Lab 5: Introduction to fluids

Bio427 — Biomechanics

In this lab we will explore some of the biologically interesting properties of fluids, including viscosity and surface tension. There will be several workstations for you to pass through as we explore (in a brief way) basic fluid mechanics that relevant to biological systems.

http://cals.arizona.edu/arizonawet/teachersupport/supportmats/water-strider

Figure 1: This water strider relies on surface tension to inhabit a unique ecological niche at the interface of air and water

Goals

- Measure viscosity of sugary fluid using a falling ball viscometer, and observe how the viscosity of this fluid changes as it is diluted with water.
- Test a hypothesis about the use of surfactants in insect capture by carnivorous plants.

Conceptual Basis

Surface Tension

Surface tension arises from cohesion between molecules in a fluid. In the interior of a liquid the cohesive forces on all of the molecules are balanced in all directions. The liquid molecules on the surface of the fluid, however, experience no significant cohesive forces from the molecules in the air, and therefore experience a net cohesive force that draws them inward. That inward force is manifested as a tension in the free surface.

Surface tension phenomena are important in a host of biological problems: transport of fluids in plants, the locomotion by water striders, nectar feeding in insects, birds and bats, and even the physiology and physics of mammalian respiration.

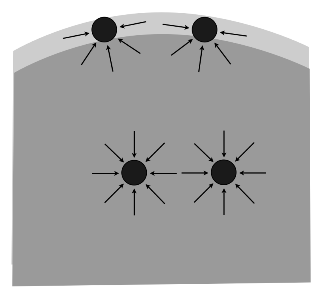


Figure 2: At the air-liquid interface cohesive forces on molecules are unbalanced leading to a tension in the free surface

Viscosity

In lecture, we differentiated between fluids and solids by examining how they respond to an applied stress: solids deform to some equilibrium strain whereas fluids strain continuously. The rate of strain is proportional to the viscosity of the fluid and the applied shear stress, as described by Newton's law of viscosity:

$$\tau = \mu \frac{d\epsilon}{dt} \qquad (1)$$

Here, τ is the applied shear stress (in Pa) , μ is the viscosity of the fluid (in Pa s) and $d\epsilon/dt$ is the fluid strain rate. Biological fluids vary wildly in viscosity, the success of important processes such as pollinator feeding and blood flow depend on the tuning of fluid viscosity. In this lab, we will be looking at how the viscosity of sugary fluids like nectar depend on the degree to which they are diluted with water, which must be finely balanced for flowers to provide an effective energy source to attract pollinators (too viscous and feeding may be impaired, too dilute and the benefit to the pollinator of feeding becomes negligible). But how do we measure viscosity?

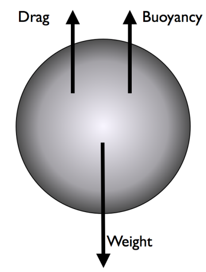


Figure 3: Three forces acting on a falling sphere

There are many ways to measure the viscosity of a fluid, and in this lab we will introduce one of the simplest methods, which relies on the physics of a sphere falling within a fluid. A sphere falling through a fluid experiences three forces: a downward force due to gravity, an upward force due to the buoyancy of the sphere, and an upward force caused by the fluid drag resisting its downward motion. The falling sphere will eventually reach a speed of descent where these forces are balanced – that is, the net force acting on the sphere is zero – and here the sphere is said to be in **equilibrium**. In equilibrium, then, this balance of forces can be expressed as follows.

$$\text{weight} = \text{buoyant force} + \text{drag} \tag{2}$$

The weight of the sphere is mg, and the buoyant force acting on the sphere is equal to the weight of the fluid that it displaces (volume of the sphere[1] times the density of the fluid times g, or $\rho V g$). The drag force, as we will see in later lectures, is a more complicated affair. The appropriate equation to use for drag depends on whether the viscous forces acting are dominant over the inertial forces. In this lab, we will assume that the viscous forces are dominant, and given that assumption the drag on the sphere is given by

[1] $V = \frac{4}{3}\pi r^3$

$$F_{\text{drag}} = 6\pi r \mu U \tag{3}$$

where r is the radius of the sphere, and U is the speed with which it moves through the fluid of viscosity μ. Armed with Eqn. 3, we can rewrite Eqn. 2 as

$$mg = \rho V g + 6\pi r \mu U \tag{4}$$

Eqn. 4 implies that spheres of different sizes or weights present the fluid with different strain rates as they fall at different velocities. To measure the viscosity μ using the motion of sphere descending through the fluid, we first rearrange Eqn. 4 so that μ is the dependent variable:

$$\mu = \frac{mg - \rho V g}{6\pi r U} \tag{5}$$

Using Eqn. 5, we can measure the viscosity of a fluid by measuring the speed with which a sphere of known size and mass descends due to gravity when dropped into the fluid.

Methods

Viscosity of nectar

In the first part of this lab, we will be measuring the viscosity of a (somewhat distantly) biologically derived fluid – high fructose corn syrup – and observing how its viscosity changes as it is diluted with water.

