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Newtonian Fluids in Piping System

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Abstract: ***A Newtonian fluid is defined as one with constant viscosity, with zero shear rate at zero shear stress, that is, the shear rate is directly proportional to the shear stress. From: Biomaterials, Artificial Organs and Tissue Engineering, 2005. 1 Such as water or oil, are characterized by a viscosity (i.e. the ratio between shear stress and shear rate) that is independent of shear rate. These fluids display a linear relation between shear stress and shear rate. In this study two different Newtonian fluid systems (water and water+50% Ethanol) were used with different physical properties. Friction and pressure losses were measured and compared at constant temperature 25^0 C (298K). Both solutions were homogenous.***

Keywords: Newtonian fluids, Density, Viscosity, piping system, friction and pressure losses

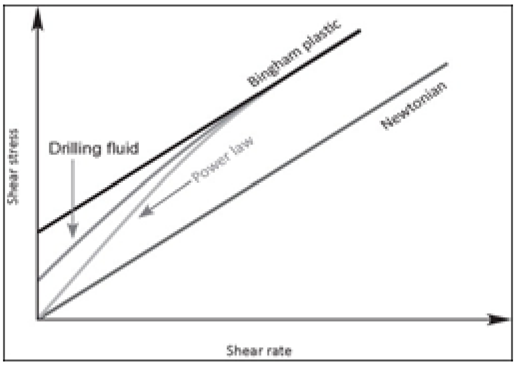
1. Theory

A Newtonian fluid is defined as one with constant viscosity, with zero shear rate at zero shear stress, that is, the shear rate is directly proportional to the shear stress. From: Biomaterials, Artificial Organs and Tissue Engineering, 2005. 1 Such as water or oil, are characterized by a viscosity (i.e. the ratio between shear stress and shear rate) that is independent of shear rate. These fluids display a linear relation between shear stress and shear rate.

The only parameter needed to describe the model is the slope of the shear stress–shear rate relationship (Figure 1). By definition, this slope corresponds to the Newtonian materials are characterized by a constant viscosity independent of shear rate. Newton's model is given by Eqn (1):

$$\tau=\eta\gamma \qquad (1)$$

Figure(1) Relation between shearτ = shear rate
Rate & Shear stressη = viscosity, (Pa·s).
γ = shear stress



Newtonian fluids as simple as water already present their own considerable challenges for micro-scale swimmers. At such a small scale, the characteristic Reynolds number *Re*, which represents the ratio between inertial and viscous forces, is lower than unity, thus inertia is negligible and time-reversibility applies (low-*Re* regime). This means that reciprocal motions, such as the opening and closing of a single-hinge mechanism, lead to no net displacement, no matter how fast or slow the different phases are (which is known as the *scallop theorem* [2]). In other words, small scale organisms and devices must perform complex non-reciprocal motions to effectively swim in Newtonian fluids. The main strategies adopted by microorganisms and cells to swim in such conditions rely on three different kinds of propellers and appendages.(1)

A Newtonian fluid is a fluid in which the viscous stresses arising from its flow, at every point, are linearly correlated to the local strain rate—the rate of change of its deformation over time that is equivalent to saying those forces are proportional to the rates of change of the fluid's velocity vector as one moves away from the point in question in various directions. (2, 3, 3)

Newtonian fluids are named after Isaac Newton, who first used the differential equation to postulate the relation between the shear strain rate and shear stress for such fluids. (2, 3 & 4)

Newtonian fluids are class of fluids which obeys Newton's law of viscosity. The ratio of shear stress to shear strain rate is a constant, for a given temperature and pressure, and is defined as the viscosity. for Newtonian fluid the viscosity is independent of the shear rate but for Non-Newtonian fluids viscosity is not constant and is dependent on the shear rate.

