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EFFECT OF VISCOUS DISSIPATION TERM ON A FLUID BETWEEN TWO MOVING PARALLEL PLATES

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Abstract: The fully developed laminar heat transfer of a Newtonian fluid flowing between two parallel plates where the bottom plate is fixed and the top plate is moving in an axial direction at constant speed was analyzed taking into account the viscous dissipation of the flowing fluid. Applying the velocity profile obtained for the plane Coutte-Poiseuille laminar flow, the energy equation with the viscous dissipation term was exactly solved for the boundary conditions of constant wall heat flux at one wall with the other insulated. Special attention is given to the shear produced by the movable top plate over and above the viscous dissipation due to internal fluid friction. The reason behind the behaviour exhibits by the temperature profile obtained at different velocities can be attributed to the effect of viscous dissipation coming into play due to the shear stress within the fluid layer induced by the movement of the upper plate.
Keywords: heat transfer, parallel plates, viscous dissipation, velocity profile, boundary conditions

1. INTRODUCTION

Deformation and flow of materials require energy. This mechanical energy is dissipated during the flow and is converted into internal energy of the material. The increase of internal energy is in form of temperature rise. Viscous dissipation is of interest for many applications: significant temperature rises are observed in polymer processing flows such as injection molding or extrusion at high rates. Aerodynamics heating in the thin boundary layer around high speed aircraft increases the temperature of skin. Viscous dissipation for a fluid with suspended particles is equated to the viscous dissipation in a pure Newtonian fluid, both being in the same flow (same macroscopic velocity gradient). The fluid flow in small devices and the corresponding heat transfer has received serious attention in recent past in view of the remarkable development in the field of microelectronics and MEMS. In small devices the effect of viscous dissipation that could play a vital role, result in inefficient heat dissipation leading to overheat problems. The understanding of the fluid flow phenomena has been critically reviewed [1] through micro scale devices and explored the physics of flow emphasizing the use of MEMS in different areas for flow control.

There has been an increase in research on flow and heat in microchannels recently due to the development in specific areas such as microfabrication technology, micro devices, micro electromechanical systems (MEMSs), the electronic Industry and the biomedical engineering. For a rarefield fluid flow at microscale a slip condition for the velocity and a jump condition for the temperature should be adopted [2]. Viscous dissipation is another parameter that ought to be taking into account at microscale. Viscous dissipation changes the temperature by behaving like an energy source due to a power generation induced by the shear stresses. Heat transfer and microscale fluid flow has a different behavior from that of macroscale case. At macroscale, a slip condition for the velocity and a jump condition for the temperature should be adopted. Gad-el-Hak [1]treated analysis for microchannel flows through study of microdevices fluid mechanics. Guo and Li [3] studied the size effects on micro scale single-phase fluid flow and heat transfer. Wu and Cherg[4] studied the friction factor and convective heat transfer in smooth silicon microchannels of trapezoidal cross-section. Zhang *et al.* [5] validated the Navier-Stokes equation for slip flow in transition region.

A numerical study [6] reported the influence of viscous dissipation for the flow of a Newtonian for the flow of a Newtonian fluid through a parallel plate channel. The effects of viscous dissipation on laminar forced convection through a pipe and channel have been studied [7] for the flow of a Phan-Thien Tanner fluid. The study has revealed that the viscous dissipation enhances the fluid elasticity. Performing an analytical study, using a functional analysis method, the effects of viscous dissipation on the heat transfer have been investigated [8] for a thermally-developing laminar Hartman flow through a parallel plate channel with the aid of a magnetic field. In a study of thermal development of forced convection in a parallel plate channel filled by porous medium, an investigation of the effects of viscous dissipation has been done [9] with the thermal boundary condition of uniform wall temperature including axial conduction effects. The analysis of laminar forced convection in a pipe for a Newtonian fluid of constant properties has been performed [10] by taking the effect of viscous dissipation into account. The analytical work by Aydin and Avci [11] has dealt with the convective heat transfer problem for the plane Poiseuille flow with an emphasis given on the viscous dissipation effect. In a recent study, [12] the effects of viscous of viscous dissipation on heat transfer between two fixed parallel plates with constant heat flux boundary condition has been reported. Performing a numerical study, the influence of viscous dissipation on fully developed laminar heat transfer has been investigated [13] for a non-Newtonian fluid flowing between two parallel plates with the axial movement of one of the plates.

