EVERYDAY EXAMPLES OF ENGINEERING CONCEPTS

F1: Fluids & their properties

This is an extract from 'Real Life Examples in Fluid Mechanics: Lesson plans and solutions' edited by Eann A. Patterson, first published in 2011 (ISBN:978-0-9842142-3-5) which can be obtained on-line at www.engineeringexamples.org and contains suggested exemplars within lesson plans for Sophomore Fluids Courses. They were repared as part of the NSF-supported project (#0431756) entitled: "Enhancing Diversity in the Undergraduate Mechanical Engineering Population through Curriculum Change".

INTRODUCTION

(from *'Real Life Examples in Fluid Mechanics: Lesson plans and solutions'*)

These notes are designed to enhance the teaching of a sophomore level course in fluid mechanics, increase the accessibility of the principles, and raise the appeal of the subject to students from diverse backgrounds. The notes have been prepared as skeletal lesson plans using the principle of the 5Es: Engage, Explore, Explain, Elaborate and Evaluate. The 5E outline is not original and was developed by the Biological Sciences Curriculum Study[1] in the 1980s from work by Atkin & Karplus[2] in 1962. Today this approach is considered to form part of the constructivist learning theory[3].

These notes are intended to be used by instructors and are written in a style that addresses the instructor, however this is not intended to exclude students who should find the notes and examples interesting, stimulating and hopefully illuminating, particularly when their instructor is not utilizing them. In the interest of brevity and clarity of presentation, standard derivations, common tables/charts, and definitions are not included since these are readily available in textbooks which these notes are not intended to replace but rather to supplement and enhance. Similarly, it is anticipated that these lesson plans can be used to generate lectures/lessons that supplement those covering the fundamentals of each topic.

It is assumed that students have acquired a knowledge and understanding the following topics: first and second law of thermodynamics, Newton's laws, free-body diagrams, and stresses in pressure vessels.

This is the fourth in a series of such notes. The others are entitled 'Real Life Examples in Mechanics of Solids', 'Real Life Examples in Dynamics' and 'Real Life Examples in Thermodynamics'. They are available on-line at www.engineeringexamples.org.

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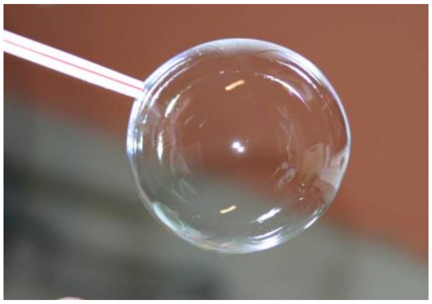
[1] Engleman, Laura (ed.), *The BSCS Story: A History of the Biological Sciences Curriculum Study*. Colorado Springs: BSCS, 2001.
[2] Atkin, J. M. and Karplus, R. (1962). Discovery or invention? *Science Teacher* 29(5): 45.
[3] e.g. Trowbridge, L.W., and Bybee, R.W., *Becoming a secondary school science teacher*. Merrill Pub. Co. Inc., 1990.

INTRODUCTORY CONCEPTS

1. Topic**: Fluids and their properties**

Engage:



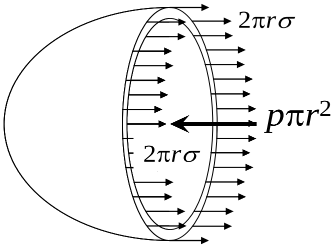
Take into class a pile of drinking straws, some paper cups, a bottle of dish washing detergent and a bottle of water. In front of the students, add detergent to water so that the solution is about one part detergent to ten parts water. Give each student a straw and a paper cup with a small amount of the mixture in the bottom and invite them to blow bubbles. Alternatively if you just want to give a demonstration – kits are available on-line (search under soap bubbles) as well as advice on solutions etc.[4]

Explore:

Ask students to work in pairs and draw a free-body diagram for a stationary, spherical bubble. If necessary, give them a hint by telling them to treat it like a pressure vessel.
Invite a pair to draw their result for the rest of the class. Discuss how the circumferential stress in a solid pressure vessel can be replaced by the surface tension, σ in the inner and outer surfaces of the bubble. So that summing the forces in the horizontal direction in the figure we obtain

$$p\pi r^2 = 2\times 2\pi r\sigma$$

or $$p = \frac{4\sigma}{r}$$



Explain:

Discuss that the surface of the fluid acts like a tensioned membrane. The bubble prefers to form into a sphere because a sphere has the smallest surface area for a given volume. So in a sphere the molecules of the fluid can be uniformly close to one another.

A bubble of pure water would be very unstable whereas the detergent is a surfactant that decreases the surface tension. When a region of the surface of the bubble gets stretched by an external force, the tension in the membrane increases. This causes detergent to flow away, thus decreasing the concentration of detergent and raising the surface tension of the fluid mixture which prevents the bubble from bursting.

Changes in the air temperature will cause expansion or contraction of the bubble and disturb the equilibrium between internal pressure (increases with temperature) and surface tension (decreases with temperature) so that it collapses.