Fluid flow is highly dependent on the viscosity of fluids. At the same time for a non-Newtonian fluid, the viscosity is determined by the flow characteristics. Looking at Figure 3, you can observe three very different velocity profiles depending on the fluid behavior. For all these fluids, the shear rate at the walls (i.e. the slope of the velocity profile near the wall) is going to determine viscosity. Successful characterization of viscosity is key in determining if a fluid is Newtonian or non-Newtonian, and what range of shear rates needs to be considered for a specific application. Many viscometers on the market measure index viscosity but often lack proper characterization of shear rate and absolute or true viscosity. Absolute viscosity is one of the most important parameters in the development and modeling of applications that involve fluid flow. Therefore, proper characterization of viscosity must be carried out at a shear rate that is relevant to the specific process. Learn more about RheoSense viscometers and how they allow measurements of true viscosity over a wide range of shear rates. (5)

Newtonian fluid flow in a duct has been studied extensively, and velocity profiles for both laminar and turbulent flows can be found in countless references. Non-Newtonian fluids have also been studied extensively, however, but are not given the same attention in the Mechanical Engineering curriculum. Because of a perceived need for the study of such fluids, data were collected and analyzed for various common non-Newtonian fluids in order to make the topic more compelling for study. The viscosity and apparent viscosity of non-Newtonian fluids are both defined in this paper. A comparison is made between these fluids and Newtonian fluids. Velocity profiles for Newtonian and non-Newtonian fluid flow in a circular duct are described and sketched. Included are profiles for dilatant, pseudoplastic and Bingham fluids. Only laminar flow is considered, because the differences for turbulent flow are less distinct. Also included is a procedure for determining the laminar flow friction factor which allows for calculating pressure drop.

Viscosity data and how it is measured for several common non-Newtonian fluids; • A knowledge of velocity profiles for laminar flow in a circular duct for both Newtonian and non-Newtonian fluids (6).

Density is a measure of mass per volume. The average **density** of an object equals its total mass divided by its total volume. An object made from a comparatively dense material (such as iron) will have less volume than an object of equal mass made from some less dense substance (such as water). Density of water, ethanol and mixture of (water +30% ethanol and 50% ethanol) at 20^0 C is 0.998, 0.789 0.954 and 0.910 kg/m^3 (7)

$$\rho = \frac{m}{V} \quad (2)$$

ρ = density

m = mass

V = volume

Viscosity, resistance of a fluid (liquid or gas) to a change in shape, or movement of neighbouring portions relative to one another. **Viscosity** denotes opposition to flow. The reciprocal of the **viscosity** is called the fluidity, a measure of the ease of flow. Molasses, for example, has a greater viscosity than water (12).

Table 1: Physical properties of water and water +50% Ethanol mixture at 25^0C

Density kg/m^3 at 298k	0% ethanol 0.9987	50% ethanol 0.8529
μ x 10^3 pa.s	0.8529	2.0271
Surface tension103N/m	72.15	25.78

According to Newton's Law, shear stress is viscosity times shear rate. Therefore, the viscosity (eta) is shear stress divided by shear rate. Only Newtonian liquids can be described by this simple relation. Equation 3: Newton's Law reformulated: Dynamic viscosity is shear stress divided by shear rate.

Newtonian fluids described the flow behavior of fluids with a simple linear relation between shear stress [mPa] and shear rate [1/s]. This relationship is now known as Newton's Law of Viscosity, where the proportionality constant η is the viscosity [mPa-s] of the fluid:

$$\text{Shear stress} = \text{viscosity x shear rate} \quad (3)$$

Some examples of Newtonian fluids include water, organic solvents, and honey. For those fluids viscosity is only dependent on temperature. As a result, if we look at a plot of shear stress versus shear rate (See Figure 2) we can see a linear increase in stress with increasing shear rates, where the slope is given by the viscosity of the fluid. This means that the viscosity of Newtonian fluids will remain a constant (see Figure 3) no matter how fast they are forced to flow through a pipe or channel (i.e. viscosity is independent of the rate of shear).

