Non-Newtonian fluids

Fluids which do not obey the Newton's law of viscosity are called as non-Newtonian fluids. Generally non-Newtonian fluids are complex mixtures: slurries, pastes, gels, polymer solutions etc.,

A Non-Newtonian fluid is a fluid which is different from the Newtonian fluid as the viscosity of non-Newtonian fluids is dependent on shear rate or shear rate history. In a non-Newtonian fluid, the relation between the shear stress and the shear rate is different and can even be time-dependent (Time Dependent Viscosity). Therefore, a constant coefficient of viscosity cannot be defined. Non-Newtonian fluids change their viscosity or flow behavior under stress. If a force is applied to such fluids, the sudden application of stress can cause them to get thicker and act like a solid, or in some cases, it results in the opposite behavior and they may get runnier than they were before. Removal of the stress causes them to return to their earlier state. Not all non-Newtonian Fluids behave in the same way when stress is applied – some become more solid, others more fluid. Some non-Newtonian fluids react as a result of the amount of stress applied, while others react as a result of the length of time that stress is applied. The generalized power law for all fluids can be written as:

$$\tau = K(\frac{dy}{dx})^n$$

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Where  K = flow consistency index
       n = Fluid behavior index, n=1 for Newtonian fluids
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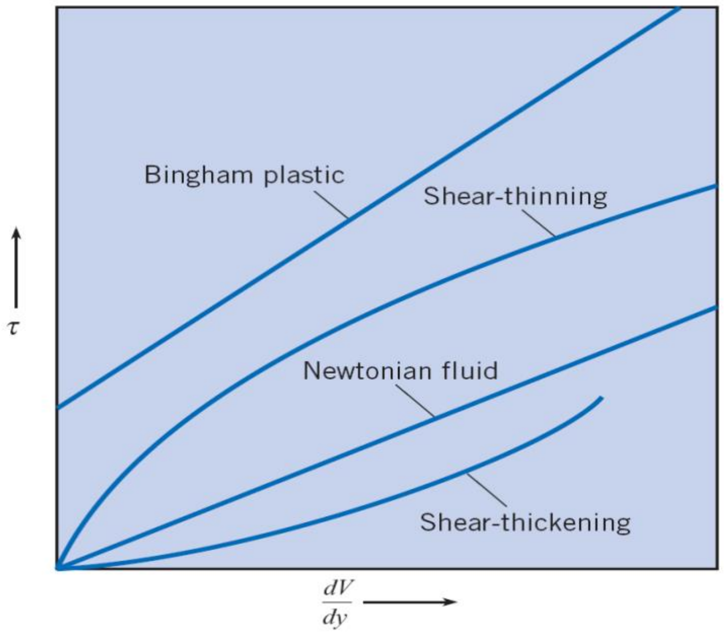


Various non-Newtonian Behaviors:

The viscosity (m) of a fluid measures its resistance to flow under an applied shear stress. Representative units for viscosity are kg/(m.sec), g/(cm.sec) (also known as poise designated

by P). The centipoise (cP), one hundredth of a poise, is also a convenient unit, since the viscosity of water at room temperature is approximately 1 centipoise.

The *kinematic viscosity* (n) is the ratio of the viscosity to the density:

n = m/r,

and will be found to be important in cases in which significant viscous and gravitational forces exist.

Thixotropic Fluid: Its viscosity decreases with stress over time. Example - Honey – keep stirring, and solid honey becomes liquid.

Rheopectic Fluid: Its viscosity increases with stress over time. Example - Cream – the longer it is whipped, the thicker it gets.

Shear Thinning Fluid: Its viscosity decreases with increased stress. Example – Blood, Tomato sauce.

Dilatant or shear thickening Fluid: Its viscosity increases with increased stress. Example – Oobleck (a mixture of cornstarch and water), Quicksand.

A Bingham plastic is neither a fluid nor a solid. A Bingham plastic can withstand a finite shear load and flow like a fluid when that shear stress is exceeded. Toothpaste and mayonnaise are examples of Bingham plastics. Blood is also a Bingham plastic and behaves as a solid at shear rates very close to zero. The yield stress for blood is very small, approximately in the range from 0.005 to 0.01 N/m2.

Reynolds number of the flow is defined as the ratio of inertia forces to viscous forces. Mathematically it is written as:

$$Re = \frac{\rho v d}{\mu}$$

Where
- ρ = density of fluid
- v = velocity of fluid
- d = characteristic length
- μ = dynamic viscosity of fluid

The Reynolds number helps us to predict the transition between laminar and turbulent flows. Laminar flow is highly organized flow along streamlines. As velocity increases, flow can become disorganized and chaotic. This is known as turbulent flow. Laminar flow occurs in flow environments where Re < 2000. Turbulent flow is present in circumstances under which Re > 4000. The range of 2000 < Re < 4000 is known as the transition range. Most blood flow in humans is laminar, having a Re of 300 or less, it is possible for turbulence to occur at very high flow rates in the descending aorta, for example, in highly conditioned athletes. Turbulence is also common in pathological conditions such as heart murmurs and stenotic heart valves. Stenotic comes from the Greek word "stenos," meaning narrow. Stenotic means narrowed, and a stenotic heart valve is one in which the narrowing of the valve is a result of the plaque formation on the valve.

