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Numerical Simulation of Non-Newtonian Fluid in Horizontal pipe by using MATLAB program

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Abstract: Numerical simulation of Non-Newtonian fluid in horizontal pipe are investigations by computer simulation. The derivation of the principal equations of fluid dynamics is based on the fact that the dynamical behavior of a fluid is determined by the following conservation laws, namely: the conservation of mass, the conservation of momentum, and the conservation of energy. The momentum equations are derived by applying Newton's second law of motion to a small path of fluid. We estimate the velocity distribution through the pipe by solution the finite difference equation by using Matlab program.

Key words: Non-Newtonian, Finite difference, Horizontal Pipe and Matlab programe.

1- Introduction

In the substance and methodology commercial enterprises, it is regularly needed to pump fluids over long separations from capacity to different preparing units and/or starting with one plant site then onto the next. There may be a generous frictional weight misfortune in both the funnel line and in the individual units themselves. It is hence regularly important to consider the issues of ascertaining the force prerequisites for pumping through a given channel arrange, the choice of ideal funnel measurement, estimation and control of flow rate, and so on. An information of these components additionally encourages the ideal outline and design of flow systems which may speak to a significant piece of the aggregate plant expense (Chhabra & Richardson, 2008).

Exceedingly gooey liquids oblige much vitality to stream in pipelines and preparing supplies. Nonetheless, for a non-Newtonian liquid with shear diminishing attributes, producing extra shear in the liquid can prompt huge decreases in its thickness, hence encouraging its stream. This extra shear can be created by method for mechanical shaking. In fact, mechanical swaying toward stream has been indicated to offer climb to a critical upgrade in the stream of gooey non Newtonian liquids. This marvel has been abused for a long time, for instance, in the building and confectionery commercial enterprises yet predominantly on an exact premise. Considering the hugeness of this sensation, the information accessible in the writing on the stream improving impacts of vibration are exceptionally constrained. The accessible studies here have been constrained to restricted scopes of vibration conditions and rheological practices. No information have been accounted for in the writing identifying with vibration modes other than longitudinal (toward stream) and transversal (ordinary to the heading of stream).

Mechanical vibration has an alternate guaranteeing potential. In the nonstop warm handling of thick liquids, where the liquid is warmed through the channel divider, the speed circulation over the funnel brings about a wide temperature dissemination. This thus brings about noteworthy neighborhood varieties in the warm treatment got by the item, which may have unfriendly consequences for the item quality. To keep away from or minimize such impacts, it is crucial to guarantee that all parts of the liquid get an equivalent high temperature treatment by inciting some level of liquid blending. This is particularly critical in the nourishment and pharmaceutical commercial enterprises, where noteworthy varieties in the warm treatment got by the liquid may influence its sterility or quality. Liquid blending can be attained to utilizing turbulent stream, yet the high thickness of the liquids included makes this an unrealistic alternative. In-line static blenders can likewise be utilized to actuate spiral blending, however their many-sided geometries make them hard to clean, and where cleanliness is of the embodiment as in nourishment and pharmaceutical generation, the danger of pollution denies the utilization of such gadgets. In such cases, mechanical vibration appears a more suitable strategy. The profits of vibration in this connection don't seem to have been considered in the recent past. The investigation of these streams is convoluted by the shaky nature of the stream and the temperature-subordinate rheological properties of the liquids included.

The issue is considerably further confused when coarse robust particles are added to the liquid. The huge size of the robust particles implies that the streamlining suspicion of a homogeneous mixture utilized for fine molecule suspensions is obviously inapplicable, and in this manner the mixture can't be displayed as a solitary stage.

