Civil Engineering Hydraulics
Mechanics of Fluids

Fundamentals and Units

An average of two people die every year from flatulence.

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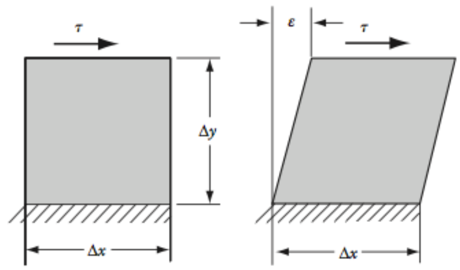
What Defines a Fluid

- A fluid is any material/substance that deforms continuously under a shear stress

What Defines a Fluid



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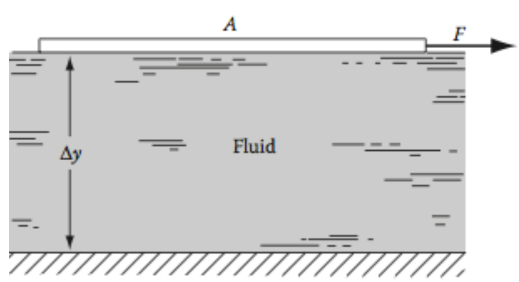
What Defines a Fluid



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Unit Fundamentals

- In the English Customary system of units, there are fundamental units that all other units are built from
- Three of these units are
  - Foot (ft) a unit of length
  - Second (s) a unit of time
  - Pound Force (lbf) a unit of force

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Unit Fundamentals

- There are other fundamental units in the English Customary (amp, mole, etc.)
- All other units are derived from these fundamental units

Unit Fundamentals

- For example, in the English Customary system, mass is defined by using force, time, and length units
- The fundamental units of mass then would be

$$m = \frac{F \times t^2}{l}$$

Unit Fundamentals

- Now here is where we run into some twists and turns from mass being defined as a derived unit because we actually have two English units of mass

$$m = \frac{F \times t^2}{l}$$

Unit Fundamentals

- The older unit is the Slug and it is defined as

$$1 slug = 1 \frac{lbf \times s^2}{ft}$$

- Which is the same as saying that it takes 1 lbf to accelerate a slug at a rate of 1 ft/s

Unit Fundamentals

- The newer unit is the pound mass, which is sometimes just called the pound.
- You may see it written as lb or as lbm
- Pound force is usually written as Lb or lbf
- Be very careful to identify which is being considered

Unit Fundamentals

- It takes one pound force to accelerate one pound mass with an acceleration equal to the acceleration of gravity at the earth's surface which is usually taken as 32.174 ft/ s^2
- Therefore

$$1lbm = \frac{lbf \times s^2}{32.174\,ft}$$

Unit Fundamentals

- In SI units the world is much saner.
- The fundamental quantities that we are interested in are mass, length, and time
- Force is defined in terms of these fundamentals

Unit Fundamentals

- The unit of mass is the kilogram (kg)
- The unit of time is the second (s)
- And the unit of length is the meter (m)
- The derived unit of force is the Newton (N) which is defined as

$$1N = 1\frac{kg \times m}{s^2}$$

Unit Fundamentals

- So 1 N would be the force required to provide an acceleration of 1 m/s^2 to a 1 kg mass

$$1N = 1\frac{kg \times m}{s^2}$$

Unit Fundamentals

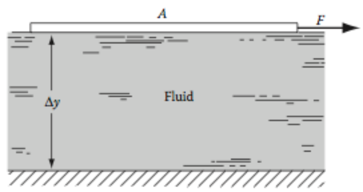
- What we consider standard acceleration due to gravity is
  - 9.81 m/s^2 in SI
  - 32.2 ft/s^2 in USCS or English Customary

Language - Viscosity

- Viscosity is a measure of the resistance of a fluid to deformation under shear stress.
- The word "viscosity" derives from the Latin word "viscum" for mistletoe. A viscous glue was made from mistletoe berries and used for lime-twigs to catch birds.
- It is commonly perceived as "thickness", or resistance to pouring.

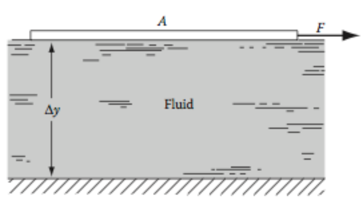
Language - Viscosity

- If we go back to the definition of a fluid we can develop a definition of fluid properties from there



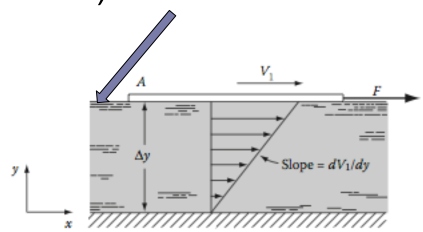
Language - Viscosity

- The plate has an area A in contact with the water and it is being acted on by a force F
- This develops a shear stress τ (tau) at the top surface of the water equal to F/A



