$$

where non-dimensional parameters stated as:

$$\Lambda_1=\frac{\beta U^2}{\mu_0 h^2},\ \Lambda_2=\frac{\varphi h^2}{k\mu_0},\ \Lambda_3=\frac{C_0 h^2}{\mu_0 U},\ \Gamma=\frac{\mu_0 U^2}{k_{th}(T_2-T_1)},$$
$$\mu=\frac{\mu^*}{\mu_0},\ \delta=\frac{QEA_0h^2C_0}{k\theta_0^2} \tag{4}$$

where Λ_1 is the dimensionless parameter which measures the non-Newtonian effect on the fluid viscosity, $\Lambda_2$shows the influence of porosity on fluid flow, Λ_3 is the dimensionless parameter illustrating the effect of pressure drop on flow and heat transfer, Γ is the

Fig. 1. Physical model of problem.

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