The Womersley number, or alpha parameter, is another dimensionless parameter like the Prandtl number or Reynolds number that has been used in the study of fluid dynamics. This parameter represents a ratio of transient to viscous forces, just as the Reynolds number represented a ratio of inertial to viscous forces. A characteristic frequency represents the time dependence of the parameter. The Womersley number may be written as.:

$$\alpha = r\sqrt{\frac{\omega}{\vartheta}}$$

Where
- α = Womersely Number
- r = vessel radius
- ω = fundamental frequency
- ϑ = kinematic viscosity = $\frac{\mu}{\rho}$

The flow profile becomes blunter near the centreline of the vessel in high frequency flows, because the inertia forces become more important than viscous forces. But viscous forces are still important near the wall as here the velocity of the flow is almost zero due to the effect of the wall and the no-slip condition. Moreover, it can be shown that the transient forces become relatively more important than viscous forces as the animal size increases

Viscosity of liquids:

Viscosity of liquids in general, decreases with increasing temperature.

The viscosities (m) of liquids generally vary approximately with absolute temperature T according to:

$\ln m = a - b \ln T$

Viscosity of gases:

Viscosity of gases increases with increase in temperature.

The viscosity (m) of many gases is approximated by the formula:

$m = m_o(T/T_o)^n$

in which T is the absolute temperature, m_o is the viscosity at an absolute reference temperature T_o, and n is an empirical exponent that best fits the experimental data.

The viscosity of an ideal gas is independent of pressure, but the viscosities of real gases and liquids usually increase with pressure.

Viscosity of liquids are generally two orders of magnitude greater than gases at atmospheric pressure. For example, at 25°C, m_{water} = 1 centipoise and $m_{air} = 1 \times 10^{-2}$centipoise.

Steady flow:

When the velocity at each location is constant, the velocity field is invarient with time and the flow is said to be steady.

Uniform flow:

Uniform flow occurs when the magnitude and direction of velocity do not change from point to point in the fluid.

Flow of liquids through long pipelines of constant diameter is uniform whether flow is steady or unsteady.

Non-uniform flow occurs when velocity, pressure etc., change from point to point in the fluid.

Steady, uniform flow:

Conditions do not change with position or time.

e.g., Flow of liquid through a pipe of uniform bore running completely full at constant velocity.

Steady, non-uniform flow:

Conditions change from point to point but do not with time.

e.g., Flow of a liquid at constant flow rate through a tapering pipe running completely full.

Unsteady, uniform Flow: e.g. When a pump starts-up.

Unsteady, non-uniform Flow: e.g. Conditions of liquid during pipetting out of liquid.

Blood flow is the continuous circulation of blood in the cardiovascular system. This process ensures the transportation of nutrients, hormones, metabolic wastes, $O_2$and CO_2 throughout the body to maintain cell-level metabolism, the regulation of the pH, osmotic pressure and temperature of the whole body, and the protection from microbial and mechanical harms

Blood is a suspension of cellular elements—red blood cells (erythrocytes), white cells (leukocytes), and platelets—in an aqueous electrolyte solution, the plasma.

Red blood cells (RBC) are shaped as a biconcave saucer with typical dimensions of 2 × 8 μm. Erythrocytes are slightly heavier than the plasma (1.10 g/cm3 against 1.03 g/cm3); thus they can be separated by centrifugation from the plasma.

In normal blood they occupy about 45 percent of the total volume. Although larger than erythrocytes, the white cells are less than 1/600th as numerous as the red cells.

The platelet concentration is 1/20th of the red cell concentration, and their dimensions are smaller (2.5 μm in diameter). The most important variable is the hematocrit, which defines the volumetric fraction of the RBCs in the blood.