Problems that involve fluid flow and heat transfer with an axially moving core of solid body or fluid in an annular geometry can be found in many manufacturing processes, such as extrusion, drawing and hot rolling. In such processes, a hot plate or cylindrical rod continuously exchanges heat with the surrounding environment. For such case, the fluid involved may be Newtonian or non–Newtonian and the flow situations encountered can be either laminar or turbulent. In such industrial applications, it is of great importance to encounter the heat transfer from the moving boundary to the surrounding fluid and vice-versa.

In the previous report, the effect of viscous dissipation on fully developed Newtonian laminar heat transfer was discussed for the case of concentric annuli with axially moving cores. In this report, developed laminar heat transfer of a Newtonian fluid flowing between two parallel plates with one moving plate was analyzed taking into consideration the viscous dissipation of the flowing fluid. Applying the velocity profile obtained for the plane Coutte-Poiseuille laminar flow, the energy equation with the viscous dissipation term was exactly solved for the boundary conditions of constant wall heat flux at one wall with the other insulated. The objective of the paper is to investigate the effect of viscous dissipation on the heat transfer on a two parallel plates where one plate is moving and between two moving parallel plates.

2. NUMERICAL FORMULATION

The assumptions used in this analysis are:

1. The flow is incompressible and steady- laminar, and fully developed hydro-dynamically and thermally.
2. Either of two parallel plates is axially moving at a constant velocity.
3. The fluid is Newtonian and physical properties are constant.
4. The body forces and axial heat conduction are neglected.

The governing equations consist of continuity, momentum and energy equations. In order to get the velocity and temperature distributions between two plates, the governing equations have been derived based on the above-mentioned assumptions.

Governing Equations

For steady, and two dimensional flow of an incompressible fluid with constant fluid properties, the continuity equation and momentum equations are given in equation (1) and (2) respectively [14]

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

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+F_x \tag{2a}$$

$$\rho\left(u\frac{\partial v}{\partial x}+\frac{\partial v}{\partial y}\right) = -\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+F_y \tag{2b}$$

Also, the energy equation containing the viscous dissipation term μØ is given in equation (3)

$$\rho C_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right) = -\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+\mu Ø+q \tag{3}$$

where

$$\mu Ø = \mu\left[\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2+2\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2\right]\right]$$

For a fully developed fluid flow between two parallel plates where one of the plates is set in motion and the other plates is kept stationary, the fluid between the plate is said to be subjected to coquette flow. Example of this flow can be found in journal bearing.

This fluid motion is also the case of parallel flow, in which the flow motion is only in one direction, which indicates that the velocity component in y-direction is zero (*v=0*). Therefore, from equations (1), the continuity equation reduces to

$$\frac{\partial u}{\partial x} = 0 \tag{4}$$

Also, from equations (1) and (2), the momentum equation reduces to

$$0 = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial y^2}\right) \quad (5)$$

Neglecting the body forces F_x and F_y.