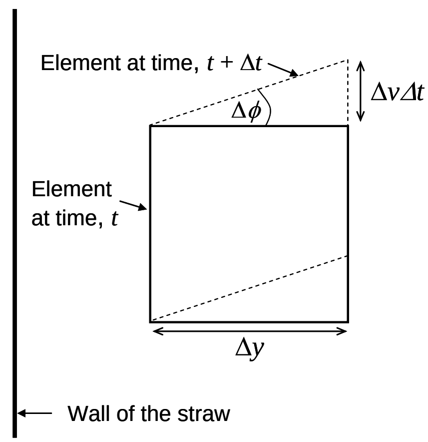
[4] http://www.bubbles.org/solutions/

Elaborate:

Pour a little pure detergent into a paper cup and, as you do so, point out to the students the slow rate at which it flows compared to water. Explain that this is a result of the high viscosity or internal stickiness of the detergent. Fluids which have complex molecules that cannot slide easily past one another tend to have a high viscosity.

Consider liquid being sucked up a drinking straw (don't try it with the water-detergent solution!). The molecules in the fluid that are in contact with the inside surface of the straw tend to get stuck in the surface roughness of the straw so that they move very slowly relative to those along the center line of the straw. This creates a velocity gradient in the fluid. When we consider a square element in the fluid, then the velocity difference between the faces parallel to the inside surface of the straw can be described by Δv, and after time Δt the element will be sheared such that the shear angle, $\Delta\phi$ is given by

$$\Delta\phi = \frac{\Delta v \Delta t}{\Delta y} \text{ or } \frac{\Delta\phi}{\Delta t} = \frac{\Delta v}{\Delta y}$$



and in the limit as $\Delta t \rightarrow 0$ and $\Delta y \rightarrow 0$ so the rate of shear strain is

$$\dot{\phi} = \frac{dv}{dy}$$

For 'Newtonian' fluids, the shear stress is given by

$$\tau = \mu \frac{dv}{dy}$$

where μ is known as the dynamic viscosity.

Note that if dynamic viscosity is normalized by the density it is referred to as kinematic viscosity, $\nu = \mu/\rho$

Observe that the fluid mechanics has been discussed using analogies to solids and employing similar language. Another term that can be taken from mechanics of solids is modulus of elasticity. The bulk modulus of elasticity, B of a fluid relates changes in volume, dV to the change in pressure, dp causing them, i.e.

$$B = \frac{dp}{dV/V} \text{ or for constant mass, } m(=\rho V) \quad B = \frac{dp}{d\rho/\rho}$$

and B is a measure of the compressibility of a fluid.

Evaluate:

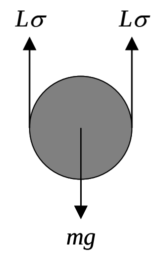
Invite students to attempt the following examples:

Example 1.1

Demonstrate by analysis and by experiment that a paperclip will float in water at room temperature.

<u>Solution:</u>

Summing forces in the vertical direction:



$$mg < 2L\sigma$$

substituting for mass

$$\rho_{steel}\left(\frac{\pi d^2}{4}\right) Lg < 2L\sigma$$

Assuming the density of steel, $\rho_{steel} = 7850\text{kg/m}^3$ and surface tension of water, $\sigma_{H_2O} = 0.073\text{N/m}$

$$d < \sqrt{\frac{8\sigma}{\rho_{steel}\pi g}} = \sqrt{\frac{8\times 0.073}{7850\times \pi \times 9.81}} = 1.55\times 10^{-3}\text{ m}$$

The paperclips on the editor's desk have a diameter of about 0.75mm ($=0.75\times10^{-3}$m) so they should float based on this analysis.

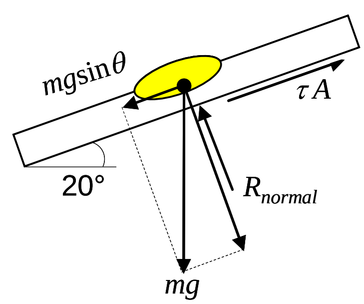
If you try to float them from your fingers in a cup of water, then they will almost always sink because you disturb the surface tension in process. However, balance the paperclip on a thin piece of tissue and gently lower it to the water surface without touching the surface with your fingers. Then gently push the paper underwater with a pencil without touching the paperclip. The paperclip should be left floating.

<u>Example 1.2</u>

A fried egg of mass 65g sits in a frying pan with a 0.5mm layer of cooking oil between it and the pan surface. If the oil has a viscosity of 0.05 Ns/m^2, then how fast will the egg slide across the pan if the pan is tipped to an angle of 20°. Assume that the egg is flat on the underside, is approximately circular with a diameter of 12cm and neglect edge effects.

<u>Solution:</u>

Equating forces on in the direction of sliding using the free-body diagram,



so $\quad mg\sin\theta = \tau A$

and $\tau = \mu\dfrac{dv}{dy}$ so $\quad mg\sin\theta = \mu\dfrac{dv}{dy}A$

let $\dfrac{dv}{dy} = \dfrac{\Delta v}{\Delta y}$ and $\quad mg\sin\theta = \mu\dfrac{\Delta v}{\Delta y}A$

rearranging $\quad \Delta v = \Delta y\dfrac{mg\sin\theta}{\mu A} = 0.0005\dfrac{0.065\times 9.81\times \sin 20}{0.05\times\left(\pi\times 0.12^2/4\right)} = 0.193\text{m/s}$

So your egg will be out of the pan pretty fast!