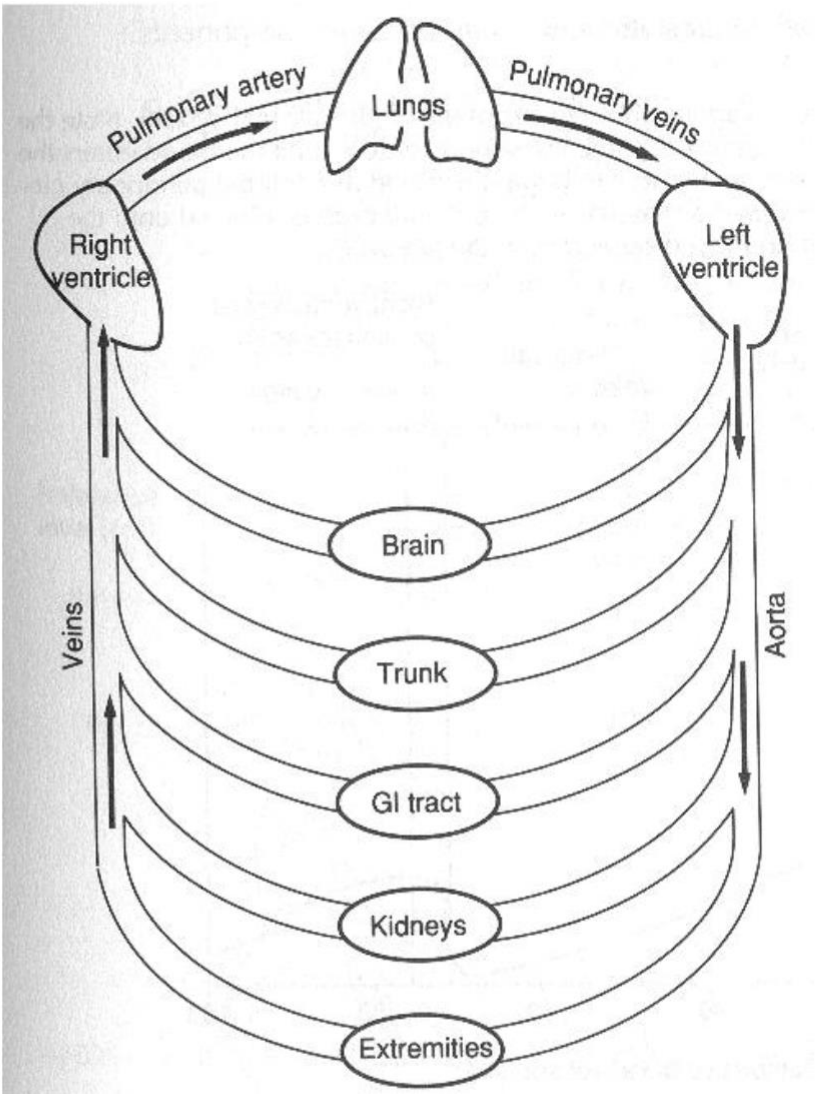
The plasma contains 90 percent of its mass in water and 7 percent in the principal proteins albumin, globulin, lipoprotein, and fibrinogen. Albumin and globulin are essential in maintaining cell viability.

The lipoproteins carry lipids (fat) to the cells to provide much of the fuel of the body. The osmotic balance controls the fluid exchange between blood and tissues. The mass density of blood has a constant value of 1.05 g/cm3 for all mammals and is only slightly greater than that of water at room temperature (about 1 g/cm3).

The macroscopic rheologic properties of blood are determined by its constituents. At a normal physiological hematocrit of 45 percent, the viscosity of blood is μ = 4 × 10-2 dyne · s/cm2 (or poise), which is roughly 4 times that of water.

Plasma alone (zero hematocrit) has a viscosity of μ = 1.1 × 10-2 to 1.6 × 10-2 poise, depending upon the concentration of plasma proteins. After a heavy meal, when the concentration of lipoproteins is high, the plasma viscosity is quite elevated (Whitmore, 1968).

In large arteries, the shear stress (τ) exerted on blood elements is linear with the rate of shear, and blood behaves as a newtonian fluid, for which, where u is blood velocity and r is the radial coordinate perpendicular to the vessel wall. In the smaller arteries, the shear stress acting on blood elements is not linear with shear rate, and the blood exhibits a nonnewtonian behavior.



The Cardiovascular System

The Heart, arteries, and veins (a network of tubes to carry blood) constitute the cardiovascular system or circulatory system of our body which transports the blood throughout the body. The heart can be thought of as a muscular pump, consisting of four chambers, and pulsatile muscles which pump and circulates the blood through the vasculature. Arteries, arterioles, capillaries, venules, and veins make up the vasculature. The cardiovascular system circulates about 5 litres of blood at a rate of approximately 6 l/m. The pulmonary and the systemic circulations are the two parts of the vasculature. The pulmonary circulation system consists of the network of blood vessels from the right heart to the lungs and back to the left heart.

The rest of the blood flow loop is called systemic circulation system. The pulmonary and systemic circulations take the blood through large arteries first and then branches into smaller arteries before reaching arterioles and capillaries. After capillaries, the blood enters the venules before joining smaller veins first and then larger veins before reaching the right heart. Thus, completing the cycle of blood going to heart and then coming from it and going to all parts of the body. The tricuspid valve, right heart (right ventricle), pulmonary valve, pulmonary artery, lungs, pulmonary veins and right heart are the elements of the Pulmonary Circulation System.

The process of gas exchange, that is, exchange of carbon dioxide with oxygen in the lungs is the main function of the pulmonary system. The de-oxygenated blood from the right ventricle is pumped to the lungs where the capillaries surrounding the alveoli sacks exchange carbon dioxide for oxygen. The red blood cells and the haemoglobin present in the blood, which is the main carrier of oxygen in the blood are responsible for this exchange of gases before they are carried to the left ventricle of the heart. The systemic circulation is responsible for taking the oxygenated blood to various organs and tissues via the arterial tree before taking the deoxygenated blood to the right ventricle using the venous system (a network of veins). Arteries carry the oxygenated blood while the veins carry the deoxygenated blood.

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