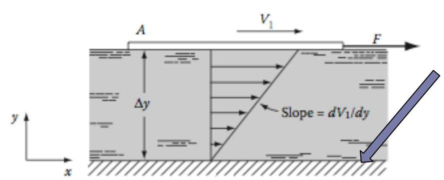
Language - Viscosity

- The plate will begin to move with a velocity V along the surface of the fluid
- The fluid layer next to the plate will also move with this velocity (the why for this will come later)



Language - Viscosity

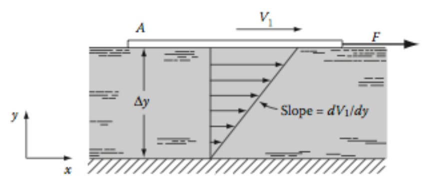
- The lowest layer of the fluid will not move at all (again, more on this later)
- So there will be a velocity gradient through the fluid from top to bottom
- If this gradient is linear, the fluid is considered at Newtonian



Language - Viscosity

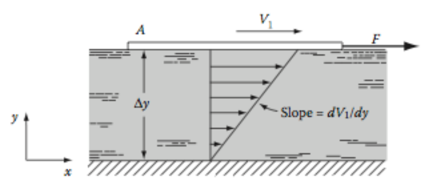
- From the rate at which the fluid velocity changes from top to bottom, a slope can be expressed as

$$\frac{dV}{dy}$$



Language - Viscosity

- If we change the force, and therefore change the shear stress, we also change the velocity profile so for every shear stress τ_n we will have a dV_n/dy



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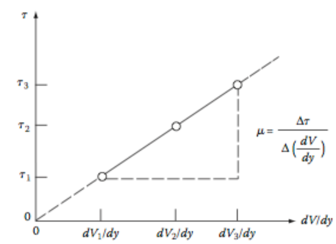
Language - Viscosity

- It the dV_n/dy is plotted as the independent variable and the τ_n as the dependent variable, a Newtonian fluid will generate linear relationship.



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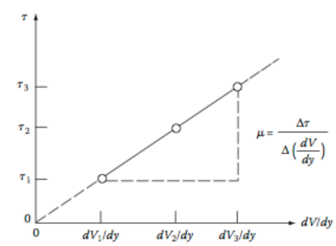
Language - Viscosity

- The slope of the linear relationship is the absolute or dynamic viscosity of the fluid and is given the symbol μ (mu)
- It has dimensions of force*time/length^2



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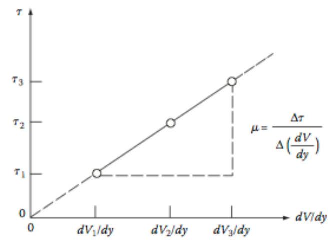
Language - Viscosity

- In USCS this would be
  - lbf*s/ft^2
- In SI it would be
  - N*s/m^2



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Language - Viscosity

- Non-Newtonian fluids are described in the text but in this class we will most often be dealing with Newtonian fluids
- NOTE: If you are working the examples in the text, in Example 1.3 part c, grease is assumed to be a Bingham plastic mixture rather than a pseudo plastic fluid

Language - Pressure

- Pressure is the normal force per unit area exerted by a fluid
- It appears to be almost the exact thing as normal stress
- Pressure is given the symbol p (lower case P) and has the units of force/length^2
  - In USCS the units are lbf/ft^2 (may be written as psf or sometimes as psi (lbf/in^2))
  - If SI the units are N/m^2 which is also given the name Pascal (Pa)

Language – Mass Density

- The mass density is the mass of the fluid per unit volume of the fluid and is represented by the symbol ρ (rho).
- You may see weight density given but it is more common to be given as the specific weight of a fluid.
- The specific weight (SW) of a fluid is the mass density of the fluid times the acceleration of gravity (g) in the respective unit system
- It is often represented by γ (gamma)

Language – Mass Density

- Another term that is commonly used is the specific gravity of a fluid.
- The specific gravity (s) is the ratio of the mass density of the fluid to the mass density of water
- The mass density of water in SI units is taken to be about 1000 kg/m^3 while the mass density of water in the USGS system is 62.43 lbm/ft^3 or 1.94 $slugs/ft^3$

Language – Kinematic Viscosity

- There is a second type of viscosity term known as kinematic viscosity represented by ν (nu) which is the ratio of the dynamic viscosity to the mass density of a fluid. It has units of $length^2/time$

