A Study of Non – Newtonian Fluid Flow and Constricted Tubes in Circular Tubes

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Abstract

A non-Newtonian fluid is a fluid that doesn't keep Newton's law of viscosity, i.e., constant viscosity autonomous of stress. In non-Newtonian fluids, viscosity can change when under force to either more fluid or stronger. Ketchup, for instance, becomes runnier when shaken and is along these lines a non-Newtonian fluid. Many salt solutions and liquid polymers are non-Newtonian fluids, as are many commonly discovered substances like custard toothpaste, starch suspensions, corn starch, paint, blood, liquefied spread, and cleanser. The mathematical analysis of non-Newtonian fluid flows through constricted tubes in various conditions has been investigated in this study. As a result, the flow problems have been linearized, and equations for flow resistance and shear stress on the wall have been derived. The flow resistance of micropolar fluid increases with stenosis height and coupling number and decreases with micropolar fluid parameter, stenotic dilatation, and tube length. We have taken a steady and laminar flow of Newtonian and non-Newtonian fluids, Here Navier-Stokes's equations is used in the formulation of the model. The Newtonian and non-Newtonian fluids were examined in the effects of porous medium. The experimental data were compared with theoretical predictions. Aforesaid flow quantities are significantly higher for flow in tubes with variable permeability than for flow in tubes with constant permeability.

Keywords: *Non – Newtonian Fluid Flow, Constricted Tubes, Circular Tubes, Newtonian fluids, mathematical analysis.*

1. INTRODUCTION

The investigation of flow through tightened channels is significant for a comprehension of the as well as for the plan of prosthetic blood vessels. Limited narrowing in a blood vessel is normally alluded to as a stenosis. This vascular infection is of as often as possible happen, specific in mammalian veins. The intimal thickening of stenotic corridor was perceived as an early cycle in the start of atherosclerosis. In this examination, pressure drop, pressure slope and motion were estimated in unbending walled model of tightened joins under consistent flow conditions. Both Newtonian and non-Newtonian liquids were inspected and the exploratory information were contrasted and hypothetical forecasts pressure drop flow rate information were gotten in each of the four test segments for both Newtonian and non-Newtonian flow. Worked on exploratory examinations on the blood flow all through tightened tubes. gave a thought pressure advancement in a non-Newtonian flow through a tightened tube, while examined about blood flow in tightened tubes. Chipped away at mathematical investigation of throbbing flow through a tightened course with stenosis. Examined about a flimsy investigation of non-Newtonian blood flow through tightened courses with a stenosis. chipped away at the mathematical investigation of the axisymmetric blood flow in a choked unbending tube, while researched a non-direct numerical model for blood flow through tightened tubes.

Most low atomic weight substances like natural and inorganic fluids, arrangements of low sub-atomic weight inorganic salts, liquid metals and salts, and gases show Newtonian flow attributes, i.e., at consistent temperature and pressing factor, in basic shear, the shear stress(σ) is relative to the pace of shear ($\dot{\gamma}$) and the steady of proportionality is the recognizable powerful thickness (η). Such liquids are traditionally known as the Newtonian liquids, yet the thought of flow and of thickness originates before Newton. For most fluids, the consistency diminishes with temperature and increments with pressure. For gases, it increments with both temperature and pressing factor. Comprehensively, higher is the consistency of a substance, more opposition it presents to flow (and subsequently harder to siphon!). Table 1 gives average upsides of thickness to scores of normal liquids. As we go down in the table, the thickness increments by a few significant degrees, and in this manner one can contend that a strong can be treated as a liquid whose consistency tends towards limitlessness, $\eta \rightarrow \infty$. In this way, the qualification between a liquid and a strong isn't just about as sharp as we might want to think! Since the time the plan of the conditions of congruity (mass) and energy (Cauchy, Navier-Stirs up), the liquid elements of Newtonian liquids has made considerable progress during the previous 300 or somewhere in the vicinity years, yet huge difficulties particularly in the field of disturbance and multi-stage flows actually remain.

