ISSN 2229-5518

NUMERICAL INVESTIGATION OF BINGHAM FLUID FOR SLIP AND NO SLIP CONDITIONS IN SERPENTINE CHANNEL

Kuldeep Rawat, Pankaj Negi, Ankur Dimri, Ayushman Srivastav

Abstract The flow of a Bingham fluid in a serpentine tube of circular cross section has been investigated numerically for slip and no slip conditions. The flow behaviour is studied for different parameters separately for both slip and no slip conditions. The K-ε model is used to solve the turbulent model. It is observed that parameters variation for no slip condition is better as compared to the no slip conditions in high stress. The motivation of present work is limited study in the flow behaviour of Bingham fluid in serpentine cannel.

Keywords: Serpentine Channel, Non Newtonian Channel, slip and no slip

1 INTRODUCTION

The study of flow parameters of a viscous fluid in a curved tube constitutes a problem of fundamental interest in the field of internal fluid mechanics. Adaption of the frequent occurrence of the serpentine tube geometries in industries, heat engine, heat exchangers, chemical reactors. it is essential to understand the complex flow field and secondary flow. A Bingham Plastic is a viscoplastic fluid which behaves as a rigid body in low stresses while flow as a viscous fluid at a high stress, Bingham fluid is one of the type of non-Newtonian fluid that own a yield strength which should be surpassed before the fluid will flow.

The flow of a Non Newtonian fluid in different tubes has been studied extensively in literature and brief reviews has been given by Bigyani Das [1] has presented the Bingham fluid flow in a little curved tube they use the Runga-Kutta Merson Technique, in this investigation the region of dean number was studied and the output compared with Casson fluid contains the same yield value, it is concluded that the flow characteristics of a Bingham fluid through a curved tube circular cross section in the high dean region for the dean number, momentum integral equations with the equations obtained by considering the continuity of the secondary flow at the edge of the boundary layer , give rise to a nonlinear ordinary differential equations system.

Similar work is carried out by Yildiz Bayazitoglu et al [2] for laminar Bingham fluid that flow between vertical parallel plates, flow of fluid is assumed to be laminar and offers a reference case to the solution to be linear viscous flow. The problem of natural convection of the Bingham fluid is explained in the five different regions the parallel plates possess the gap between them, starting from hotter to the cooler plates. It is concluded that it will link fluid thermal performance to the laboratory properties and will enable the creation of designer fluid. The breakdown of the gel strength with flow will alter the flow in this Bingham material model is the way the gel strength breakdown.

Another approach in the study of Bingham fluid is done by Fusi et al [3] Bingham fluid in a channel in which lubrication flow is pressure driven. This was an approach for the lubrication flow modelling of a Bingham Fluid in a channel whose amplitude is non-uniform, this approach leads an equation of integro-differential for pressure that can be solved by iteration procedure, and the study is extended to the problem of pressure dependent viscosity. Mukherjee et al [4] carried out research on the effects of the Bingham plastic viscosity and power law on the flow and the characteristics of heat transfer laminar forced convection inside non-circular ducts. Two thermal boundary conditions on the duct wall implemented. Flow resistance and Nusselt number for the flow of Bingham plastic fluids and power law in non-circular ducts and including semi-circular duct investigated for range of power laws covering both shear thinning and shear thickening properties.

Shelukhin et al [5] carried out investigation on thermodynamics of micro polar Bingham fluids, Bingham fluids allowing for the different concentration of polar particles, such fluids exhibit couple stresses a non-symmetrical stress tensor, microrotations and microinertia also the fluid support a yield stress. Calculation is performed on a steady flow between two parallel planes prove that both the yield stress and yield couple stress reduce this tabular pinch effect.

Slip flow region is a low pressure region for gas flows through micro channels. In this region the micro channel has slip velocity. For the gaseous flow the there is always a non-zero velocity near the wall, which is based on momentum imbalance at the wall. This slip velocity is a function of the velocity gradient at the wall.

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2. GEOMETRY

In present work serpentine channel is used to analyse the Bingham fluid behaviour with slip and no slip conditions. ANSYS workbench 15 is used for designing the geometry. The length of the channel is 150 mm with circular cross section having 5 mm radius, Fig 1 shows the geometry of the channel, geometry is same for both the slip and no slip conditions. Fig 2 shows the cross section of the serpentine geometry.