In couette flow, the fluid motion is sustained by the force provided by one of the plates and not by the pressure gradient, therefore, equation (5) further reduces to

$$0 = \frac{\partial^2 u}{\partial y^2} \quad (6)$$

Since uniform temperature field is going to be experienced on both plates, from equation (3), the convection term which has the temperature gradient, reduces to zero: Therefore, if the heat generation term, q is neglected, then equation (3) can be redefined as

$$k\frac{\partial^2 T}{\partial y^2} + \mu\left(\frac{\partial u}{\partial y}\right)^2 \quad (7)$$

Boundary Conditions

The viscous domain considered is engine oil; which has a density, ρ= 888.2 kg/m3, thermal conductivity, k=0.145W/(m K), dynamic viscosity, μ=0.79938Pas and specific heat c_p=1870J/(kg K); and is bounded by two parallel plates of length 10mm each with a gap of 3mm. The lower plate velocity varies from 0 to 10m/s for each parametric run of upper plate velocity from 0 to 10m/s. The lower plate's temperature is kept at 283.15K while the temperature of the upper plate is kept at 303.15K. Since it was assumed there is no heat flux to in direction of shear, thermal insulation was applied to the two boundaries of the gap between the plates with velocity symmetry boundary condition.

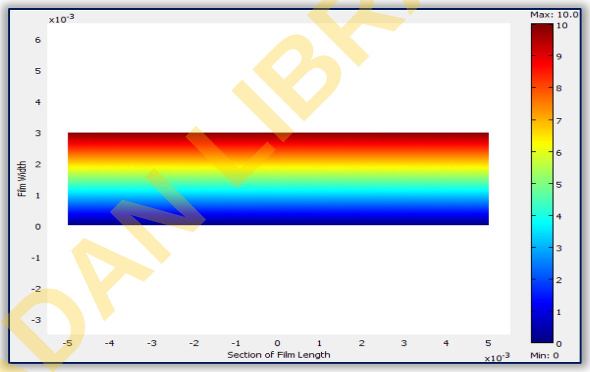

Figure 1: Velocity distribution when upper plate velocity is at 10m/s

3. RESULTS AND DISCUSSION

The velocity distribution when upper plate velocity is at 10m/s and when both plates moves in opposite direction with velocities at 10m/s are shown in Figure 1 and Figure 2 respectively. In this paper, the effect of viscous dissipation term on a fluid between two moving parallel plates, where the bottom plate is fixed and the top plate is moving in an axial direction at a constant speed has been analysed. The velocity is an important parameter governing the heat transfer and fluid flow in a channel between two plates moving in opposite direction. Actually, it is a dimensional way of representing the effect of viscous dissipation.

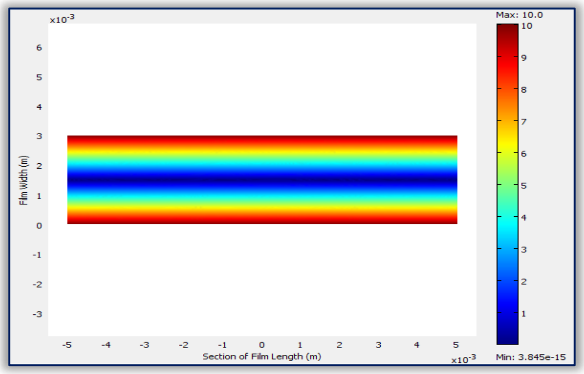

Figure 2: Velocity distribution when both plates moves in opposite direction with velocities at 10m/s

Figure 3 and Figure 4 depict the variation of temperature profile for different velocities for the upper plate while keeping the lower plate at stationary position. Viscous dissipation acts as a source of energy in the flow and this severely affect the temperature distribution in Figure 3 and Figure 4. The reason behind such a behaviour exhibits by the temperature profile obtained at different velocities, can be attributed to the effect of viscous dissipation coming into play due to the shear stress within the fluid layer induced by the movement of the upper plate.

Viscous dissipation always generates a distribution of heat source stimulating the internal energy in the fluid, and hence the temperature profile gets distorted when both plates move in opposite direction as it is clear in Figure 5 and 6. It is observed that the velocity of the upper plate has great influence on the thermal behaviour of the film as the temperature rises towards the film centre with increase in velocity.

4. CONCLUSION

In this present study, fully developed laminar heat transfer of a Newtonian fluid flowing between two parallel plates with one moving plate was analyzed taking into account the viscous dissipation for the thermal boundary conditions of constant wall heat flux at one wall with the other insulated. Apart from the effect of viscous dissipation due to internal fluid friction, an emphasis on viscous dissipation is given to include the effect of shear stress induced by the movement of the top plate.