Non-Newtonian streams are normally unpredictable obliging much pumping vitality to drive the liquid through pipelines and transforming gear, so that different methods for encouraging their stream and handling have been looked for throughout the years. Barnes et al. (1971) watched that the time-arrived at the midpoint of volumetric stream rate could be expanded when a polymer arrangement is subjected to a throbbing weight angle in the pivotal heading. The watched increment in stream rate appeared to require less vitality to keep up than the comparing relentless state stream, hence making the procedure financially invaluable. Their hypothetical examination, based on an Oldroyd rheological model for the liquid and a bother plot as far as the sufficiency and the superimposed sinusoidal weight slope, reasoned that: (i) the liquid must be shear diminishing with a specific end goal to show any stream upgrade; and (ii) the improvement in stream lessens with expanding throb recurrence. Later, Sundstrom and Kaufman (1977), through numerical work utilizing an Ellis rheological model, found that the additional force needed in throbbing the stream was constantly positive and accordingly there was no financial focal point in throbbing the stream, a conclusion along these lines affirmed by Phan-Thien and Dudek (1982) utilizing a force law rheological model.

Benhamou et al. (2001) conveyed out a numerical study on the laminar stream of a Newtonian liquid inside an even pipe subjected to sinusoidal motions around the vertical breadth at the funnel door. The representing mathematical statements were illuminated numerically utilizing a control volume strategy and the shift in weather conditions terms were discretised utilizing an upwind contrast plan. The enduring state arrangement, which served as the beginning condition for the vibrated stream reproduction, and the vibrated stream arrangement were approved utilizing diagnostic and test results from the writing. The numerical results, acquired for a funnel Reynolds number Re = 1000, demonstrated the time development of an optional stream that happened in the transversal bearing. This stream was a auxiliary stream that happened in the transversal heading. This stream was described by a couple of counter-turning vortices, the force of which shifted with time and pivotal separation, and which affected the hub stream. The speed profile in the hub bearing was gotten at distinctive time interims amid the first wavering cycle and was discovered to be mutilate.

2- The theory

For a non-Newtonian fluid flowing in a pipe in laminar flow, the flow rate and velocity profile can both be obtained theoretically. The steady volumetric flow rate, Q, of a Herschel-Bulkley fluid in laminar flow driven by a constant pressure gradient, Δp/L, can be calculated from the following exact expression (Borghesani, 1988):

$$Q = \frac{\pi R^3 n}{\tau_w}\left[\frac{\tau_w - \tau_o}{K}\right]^{1/n}[\tau_w - \tau_o]\left\{\frac{(\tau_w - \tau_o)^2}{3n+1} + \frac{2\tau_o(\tau_w - \tau_o)}{2n+1} + \frac{\tau_o{}^2}{n+1}\right\} - - - - - (1)$$

Where R is the pipe radius, and τ_w is the wall shear stress,given by

$$\tau_w = \frac{R\Delta P}{2R}$$

For flow driven purely by gravity, the pressure gradient Δp/L is equal to gL, where gis gravitational acceleration.

For a power law fluid with τ_w=0, Equation (1) reduces to the followingexpression

$$Q = \frac{\pi R^3 n}{(3n+1)}\left[\frac{R\Delta P}{2KL}\right]^{1/n} - - - - - (2)$$

It reduces to the Buckingham-Reiner equation for a Bingham plastic fluid with k=μ_B
and n= 1, thus:

$$Q = \frac{\pi R^3}{\tau_w}\left[\frac{\tau_w - \tau_o}{\mu_B}\right]^{1/n}[\tau_w - \tau_o]\left\{\frac{(\tau_w - \tau_o)^2}{4} + \frac{2\tau_o(\tau_w - \tau_o)}{3} + \frac{\tau_o{}^2}{2}\right\} - - - - - (3)$$

And it reduces to the Poiseuille equation for a Newtonian fluid with $\tau_w=0$, K=μand n = 1, thus:

$$Q = \frac{\pi R^4 \Delta P}{8\mu L} ------(4)$$

It can be shown that the velocity distribution of a power law fluid is given as afunction of radial position, r, by the expression (Chhabra and Richardson, 1999)

$$u(r) = [\frac{\Delta P}{2KL}]^{1/n}(\frac{n}{1+n})[R^{\frac{n+1}{n}} - r^{\frac{n+1}{n}}] ------(5)$$