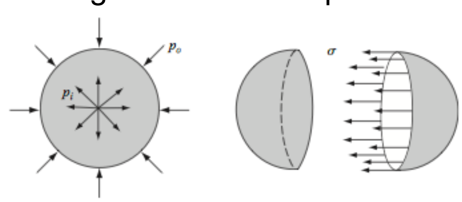
$$\nu = \frac{\mu}{\rho}$$

Language – Surface Tension

- Surface tension is a measure of the ability of a fluid to maintain a continuous surface.
- Surface tension is shown by the symbol σ (sigma) and has units of force/length
- It is a measurement of energy where the fluid molecules hold together to each other more than they are drawn to the interface where they would leave the fluid

Language – Surface Tension

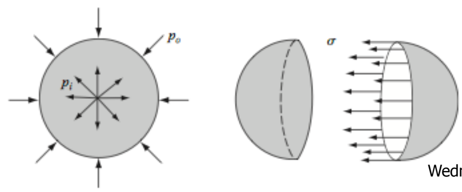
- Consider Example 1.10
- For the droplet to break into two parts, it would have to overcome the attractive force between the two hemispheres
- This is provided by the surface tension acting at the edges of the hemispheres



Language – Surface Tension

- So the force holding the hemispheres together is provided by the surface tension action along the edge
- The length of the edge is the circumference of the drop so the force provided by the surface tension is

$$F = \sigma\left(2\pi R\right)$$



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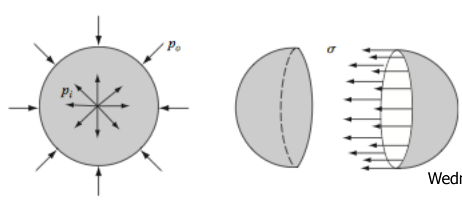
Language – Surface Tension

- The forces pushing the hemispheres apart are the differences between the internal and external pressures acting on the surfaces of the hemispheres exposed to the atmosphere (interface)

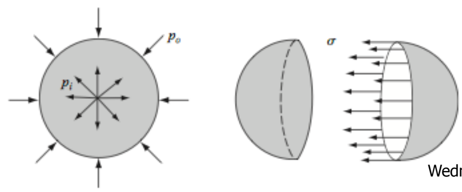
$$F = \left(p_{\text{internal}} - p_{\text{external}}\right)\left(\pi R^2\right)$$



Language – Surface Tension

- We consider a cross sectional area because we are looking at forces that would draw the hemispheres apart and therefore are normal to the cutting plane shown in the sketch

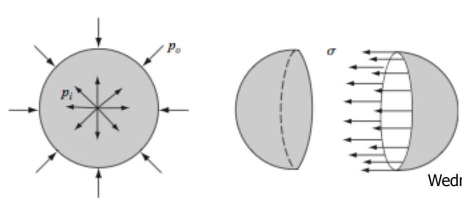
$$F = \left(p_{\text{internal}} - p_{\text{external}}\right)\left(\pi R^2\right)$$



Language – Surface Tension

- Since the droplet does not break apart, the two forces identified have to be in equilibrium

$$\sigma\left(2\pi R\right) = \left(p_{\text{internal}} - p_{\text{external}}\right)\left(\pi R^2\right)$$



Fluid Properties

- Properties of a number of common fluids are given starting in Appendix A-4 on page 729 of the 3rd Edition.

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Language

- Compressible – the density of the fluid will change with a change in pressure
- Incompressible – the density of the fluid will not change with a change in pressure

Problems

- Problem 1.12
- Problem 1.21
- Problem 1.39
- Problem 1.40

Homework

1.12 It is commonly known that there are 16 oz in 1 lb. However, Table A.2 lists the ounce as a unit of volume for liquids. Consider a $\frac{1}{2}$ lbf glass that weighs 1 lbf when filled with 8 oz of liquid. Determine the liquid density in British gravitational units and in SI units. Also calculate the specific weight in both unit systems.

1.21 A weightless plate is moving upward in a space as shown in Figure P1.21. The plate has a constant velocity of 2.5 mm/s, and kerosene is placed on both sides. The contact area for either side is 2.5 m^2. The plate is equidistant from the outer boundaries with $\Delta y = 1.2$ cm. Find the force F.

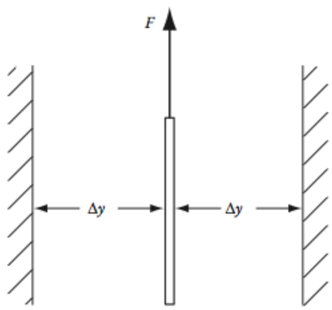

FIGURE P1.21

Homework

1.39 Calculate the pressure inside a 2-mm-diameter drop of acetone exposed to atmospheric pressure (101.3 kN/m^2).

1.40 Determine the pressure inside a water droplet of diameter 500 μm in a partially evacuated chamber where $p = 70$ kN/m^2.