The reason behind such a behaviour exhibits by the temperature profile obtained at different velocities, can be attributed to the effect of viscous dissipation coming into play due to the shear stress within the fluid layer induced by the movement of the upper plate.

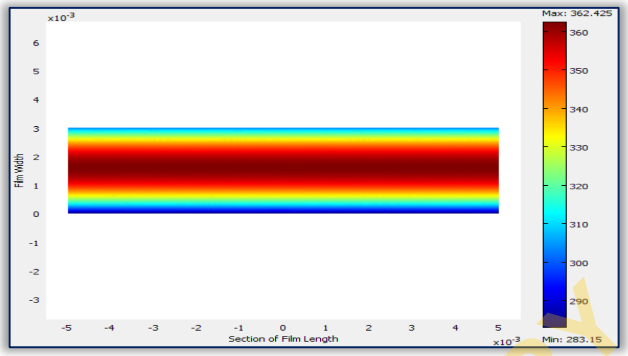

Figure 3: Temperature distribution when upper plate velocity is at 10m/s

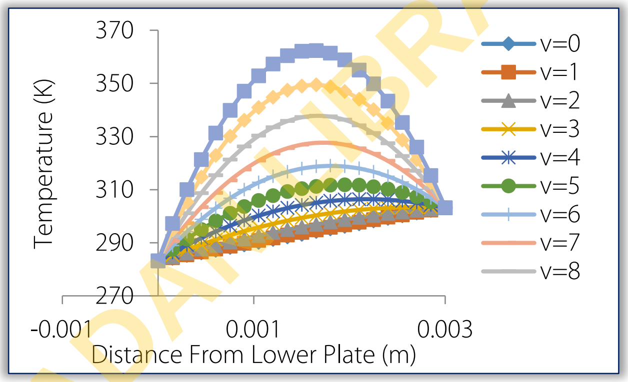

Figure 4: Temperature distribution between stationary lower plate and moving upper plate with varying velocities

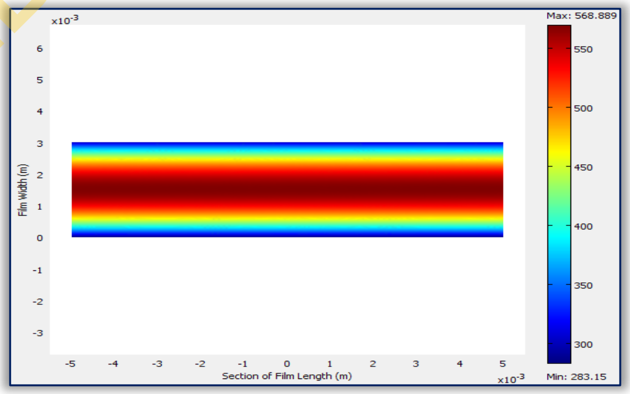

Figure 5: Temperature when both plates moves in opposite direction with velocities at 10m/s

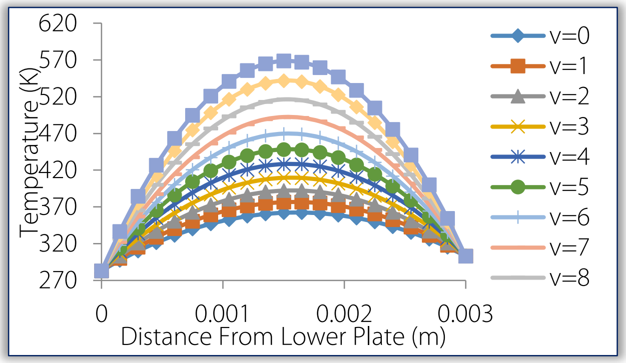

Figure 6: Temperature distribution between lower plate at 10m/s with varying upper plate velocities in opposite direction

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