For a Bingham plastic fluid, the velocity profile outside the plug region is given by

$$u(r) = [\frac{\Delta P}{L}](\frac{R^2 - r^2}{4\mu_B}) - [\frac{\tau_0}{\mu_0}(R-r)] ----- for[r \geq R_P] ------(6)$$

WhereR$_p$ is the radius of the plug region and can be calculated from

$$R_P = \frac{2L\tau_0}{\Delta P}$$

The velocity of the plug region is given by

$$u(r) = [\frac{\Delta P}{L}](\frac{R^2}{4\mu_B}) - [1 - \frac{R_P}{R}]^2 ------(7)$$

And for a Herschel-Bulkley fluid, the velocity profile is given by

$$u(r) = [\frac{nR}{n+1}](\frac{\tau_w}{K})^{1/n}\{(1-\phi)^{\frac{n+1}{n}} - (\frac{r}{R} - \phi)^{\frac{n+1}{n}}\} ------------(8)$$

Where ϕ is the ratio of yield stress to wall shear stress, i.e. τ_0 / τ_w

The Reynolds number of a Newtonian fluid is given in terms of the effective viscosityof the fluid,μ_{eff}, thus

$$R_e = \frac{\rho \bar{U} D}{\mu_{eff}}$$

where

$\bar{U}$ is the mean flow velocity, and D is the pipe diameter. For a non-Newtonian fluid, the effective viscosity is given by (Chhabra and Richardson, 1999)

$$\mu_{eff} = m'[\frac{8\bar{U}}{D}]^{n'-1}$$

For a power law fluid,

$$\bar{U} = K[\frac{3n+1}{4n}]^n$$

and (n= n')
For a Bingham plastic fluid,

$$n' = \frac{1 - \frac{4}{3}\phi + \frac{\varphi^4}{3}}{1 - \varphi^4}$$

And

$$m' = \tau_w \left[\frac{\mu_B}{\tau_w \left(1 - \frac{4}{3}\phi + \frac{\varphi^4}{3}\right)} \right]$$

3- Mathematical Model and Results

The scientific comparisons used to depict the stream of liquids are the congruity and energy mathematical statements, which portray the protection of mass and force, separately. The energy comparisons are additionally knowin as the Navier-Stokes mathematical statements. For streams including hotness exchange, an alternate set of mathematical statements is obliged to portray the preservation of vitality. The coherence comparison is determined by applying the standard of mass protection to a little fix of liquid. In Cartesian coordinates, three mathematical statements of the accompanying structure are acquired (Abbott and Basco, 1989).

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \text{ ------ } (9)$$

where ρ is liquid thickness, t is time, u is speed, and x is the direction. The subscript i shows the Cartesian coordinates and the separate speed parts. The energy mathematical statements are determined by applying Newton's second law of movement to a little fix of liquid. As per Newton's second law, the rate of progress of energy for a patch of liquid is equivalent to the entirety of all outside powers following up on this patch of liquid. The ensuing energy mathematical statements in Cartesian directions take the general structure (Abbott and Basco, 1989).

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_j u_i) = -\frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_i} + \frac{\partial u_j}{\partial x_j}\right)\right] \text{ ------ } (10)$$

where P is weight and μ is liquid consistency. Note that for a Newtonian liquid, the thickness is consistent, while for a non-Newtonian liquid, the shear rate-reliance of consistency is considered utilizing a constitutive mathematical statement for consistency. The principal term on the left hand side of the above mathematical statement speaks to the fleeting variety of energy, while the second term is the liquid quickening. The powers on the right hand side speak to the ordinary burdens (i.e. the weight inclination energy) and the tangential shear stresses (i.e. the thick constrain). Different strengths, for example, gravity, can be added to the mathematical statements as obliged utilizing a source term. The administering comparisons demonstrated above are fractional differential mathematical statements (Pdes). Since advanced machines can just perceive and control numerical information, these comparisons can't be comprehended straightforwardly. The significant strategies utilized for mathematical statement (10) are the limited contrast technique, the limited component strategy, the limited volume system and arrangement by utilizing Matlab program.