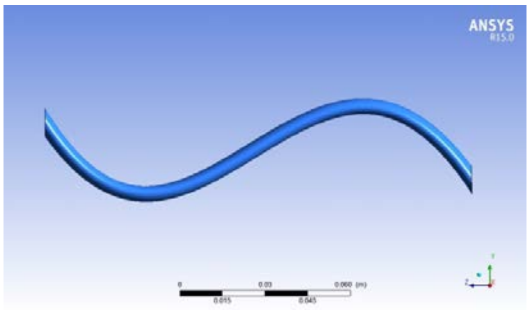

Fig 1: Geometry of the serpentine channel

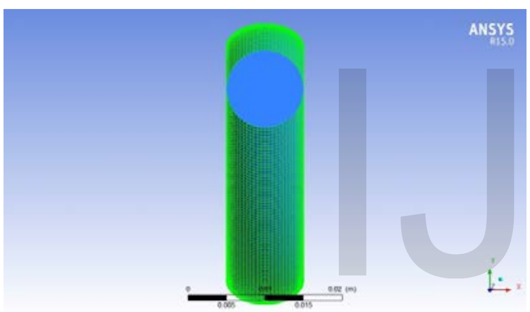

Fig 2: Cross section view of the geometry

2.1 MESH

The computational domain contains quadrilateral mesh on all sides of the geometry, because quadrilateral

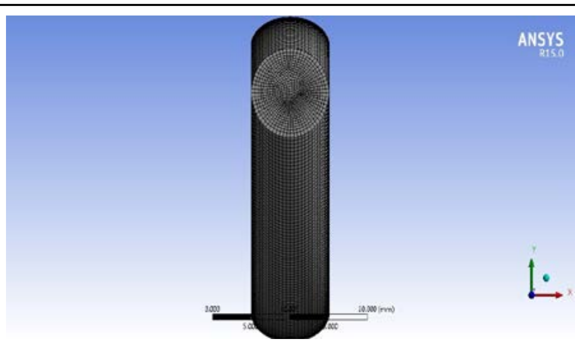

Fig 3: Mesh of the channel

mesh can be easily stretched around the corners of the geometry.Approximately 300000 quadrilateral mesh elements are generated for the whole domain. Mesh sensitivity analysis is used to find the better mesh elements to obtain the Optimized results.

3. SOLUTION

3.1 BOUNDARY CONDITIONS

Boundary conditions are used according to the need of the model. At inlet of the channel velocity inlet is used for which 0.50m/s velocity is provided and at outlet of the channel pressure outlet boundary condition is used, for the calculation purpose the properties of Bingham fluid is used. The analysis of Bingham fluid through serpentine channel is done under slip and no slip condition of fluid flow. Different parameters like wall shear stress, turbulent viscosity static pressure etc. was analysed in both cases of slip and no slip for the analysis of fluid behaviour inside the channel.

K-epsilon (k-ε) turbulence equation is used for solving the present problem. In this investigation we are trying to analyse the Bingham fluid behaviour, hence we are using this equation to solve this problem due to its efficient behaviour for turbulent flow inside the channel.

For turbulent kinetic energy (k)

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\frac{\mu_t}{\sigma_k}.\frac{\partial k}{\partial x_i}\right]+2\mu_t E_{ij}E_{ij}$$

For dissipation (ε)

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}.\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}E_{ij}-C_{2\varepsilon}\rho\frac{\varepsilon}{k}$$