Infections in the blood vessels and in the heart, for example, coronary episode and stroke, are the significant reasons for mortality around the world. The hidden reason for these occasions is the development of injuries, known as atherosclerosis, in the enormous and mediumsized corridors in the human course. Atherosclerosis is a vascular pathology that has become a conspicuous illness in Western culture. The term comes from the Greek words athero (slop or glue) and sclerosis (hardness), and the issue is portrayed by reformist narrowing and impediment of blood vessels. At the point when greasy substances, cholesterol, cell side-effects, calcium, and fibrin develop in the inward covering of a supply route, this causes a narrowing of the lumen of the vessel and furthermore an increment in the divider firmness or a lessening in consistence of the vessel. The development that outcomes is called plaque. Some degree of solidifying of the veins and narrowing is an ordinary aftereffect of maturing. In the long run, the plaque can impede a course and confine flow through that vessel, bringing about a coronary failure if the vessel being obstructed is one that provisions blood to the heart. Atherosclerosis can likewise create blood clump development, here and there bringing about a stroke. At the point when a piece of plaque splits from the blood vessel divider and flows downstream, it can likewise become held up in more modest vessels and square flow, additionally bringing about the arrangement of apoplexy which cause stroke. Atherosclerosis normally influences medium sized or huge corridors. The normal component in the area for the improvement of the sore is the presence of ebb and flow, spreading, and bifurcation present in these locales. The liquid elements at these locales can be expected to be immensely not the same as different fragments of the corridors that are moderately straight and without any fanning sections. As referenced above, atherosclerosis happens when the idea of blood flow changes from its standard state to an upset flow condition because of the presence of a stenosis in a corridor. The commencement and improvement of atherosclerotic plaques is portrayed in Figure 1.1. A few analysts have examined the flow of blood in stenosed supply route by thinking about it as a Newtonian liquid. It is notable that blood, at low shear rates and during its flow through slender blood vessels, acts like a non-newtonian liquid. In spite of the fact that there are many models to depict non-Newtonian conduct of the liquids, the micropolar liquid presented has an uncommon significance, as it displays some tiny impacts emerging from the neighborhood structure and miniature movement of the liquid components. Further, they can two or three anxieties. The model of miniature polar liquid addresses liquids comprising of inflexible haphazardly situated (or circular) particles suspended in a gooey medium where the deformity of the particles is disregarded. The liquids containing certain added substances, some polymeric liquids and creature blood are models.

2. REVIEW OF LITERATURE

Anil Kumar (2014) study the impact of permeable medium on a Newtonian and non-Newtonian flow through tapered tubes. In this paper, we have taken a steady and laminar flow of Newtonian and non-Newtonian liquids; Here Navier-Stokes' conditions are utilized in the plan of the model. The Newtonian and non-Newtonian liquids were inspected in the impacts of permeable medium. The exploratory information was contrasted and theoretical predictions. Aforesaid flow quantities are essentially higher for flow in tubes with variable porousness than for flow in tubes with steady penetrability. The current work is approved from the recently distributed writing.

Ramesh Kumar Karthick (2016) the impact of non-Newtonian behavior of the fluid and catheterization on flow characteristics were examined. Examined the attractions and infusion consequences for pulsatile motion of hydromagnetic fluid between two permeable beds for both steady and unsteady parts and impact of magnetic field on the peristaltic motion of Jeffrey fluid Mathematical model for pulsatile nature of non-Newtonian fluid flow in arteries with stenosis was introduced. Unsteady Jeffrey fluid flow through elastic tube with stenosis was examined. A detailed analysis of MHD pulsating flow through permeable channel was investigated the impact of thermal dissemination and chemical reaction on fluid flow under the assumptions of slip and convective boundary conditions. As of late, pulsatile flow in a narrow artery and its applications to blood flow model was introduced. we consider the study of impact of applied magnetic field on pulsating Jeffrey fluid flow through a permeable elastic container of varying cross segment.

Arun Kumar Maiti (2017) an attempt has been made to study the job of arterial stenosis on blood flow in presence of slip velocity. In the current analysis Herschel-Bulkley fluid addresses the non-Newtonian character of blood. The hemodynamic behavior of blood flow is impacted by the presence of arterial stenosis. The articulations for velocity profile, pressure drop and shear stress have been investigated here. The outcomes are displayed in graphical structure.

M Kamran Alam (2015) The goal of this research is to investigate the behaviors of porosity and squeezing phenomena in the presence of time-subordinate heat flow that affect the flow rate and work on the framework's heating/cooling mechanism, lessen non-Newtonian fluid choppiness and scale-up flow tracers. Squeezing circles in the presence of no-slip velocity and convective surface boundary conditions induces a laminar, unstable and incompressible non-Newtonian fluid. The convective type of the force, concentration and energy equations are modeled for smooth circles to evaluate and offer an analytical and numerical examination of the flow for heat and mass transfer, which are further transformed to a profoundly non-linear arrangement of ordinary differential equation using similarity transformations.

Kazi Shafi Sami (2010) The swirling blood flow in cardiovascular framework has both gainful and hindering consequences for hemodynamic parameters. A mathematical examination has been acted in a model stenosed course to dissect the impacts of swirling in non-Newtonian pulsatile blood flow through blood vessel stenosis. The standard k-ω violent model is utilized for the reenactment of pulsatile blood flow with swirling. In this examination, the Reynolds number differs from 200 to 1000. The divider shear pressure, hydrostatic pressing factor and centreline speed designs at various time steps are gotten to contrast the swirling impact and no whirl condition. Divider shear pressure and hydrostatic pressing factor are not influenced by swirling. The smooth out shapes show that swirling causes significant variety in speed conveyance.