$$\frac{\partial}{\partial t}(\rho u \ \ ) = \left[\mu\left(\frac{\partial^2 u}{\partial x^2}\right)\right] \text{ ------ } (11)$$

$$\frac{\partial^2 u}{\partial x^2} = \frac{\rho}{\mu}\left[\frac{\partial u}{\partial t}\right] \text{ ----- } (12)$$

$$\frac{\partial^2 u}{\partial x^2} = k\left[\frac{\partial u}{\partial t}\right] \text{ ----- } (13)$$

We have an explicit method if the time derivative is approximated by a forward difference and the second spatial derivative is approximated by a central difference:

$$\frac{\partial u}{\partial t} = \frac{u_i^{n+1} - u_i^n}{\Delta t} \text{ -------- } (14)$$

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$$\frac{\partial^2 u}{\partial x^2} = \frac{u_{i+1}^n - 2u_i^n + u_{i-1}^n}{\Delta x^2} \text{ -------- (15)}$$

In finite difference form, the heat conduction equation becomes

$$\frac{u_i^{n+1} - u_i^n}{\Delta t} = k \frac{u_{i+1}^n - 2u_i^n + u_{i-1}^n}{\Delta x^2} \text{ -------- (16)}$$

The explicit scheme is depicted in Figure 1 where three nodes in the previous time t^n are required to compute the node at the present time t^{n+1}.

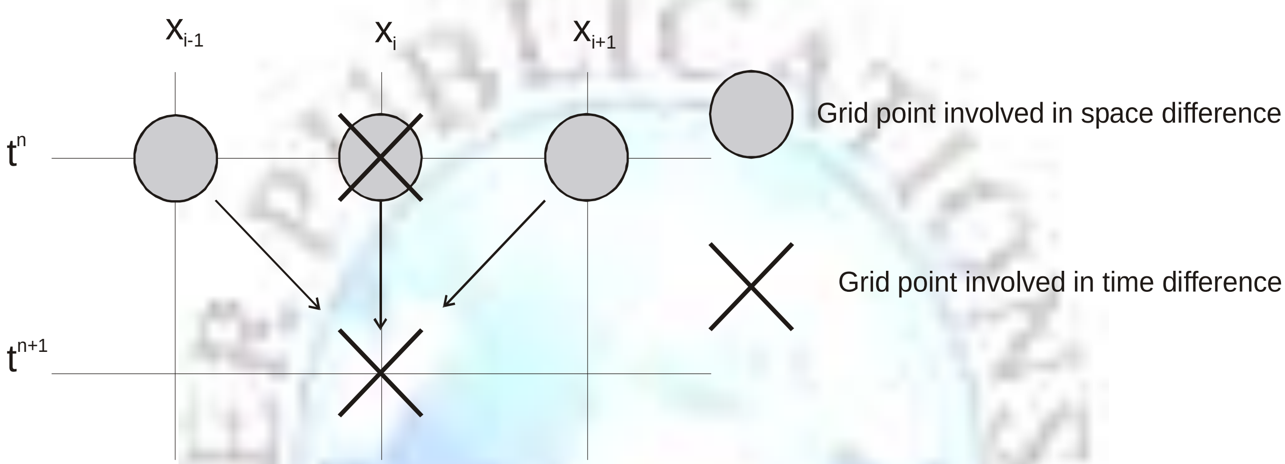

Figure 1: A computational diagram for the explicit method.

