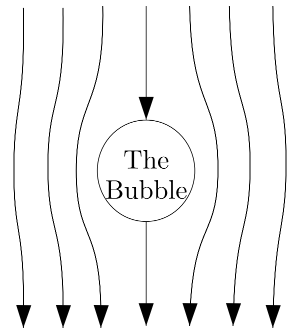
1. Floating Bubbles Out of Glass

   (a) The bubble is floating up, so in its frame of reference the fluid is flowing down:



   (b) This is just like terminal velocity of a solid sphere, but slightly simpler (since the weight is approximately zero) and with a different constant:

$$F_b = F_d = fKA,$$

$$\frac{1}{6}\pi d^3 \rho g = \frac{16\mu}{\rho U d} \cdot \frac{1}{2}\rho U^2 \cdot \frac{1}{4}\pi d^2,$$

$$U = \frac{\rho g d^2}{12\mu}.$$

   (c) The velocity which guarantees removal is the depth divided by the time. Solve for d and calculate, using that velocity:

$$d = \sqrt{\frac{12\mu U}{\rho g}} = \sqrt{\frac{12 \cdot 1.0\frac{\text{kg}}{\text{m}\cdot\text{s}} \cdot \frac{0.1\text{m}}{60\text{s}}}{3200\frac{\text{kg}}{\text{m}^3} \cdot 9.8\frac{\text{m}}{\text{s}^2}}} = 8.0 \times 10^{-4}\text{m}.$$

   (d) Since $V \propto d^2$, if we cut d in half, the velocity will be one quarter of what it was, so it will take four times as long to float out the bubbles 0.4mm in diameter.

   (e) The larger bubbles will have larger d and larger U and thus a larger Reynolds number, so if they're Stokes then both are:

$$\text{Re} = \frac{\rho U d}{\mu} = \frac{3200\frac{\text{kg}}{\text{m}^3} \cdot \frac{0.1\text{m}}{60\text{s}} \cdot 8.0 \times 10^{-4}\text{m}}{1.0\frac{\text{kg}}{\text{m}\cdot\text{s}}} = 4.3 \times 10^{-3}.$$

   This is easily within the Stokes flow régime.