Viscosity

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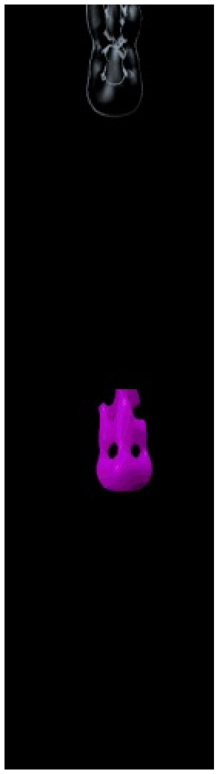
Suggested reviewer: Carmeljcaruana

Viscosity is the measure of a FLUID'S resistance to motion under an applied PRESSURE.

It is directly proportional to the force required to physically move or distribute molecular layers of a fluid in relation to one another.



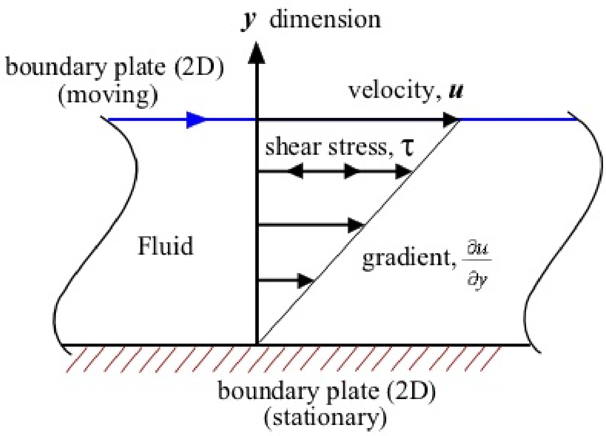
Viscosity of a fluid compared to water. Simulation of a fluid(below) with greater viscosity than water.

Understanding viscosity in fluids

Let us consider an open tube and water flowing through it:
The layer of water adheres to the walls of the tube seeming immobile. As we focus our attention further away from the walls it is possible to observe an increase in the flow's velocity. This fact is due to internal friction.
Greater internal friction results in slower fluid's velocity and greater resistance to movement. Hence, the greater the internal friction is, the higher is the viscosity.
The absence of internal friction (ideal fluid) equals zero viscosity. Fluids with smaller viscosity values are closer to ideal fluids.

Viscosity in newtonian and non-newtonian fluids

In two parallel liquid layers with different velocities the layer with greater velocity tends to pull the layer with lesser velocity. On the other hand the latter will then delay the former. This produces a velocity gradient: difference of velocity between the layers divided by the perpendicular distance between them (dv/dy).
In this case a **tangential tension** (or shear stress) arises between the layers. In laminar flow, this tension is defined by the liquid viscosity times the velocity gradient:



$\tau = \eta \times dv/dy$

This concept was first formulated by Isaac Newton. Since then, many experiments have confirmed the validity of this equation for most liquids. The liquids that fulfil this equation are called newtonian fluids. For certain liquids, however, Newton's equation is not valid. Examples thereof are colloid solutions, suspensions and emulsions. These liquids, where viscosity depends on velocity increase, are called non-newtonian fluids. This is the case of blood.

The coefficient η is called **dynamic viscosity**. The unit of dynamic viscosity is Pa x s. In some cases it is still possible to encounter the unit P (poise; 1P= 1g x cm $^{-1}$ x s^{-1}), where 1 Pa x s= 10P and 1mPa x s =1 cP.

The **kinetic viscosity** is defined as dynamic viscosity divided by the density:

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μ = η/ρ
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The unit for kinetic viscosity is m^2 s^{-1}.

Viscosity and temperature

Viscosity in liquids depends on temperature and pressure. An increase in temperature results in a decrease of viscosity.

Temperature, t in °C	**Viscosity ηx10^3 in m^{-1} kg s^{-1}**
0	1.7865
25	0.8908
50	0.5477
100	0.2829
160	0.1715
200	0.1365

Viscosity in blood

The equation to calculate the viscosity of a suspention is characterized by:

$$\eta_S = \eta\ (1 + kc)$$

η - viscosity of medium; c - volume concentration of particles; k - constant characterizing physical properties of particle

Blood is a suspension of red blood cells, white blood cells and platelets in plasma. Plasma is mostly water but also contains molecules such as electrolytes, proteins and other macromolecules. Because of the different components of plasma and their interactions the viscosity is higher than water. With the addition of red bood cells, white blood cells and platelets the viscosity is increased. The change in amount of any one of these components can lead to changes in viscosity. Under normal conditions red blood cells have the greatest effect on viscosity.

Populations living in high altitute areas, for instance, are exposed to rarified air. In this case, normal amount of red blood cells would not be sufficient to transport enough oxigen throughout the body. As a result, the organism produces more red blood cells which leads to an increase in blood viscosity.

The percentage of blood volume occupied by red blood cells is defined as **hematocrit**. Blood viscosity increases with increased values of hematrocit. This increase is non-linear. An example of the consequences of changes in blood viscosity can be observed in patients with polycythemia. This condition is defined by an abnormal elevation in hematocrit. These patients have much higher values of blood viscosity. As a result the resistance to blood flow increases and forces the heart to work harder and can impair organ perfusion.

Another example of increased blood viscosity and it's consequesces can be found in sports doping. Erythropoietin (EPO) is a protein hormone and estimulates the production of red blood cells. When athletes inject EPO into the circulatory system more red blood cells will be produced increasing the oxigen carrying capacity. The increase in red blood cells, however, leads to increase in blood viscosity. As a result, blood doping raises risks of blood clot, stroke and heart attack.

How to measure viscosity in blood

To measure viscosity an instrument called viscosimeter is used. There are three types of viscosimeters (capillary, bead and rotational).

When measuring blood viscosity a device similar to a capillary viscosimeter is used. The volume of blood is sucked through a horizontal capillary for a certain time period. At the same time and for the same time period a similar procedure is undertaken using water. The results are then compared to achieve the value of blood viscosity.

Bead viscosimeter Example of a rotational viscosimeter

The pictures above show examples of capillary, bead and rotational viscosimeters, respectively.

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