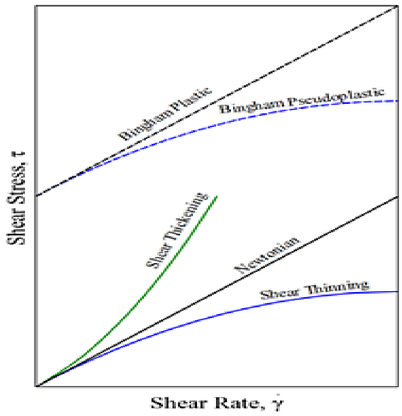


Figure 2: Shows relation between shear rate & shear stress for different fluids

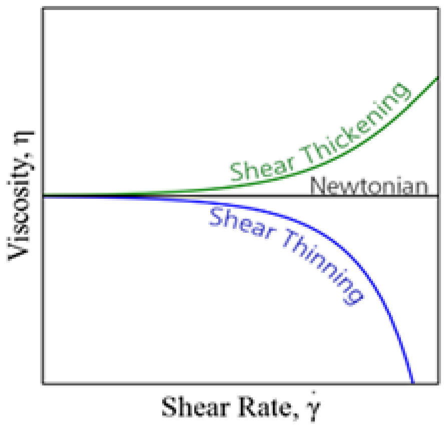


Figure 3: Shows relation between shear rate& viscosity for different fluids

Newtonian fluids are normally comprised of small isotropic (symmetric in shape and properties) molecules that are not oriented by flow. However, it is also possible to have Newtonian behavior with large anisotropic molecules. For example, low concentration protein or polymer solutions might display a constant viscosity regardless of shear rate. It is also possible for some samples to display Newtonian behavior at low shear rates with a plateau known as the zero shear viscosity region. (13)

Assuming steady-state, incompressible, and 1D flow, the energy equation becomes:

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} + gz_1 = \frac{p_2}{\rho} + \frac{V_2^2}{2} + gz_2 + \frac{p_{loss}}{\rho} \quad (4)$$

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where P loss is the pressure loss between sections 1 and 2, *V* is the average velocity, *z* is the elevation from a reference point, and is the density. Two main sources exist for pressure drop in pipelines

a) Friction loss and wall shear stress.
b) Minor loss, which is caused by changes in the geometry.

For fully-developed flow in channels frictional pressure drop can be calculated from Darcy-Weisbach equation:

$$p_{friction} = \rho f \frac{l}{d} \frac{V^2}{2} \qquad (5)$$

Where *f* is the friction factor, *d* and *l* are channel diameter and length, respectively. The friction factor is related to the flow regime. Reynolds number is a good criterion for prediction of flow regime[7]:

$$Re = \frac{\rho V d}{\mu} \qquad (6)$$

where □ is the viscosity of the fluid. For laminar flows where $Re<2300$, *f* is calculated as:

$$f = \frac{64}{Re} \qquad (7)$$

Inturbulent flows, i.e., $Re>2300$, *f* is a function of Reynolds number and pipe roughness, *k*. For hydraulically smooth pipes, $Re<65d/k$, and a Reynolds number in the range of $2320<Re<10^5$ the pipe friction coefficient is calculated using the Blasius formula:

$$f = \frac{0.3164}{\sqrt[4]{Re}} \qquad (8)$$

For rough pipes the pipe friction coefficient is read from Moody diagram or evaluated using Colebrook formula:

$$f = \left[2 \log\left(\frac{2.51}{Re\sqrt{f}} + \frac{0.27k}{d}\right)\right]^{-2} \qquad (9)$$

Special pipe components and fittings such as pipe bends or elbows, pipe branches, changes in cross- section, and valves alter flow geometry and produce additional pressure losses apart from the wall friction losses.(7)

2. Apparatus

Fig (4) shows the piping system which was installed and used in hydraulic lab and different pressure drops were measured in fittings, elbows and valves of 1" pipes with two different Newtonien fluid systems were used (water and a mixture of water + 50% ethanol).(7).

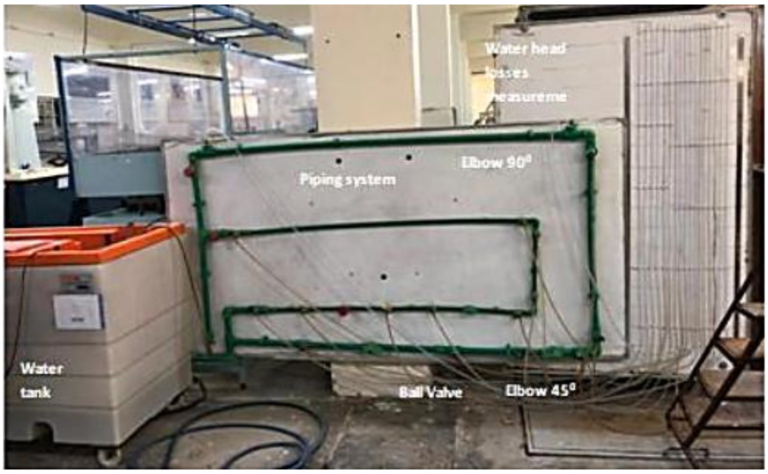

Figure 4: Apparatus used in the experiment

3. Procedure

1) Water was filled in the tank) at 25^0 C
2) Different flow rates were used by pump, head losses were measured for the different fittings and valves in attached board.
3) Same procedure was repeated using the (water + 50% Ethanol) mixture in the tank and head losses were measured.