The Velocity at node i can be obtained from the three previous time nodes as

$$u_i^{n+1} = \frac{k\Delta t}{(\Delta x)^2}(u_{i+1}^n + u_{i-1}^n) + \left(1 - 2\frac{k\Delta t}{(\Delta x)^2}\right) u_i^n \text{ -------- (17)}$$

A solution is stable when the errors at any stage of the computation are not amplified but are attenuated as the computation progresses. For stable solution

$$\left(1 - 2\frac{k\Delta t}{(\Delta x)^2}\right) \geq 0 \quad \Rightarrow \quad \frac{k\Delta t}{(\Delta x)^2} \leq \frac{1}{2}$$

Where :$k = \frac{\rho}{\mu}$

And $\mu = m'[\frac{8\overline{U}}{D}]^{n'-1}$ (Chhabra and Richardson, 1999)

The results of solution equation (17) as shown in figure (2), the shown in this figure the velocity distribution in horizontal pipe .

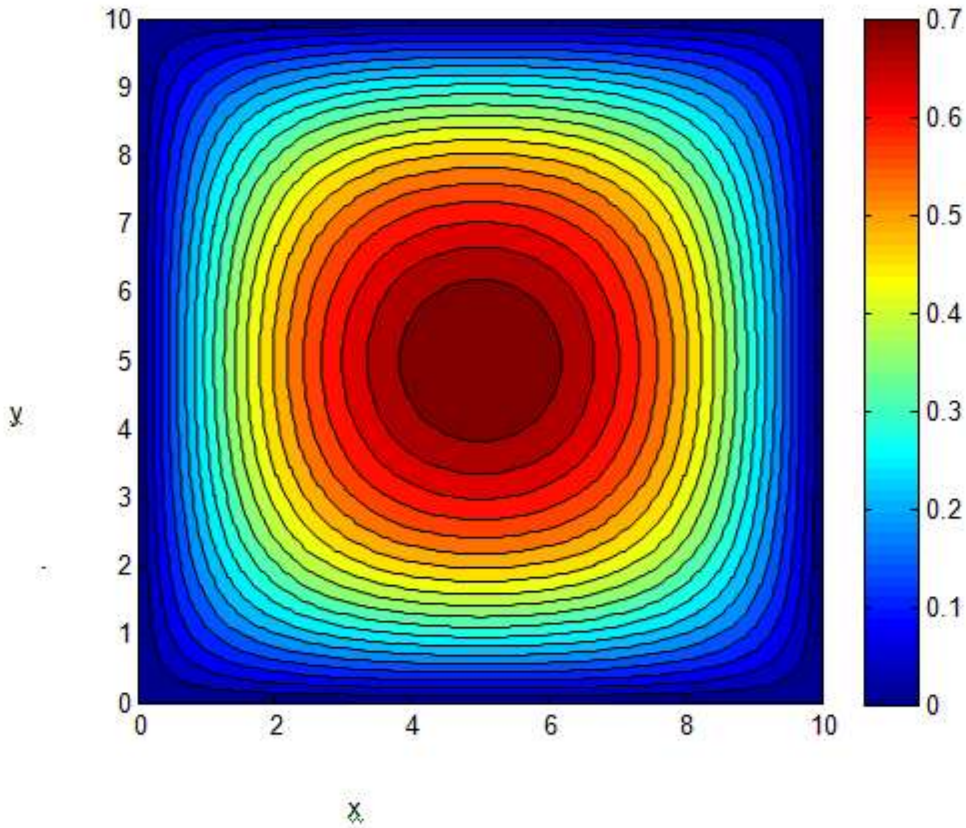

Figure (2): Two dimensional velocity profile in horizontal pipe.

Conclusion

In this paper we have been focused in the use of numerical techniques to solve the flow problem of flow of non-Newtonian fluids, whose viscosity is described by the GNM. The momentum equations are derived by applying Newton's second law of motion to a small path of fluid. We estimate the velocity distribution through the pipe by solution the finite difference equation by using Matlab program.

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