3. FLUID FLOW?

Fluid Flow is a piece of fluid mechanics and manages fluid dynamics. It includes the movement of a fluid exposed to unequal powers. This movement proceeds insofar as unequal powers are applied. For instance, in case you are pouring water from a mug, the speed of water is extremely high over the lip, modestly high moving toward the lip, and exceptionally low at the lower part of the mug. The unequal power is gravity, and the flow proceeds as long as the water is accessible and the mug is shifted.

Types of Fluids

- **Ideal fluid**

A fluid is supposed to be ideal when it can't be packed and the consistency doesn't fall in the classification of an optimal fluid. It is a nonexistent fluid which doesn't exist actually.

- **Real fluid**

Every one of the fluids is genuine as all the fluid possess viscosity.

- **Newtonian fluid**

At the point when the fluid obeys Newton's law of viscosity, it is known as a Newtonian fluid.

- **Non-Newtonian fluid**

At the point when the fluid doesn't submit to Newton's law of viscosity, it is known as non-Newtonian fluid.

- **Ideal plastic fluid**

At the point when the shear pressure is proportional to the velocity inclination and shear pressure is more than the yield esteem, it is known as ideal plastic fluid.

- **Incompressible fluid**

At the point when the thickness of the fluid doesn't change with the use of outer power, it is known as an incompressible fluid.

- **Compressible fluid**

At the point when the thickness of the fluid changes with the use of outer power, it is known as compressible fluid.

Table 1 Density and viscosity of different types of fluids

Types of fluid	**Density**	**Viscosity**
Ideal fluid	Constant	Zero
Real fluid	Variable	Non-zero
Newtonian fluid	Constant/ Variable	T=u(dudy)
Non-Newtonian fluid	Constant/ Variable	T≠u(dudy)
Incompressible fluid	Constant	Non-zero/ zero
Compressible fluid	Variable	Non-zero/ zero
Types of fluid	Density	Viscosity

Interested to learn more about other concepts related to fluid, below are the links:

1. Fluid Dynamics
2. Properties of Fluids
3. Fluid Pressure – Hydrostatic Pressure

Classification of flows on the basis of Mach number

- Incompressible flow has M<0.3.
- Compressible subsonic flow has M between 0.3 to 1.

The different types of fluid flow are represented in the graph below

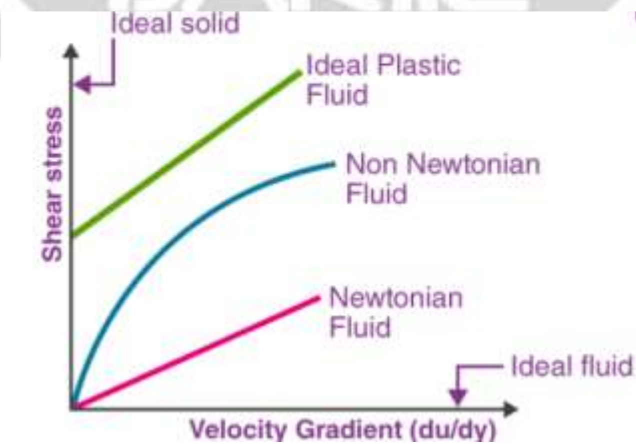

Figure 1 Velocity Gradients and Shear Stress

4. TYPES OF FLUID FLOW

Fluid flow has a wide range of viewpoints — consistent or unstable, compressible or incompressible, viscous or non-viscous, and rotational or irrotational, to give some examples. A portion of these qualities mirror the properties of the actual fluid, and others center on how the fluid is moving.

1. Steady or Unsteady Flow

Fluid flow can be steady or unsteady, depending on the fluid's velocity:

- **Steady:** In consistent fluid flow, the velocity of the fluid is steady anytime.

1. **Unsteady:** At the point when the flow is flimsy, the fluid's velocity can vary between any two focuses.
2. **Viscous or Non-viscous Flow** Liquid flow can be viscous or non-viscous.
3. **Viscosity** is a proportion of the thickness of a fluid, and very gloppy fluids, for example, motor oil or cleanser are called viscous fluids**.**
4. **Fluid Flow Equation** Mass flow rate is the rate of development of a massive fluid through a unit region. In basic words it is the development of mass per unit time.

The formula for mass flow rate is given as follows:

$$Mass\ flow\ rate = \rho\ A\ V$$ (

From the equation, we can see that mass flow rate depends on the density, velocity and the space of cross-section of the fluid.