4. Results & Discussion

1) Reynolds No. was measured in different flow rates for each system (water and water + 50% Ethanol) at 25^0 C.
2) Pressure losses were calculated for each 45^0 and 90^0 elbows for both systems
3) Comparison was made for both systems
4) It was found that physical properties like density, viscosity and surface tension effect on the friction and pressure losses at constant temperature as shown in figures (5 and 6).

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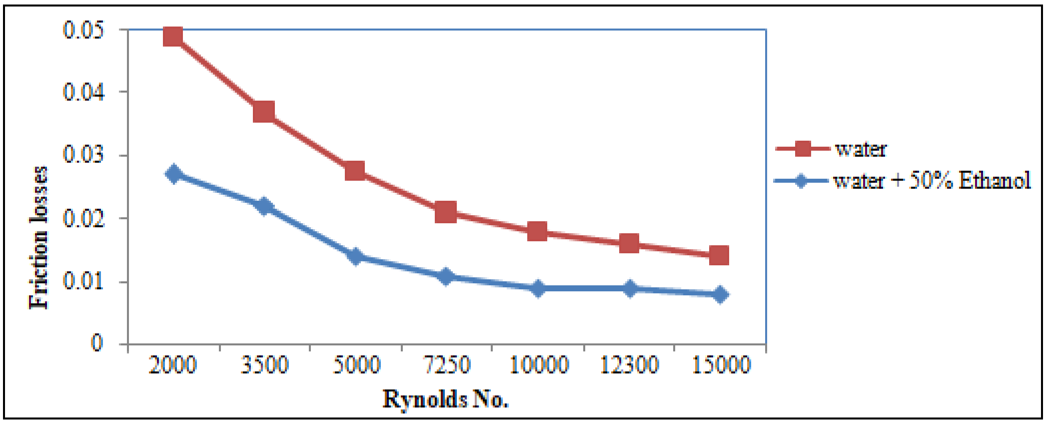

Figure 5: Relation between Friction losses Vs. Reynolds No.

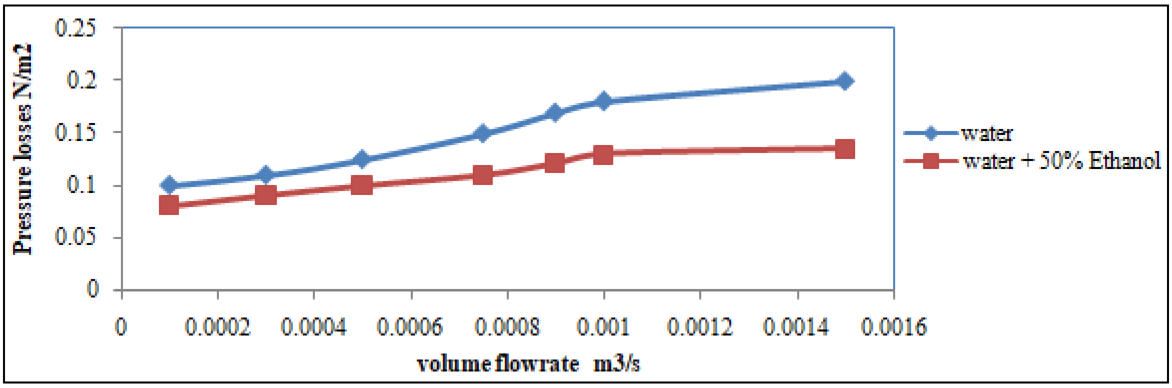

Figure 6: Relation between pressure losses Vs. flowrate

5. Conclusions & Recommendations

5.1. Conclusions

1) The physical properties density, viscosity and surface tension effect on the friction and pressure losses at constant temperature
2) Density and viscosity of both systems were changed and caused a change in pressure losses this helps in transporting systems.
3) The change in temperature causes changes in physical properties.
4) The behavior of the friction factor for the transport of water by pipes as a function of the Reynolds number exposes maximum values of the friction coefficient when the Reynolds number is less than 500; the values of the coefficient converge when the Reynolds number is greater than 2500. The results obtained are satisfactory for the calculation of the pressure variation in industrial facilities where water transported

5.2. Recommendations

1) Study different physical properties and their effect on piping system.
2) Study the effect of temperature on the system
3) Use different liquids in the piping system and compare difference in pressure losses.

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