You will begin with pure corn syrup, which as you will note is rather viscous stuff. You'll be putting the corn syrup into clear plastic containers; your TA will show you how far the containers should be filled. We will provide you with roughly spherical beads to drop into the fluid, and you will measure the speed with which a bead dropped into the fluid descends due to gravity using a stopwatch to measure the time taken for the bead to reach the bottom of the container.

Important: When setting the bead in the fluid, make sure that it falls well away from the walls of the container. If the bead is too close to the walls, it will experience wall effects that will add an additional (difficult to quantify) component to Eqn. 3, which will throw off your estimate of the fluid viscosity. You will then dilute the corn syrup

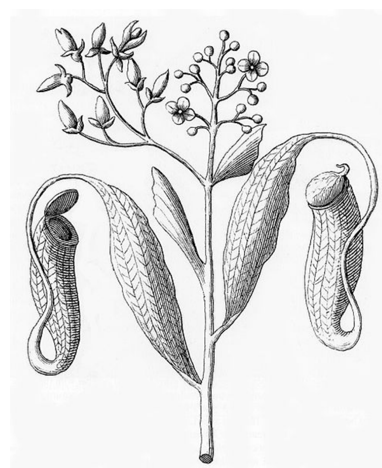


Figure 4: Plukunet's drawing of *Nepenthes distillatoria*, 1696.

by adding water, making sure that the fluid is thoroughly mixed. How do you think the viscosity of the syrup might change as water is added? Measure the change in viscosity for three different levels of dilution, and plot your results on the worksheet.

Surfactants in carnivorous plants (?)

Carnivorous plants, such as pitcher plants in the tropical genus *Nepenthes*, trap and digest small prey items (usually insects and other small arthropods) that fall into their fluid filled traps. You might quite reasonably wonder why the insects that fall into these traps do not simply walk on the surface of the fluid, relying on surface tension to prevent them from drowning and being digested. Perhaps there is a surfactant in the *Nepenthes* fluid that reduces the surface energy of the fluid such that the hapless insects that land on the surface of the fluid cannot avoid being wetted? In this section of the lab, you will test this hypothesis by observing the wettability of insects (either a mosquito or a moth). In this case of the moth, a leg or other body part of an adult *Manduca sexta* hawkmoth, which would admittedly be an unusual prey item for a *Nepenthes* pitcher plant, but happens to be an insect for which we have a nigh-inexhaustible supply) when exposed to pure water, fluid extracted from a *Nepenthes* trap, and pure water with added surfactant (dishwashing soap). In the mosquito *Aedes aegypti*, you can use the whole animal. Both insect species are dead.

First, observe that in pure water, the *Manduca* leg or *Aedes* body is almost shockingly difficult to wet. Next, try the *Nepenthes* fluid – does this fluid do any better than the water? Finally, try the soapy water, and record your results on the worksheet.

Lab 5: Introduction to Fluids

Note: Hand in one worksheet per lab group
Lab Section: ____________________
Name 1: ____________________ Name 2: ____________________

Viscosity of nectar

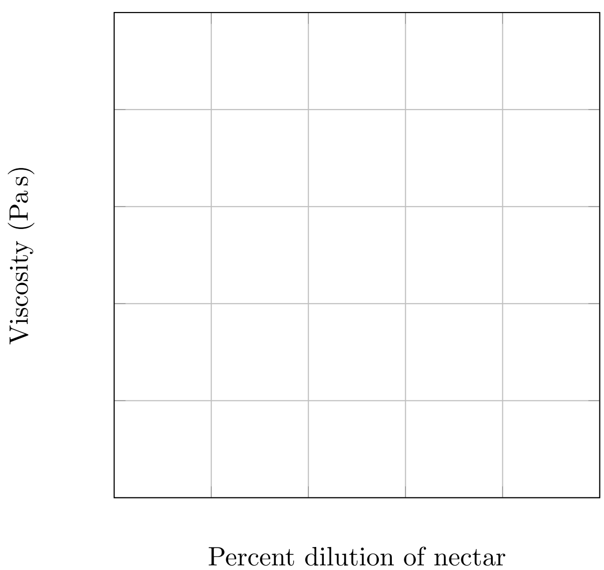
Enter the details for the sphere you used to measure the viscosity of your nectar below:

Sphere Type	Radius	Mass
____________	______	______

For each level of dilution of the nectar, measure the speed of descent for your sphere three times. Use the mean value that you obtain to calculate the viscosity of the fluid for each level of dilution.

	Percent Dilution	U_1	U_2	U_3	$\mu(\bar{U})$
1	0%	________	________	________	________
2	________	________	________	________	________
3	________	________	________	________	________
4	________	________	________	________	________

Plot your results on the axes provided. Does the viscosity of the syrup respond linearly to dilution?



Questions (Answer on back)

***Nepenthes*:** Did you find evidence to support the hypothesis that *Nepenthes* pitcher plants employ surfactants to aid in insect prey capture? Elaborate beyond a simple "yes" or "no". Which insect did you test?