Solved Example

A fluid moves through a tube of 15 m/s, the tube has a transverse area of 0.4 m^2. If the density of the fluid is ρ = 1.5 grams/m^3, what is the measure of mass flowing through the tube?

To figure the total mass of fluid flowing through the tube, we use

Mass flow rate =ρAV

Substituting the values in the above equation,

we get

Mass flow rate=1.5×15×0.4=9g/s

2. Fluid Flow through a Pipe

The general capacity of the pipes varies on its size.

Table 2 Capacity of the flow of fluid based on its size

pe size (in inch)	Maximum Flow (in gal/min)	Velocity (in ft/s)	Head Loss in (ft / 100 ft)
2	45	4.3	3.9
2.5	75	5.0	4.1
3	130	5.6	3.9
4	260	6.6	4.0
6	800	8.9	4.0
8	1600	10.3	3.8
10	3000	12.2	4.0
14	6000	14.2	4.0
16	8000	14.5	3.5
18	10000	14.3	3.0
20	12000	13.8	2.4
24	18000	14.4	2.1

5. NEWTONIAN FLUID

A non-Newtonian fluid is one that has non-linearity between shear stress and rate of shear strain. This category usually includes thick liquids. Paints, enamels, pastes, jellies, varnish, emulsions of oil in water, and particle suspension are examples. Non-Newtonian fluids are generally well described by a rheological model that yields a correla A Non-Newtonian fluid requires more than a single constitutive equation in real-world applications, which has led to the development of various constitutive models in past studies. Some non-Newtonian fluids, such as power-law fluids and Bingham plastic fluids, can have completely viscous properties. These fluids are not affected by their previous history. Some non-Newtonian fluids are reliant on non-Newtonian fluids.

The simplest possible deviation from the Newtonian fluid behavior occurs when the simple shear data □□˙ does not pass through the origin and/ or does not result into a linear relationship between □ and □˙. Conversely, the apparent viscosity, de- fined as □/□˙, is not constant and is a function of □ or □˙. in reality, under fitting conditions, the apparent viscosity of certain materials isn't only an element of flow conditions (math, speed of shear, etc), yet it moreover depends upon the kinematic history of the fluid element suitable. It is useful, anyway emotional (and apparently casual also), to gathering such materials into the going with three classes: Systems for which the value of □˙ at a point within the fluid is determined only by the current value of □ at that point; these substances are variously known as *purely viscous, inelastic, time-independent* or *generalized Newtonian fluids (GNF)*;\

1) Systems for which the relation between shows further dependence on the duration of shearing and kinematic history; these are called time-dependent fluids, and finally,

2) Systems which exhibit a blend of viscous fluid behavior and of elastic solid-like behaviour. For instance, this class of materials shows partial elastic recovery, recoil, creep, etc. Accordingly, these are called visco-elastic or elastico-viscous fluids.

As noted before, the previously mentioned order conspire is very discretionary, however advantageous, on the grounds that most genuine materials often show a mix of two or even this load of kinds of elements under proper conditions. For example, it isn't remarkable for a polymer liquefy to show time-free (shear-diminishing) and visco-flexible conduct all the while and for a china mud suspension to exhibit a mix of time-autonomous (shear-diminishing or shear-thickening) and time-subordinate (thixotropic) highlights at certain fixations and/or at appropriate shear rates. For the most part, it is, be that as it may, conceivable to recognize the prevailing non-Newtonian angle and to utilize it as reason for the ensuing interaction estimations. Each sort of non-Newtonian fluid conduct is currently managed in more detail.

6. CONCLUSION

The blood flow problems in the stenotic regions were analyzed and created various mathematical models. The effects of overlapping stenosis, stenosis and post-stenotic dilatation and electrically conducting fluid on multiple stenoses were discussed in blood flow through arteries by considering blood as a non-Newtonian fluid. In the study the non-Newtonian fluids are considered as Herschel-Bulkley fluid, Micropolar fluid and Jeffrey fluid. It deals with the effects of non-Newtonian fluids through an overlapping stenosis. The flow equations were linearised for gentle stenosis and the equations are obtained for velocity, flow resistance and shear stress on wall to interpret the results. The conclusions for the Herschel-Bulkley fluid through an overlapping stenosis and also for an inclined tube having uniform cross section are given underneath:

- The flow resistance ($\bar{\lambda}$) increases with respect to stenosis height (δ), length of the stenosis, stress ratio parameter (r), i.e the ratio between the yield stress and wall shear stress $\left(\frac{\tau_\circ}{\tau_h} = \tau\right)$power law index, yield stress ($\tau_\circ$) but decreases with the wall shear stress (r_h).
- The resistance of the Herschel-Bulkley fluid is higher than the Newtonian fluid because of yield stress.
- The flow resistance decreases with inclination (α).

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