4. RESULT AND DISCUSSION

4.1 COMPARISON OF STATIC PRESSURE FOR NO SLIP AND SLIP CONDITIONS

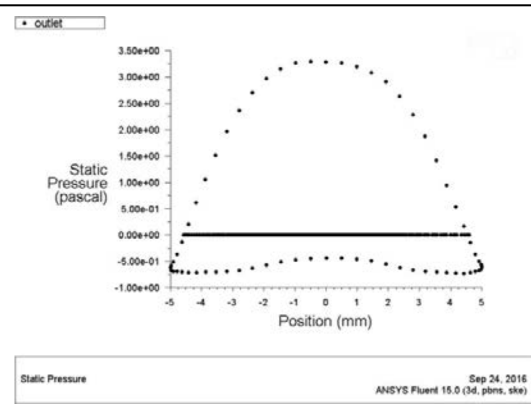

Fig 4:Static Pressure in No slip condition

ISSN 2229-5518

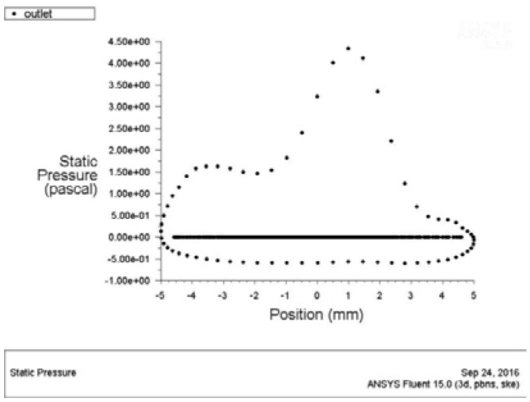

Fig 5: Static pressure in Slip Condition

4.2 COMPARISON OF WALL SHEAR STRESS FOR NO SLIP AND SLIP CONDITIONS

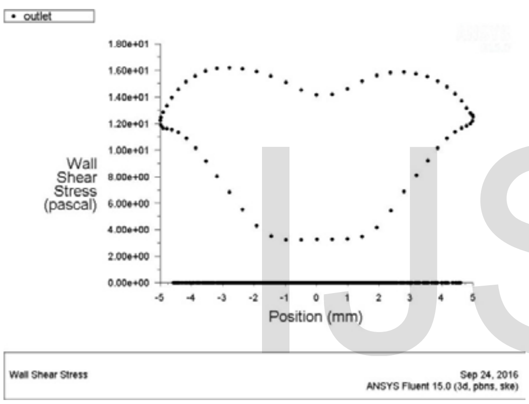

Fig 6: Wall Shear Stress in No slip condition

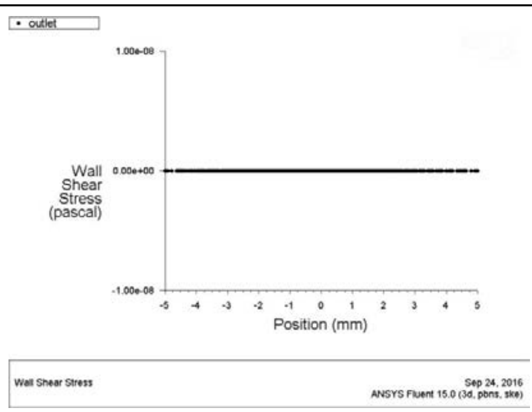

Fig 7: Wall Shear Stress in Slip condition

4.3 COMPARISON OF SKIN FRICTION COEFFICIENTS IN SLIP AND NO SLIP CONDITIONS

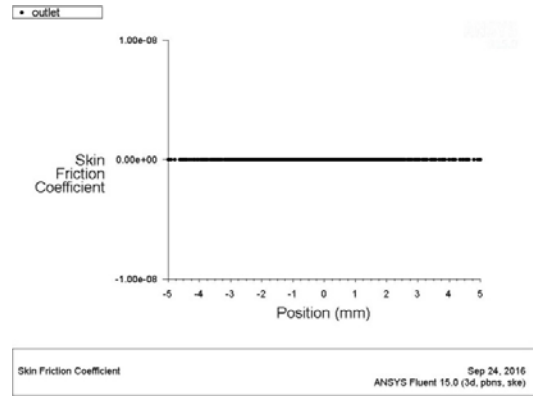

Fig 8: Skin Friction co-efficient in No slip Condition

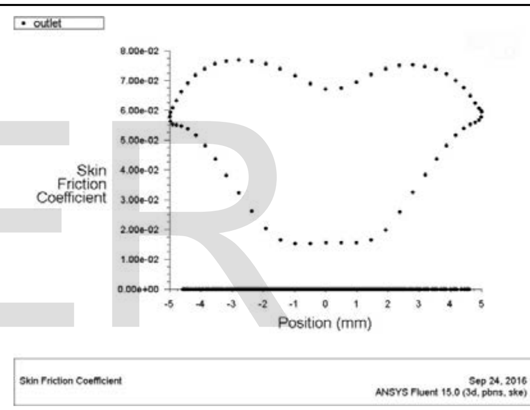

Fig 9: Skin Friction co-efficient in slip condition

It is being observes from the above graphs that there is a huge difference between the flow properties of Bingham fluid by taking fluid for both conditions slip and no slip. The shear stresses at wall is negligible or linear for no slip conditions, as In non-pulsatile flow through a straight vessel, fluid does not move with the constant velocity at every point in the vessel. Instead, fluid flow is fast at the centre and close to the wall it is slow. The fluid velocities acquire a parabolic profile termed to as the "laminar flow" profile. This form of flow is the result of friction inside the fluid and between the fluid and the wall of the vessel, and is related to the fluid viscosity. A tangential force exerted by the flowing fluid is created by this friction and is referred to as the "wall shear stress". The value of wall shear stress depends on how fast the fluid velocity increased when moving toward the centre of the vessel from the vessel wall.

Wall shear stress is defined as:

$$\tau_w = \mu \left[\frac{\partial u}{\partial y} \right]_{y=0}$$

Such variation is also seen in the skin friction coefficients as we can see that for slip flow of Bingham fluid in serpentine channel is negligible, it is taken as the local wall shear stress, is the fluid density and is the free-stream velocity (mostly taken outside of the boundary layer or at the inlet) .

5. CONCLUSION

In present work geometry of serpentine channel is analysed for different parameters in slip and no slip flow for same boundary conditions, Bingham fluid is used as a working fluid, and it is observed that the variation in parameters for slip and no slip condition for same geometry is very much alike, graphs for no slip condition is linear. A Bingham Plastic is a viscoplastic fluid which behaves as a rigid body in low stresses while flow as a viscous fluid at a high stress, Bingham fluid is a type of Non-Newtonian fluid that have a yield strength which should be exceeded before the fluid will flow. The study of curved tube is very much essential in the industries working with heat exchanger, heat engines for their efficient use.

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