Biology 427 Fall 2013

Some useful data:
density of water = 1000 kg/m^3
density of air = 1 kg/m^3
viscosity of water = 0.0011 Pa s
viscosity of air = 1.8 10^{-5} Pa s

1. Newton's law of viscosity suggests that a fluid moving tangential to a surface exerts a stress on that surface. Explain briefly why there can be a stress on the surface even though according to the "no-slip" condition there is no flow at the interface of the fluid and the surface itself.

2. Blood has a viscosity (μ_B) that depends on the concentration of red blood cells (the hematocrit):

$$\mu_B = \frac{\mu_p}{1 - \alpha\phi}$$

where μ_p is the viscosity of plasma (take that to be equal to the viscosity of water) and ϕ is the hematocrit (volume fraction of red blood cells). The term α is:

$$\alpha = 0.07 \exp[2.49\phi + 1107 \exp(-1.65\phi)/T_K]$$

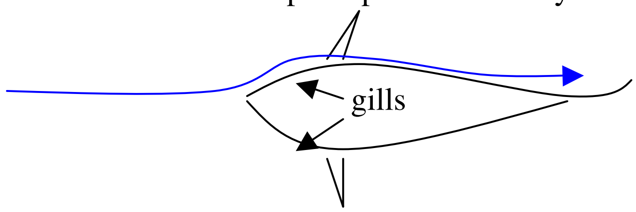
$$\alpha = 0.07 e^{(2.49\phi + 1107 e^{(-1.65\phi)}/T_K)}$$

where T_k is the temperature of blood in Kelvin. Our goal here is to understand the consequences of blood doping, a practice in which individuals increase their hematocrit by either taking EPO (a drug that augments red blood cell production) or by injecting packed red blood cells. In either case the hematocrit can increase to about 0.55 relative to the normal value of 0.40.

(a) What is the fractional increase in viscosity under conditions of blood doping (relative to normal conditions)?
(b) If the pressure required to pump blood at a given flow rate is proportional to blood viscosity, by what factor does that pressure increase?
(c) If the pressure is constant, and flow was inversely proportional to viscosity, by what factor would the oxygen delivery change (increase or decrease)?
(d) What might be the negative consequences of increased arterial pressure associated with blood doping?

3. Human aortas have a diameter of about 1 cm and the average speed of blood moving in these tubes is 20 cm/s. The average diameter of a human capillary is about 7 μm where there is an average blood flow velocity of about 0.07 cm/s. Use these data along with conservation of mass to calculate the number of capillaries contributing to blood flow in the system.

4. Tuna and many sharks use a mechanism called "ram jet ventilation" to drive water motion over their gills for oxygen uptake. By this method, they swim with their mouths slightly open, forcing fluid into the mouth, through the gill chambers and out. In this problem, we are interested in computing the energy associated with ram ventilation and will use Bernoulli's principle for the analysis.



A. Consider a streamline passing just next to the mouth and past the outer part of the gills (see diagram above). If the fluid velocity near the mouth is 0.2 m/s and that near the gill opening is 3 m/s, compute the pressure difference across the gill chamber.

B. Given that the volume flow rate (Q) of water is equal to the difference in pressure (ΔP) divided by the resistance (R) to flow in the gill chamber, compute the flow rate if the resistance (R) is 10^6 kg/(m^4 s).

C. What would the area of the mouth have to be in order to get that inward flow velocity of 0.2 m/s? What is the radius of this opening?

D. The power (energy/time) required to move fluid at a given flow rate with a given pressure difference is equal to Q ΔP. Compute this as a fraction of the total rate of metabolic energy expenditure which, for a tuna swimming at 3 m/s, is about 100 Watts.

5. A rower pulls back on a paddle to propel her boat through water. The oar has a paddle (circular disc) area of 0.2 m^2 and a drag coefficient (C_d) of 1.0. In one second, the oar swings through a 90 degree arc that is centered about the mid-section of the boat. The angle subtended between the oar and the boat is θ. The length of the oar (to the center of the disc) is 2 m and the oar is swung at a constant velocity.

A. Draw a diagram of the forces on the oar at any particular angle.

B. Derive an equation that predicts how the thrust changes in time if the boat forward velocity is assumed to be tiny with respect to the rearward oar velocity (i.e. ignore the forward velocity of the boat)

C. Plot the thrust as a function of time for one stroke.

D. Be prepared to discuss in section with your TA, how this problem is made challenging by having a forward velocity that is not negligible.