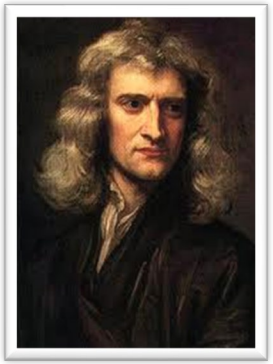
Chapter Two

Properties of fluids

Newton

1642-1727



What is fluid?

- Fluid is a substance which can flow and deform under shear stress indefinitely without returning to its original position.
- Fluid can be either gas or liquid

Flowing water

Tornado

Fluid Properties

- Every fluid has certain characteristics by which its physical conditions may be described
- The properties outlines below are general properties of fluids which are of interest in engineering
  - Mass Density/Specific Weight
  - Bulk Modulus
  - Vapor Pressure
  - Surface tension
  - Viscosity

Mass Density/Specific Weight

- Density is defined as an objects mass per unit volume. (Kg/m^3 SI Unit)

$$\rho = \frac{m}{V}$$ (mass density of water at 4℃ 1000 kg/m^3)

- Specific weight is defined as weight per unit volume (N/m^3 SI Unit)

$$\gamma = \rho g$$

- Relative Density is the ratio of the substance to the density of water at 4℃

*** *m denotes mass, g denotes acceleration of gravity*

Bulk Modulus

- Bulk modulus is defined as the ratio of the infinitesimal pressure increase to the resulting relative decrease of the volume. (Pa SI Unit)

$$K = -V\frac{dP}{dV}$$

Vapor Pressure

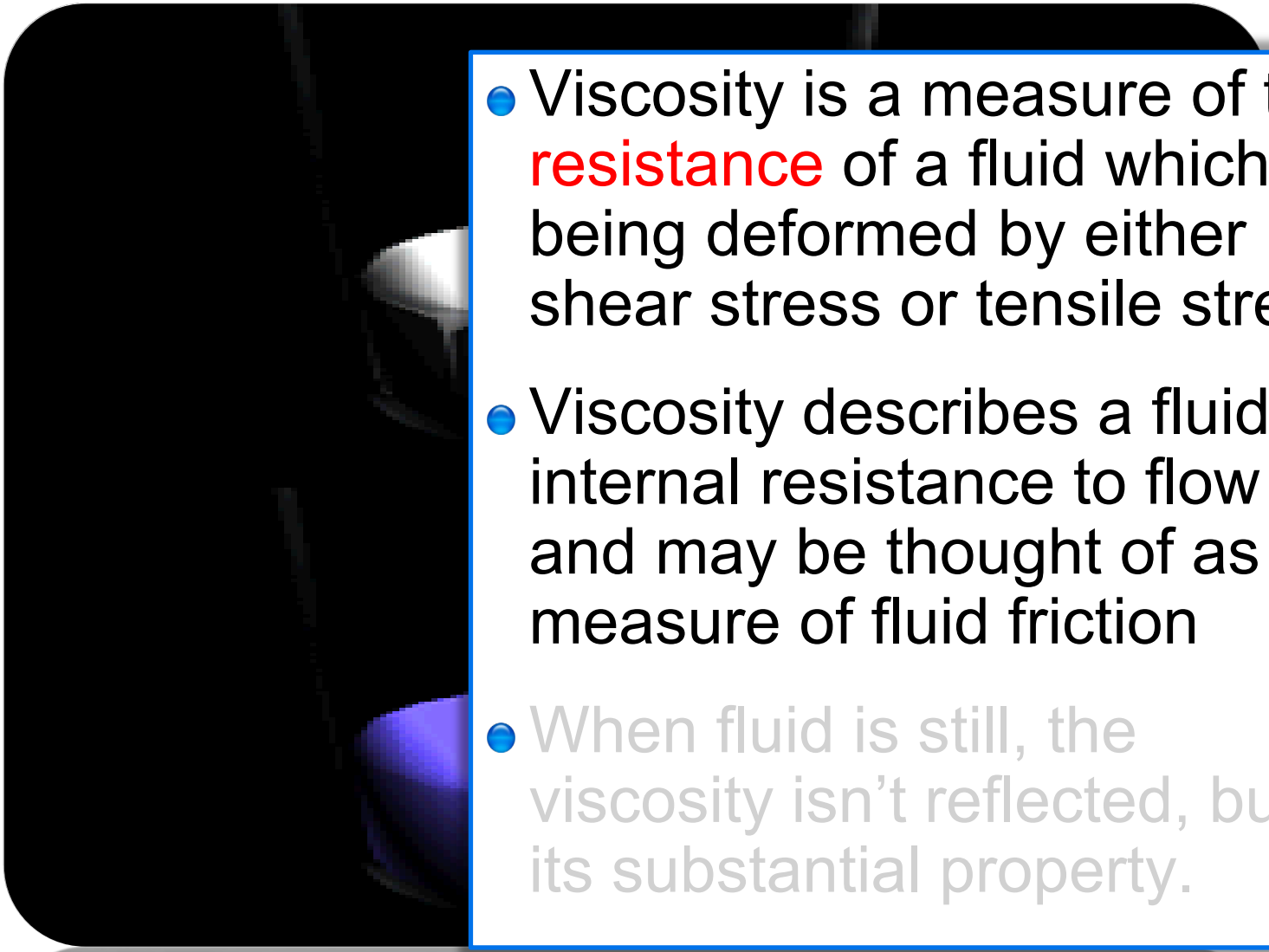
- Vapor pressure: at or below which a liquid will boil
- Vapor pressure decreases with the decrease of liquid temperature

Temperature(℃)	Pressure(atm)
−10	0. 0027
0	0. 0060
20	0. 0230
40	0. 0727
60	0. 1965
80	0. 4672
100	1. 0000
110	1. 4144

Cavitation occurs

Capillary effect

Viscosity



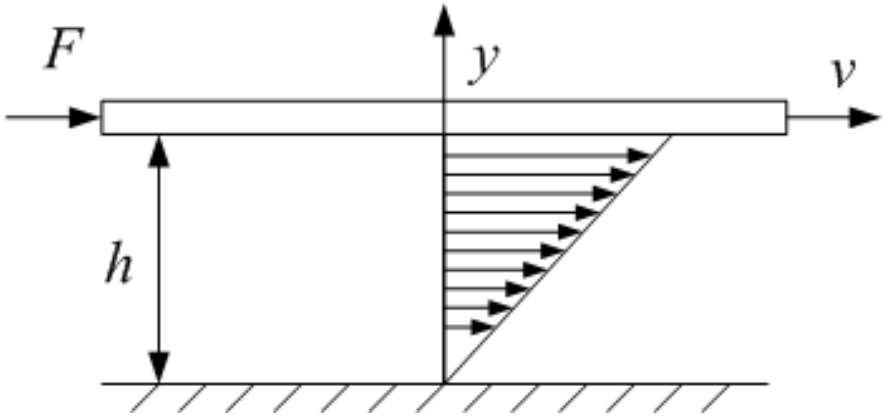
- Viscosity is a measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress
- Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction
- When fluid is still, the viscosity isn't reflected, but is its substantial property.

Newton's law of viscosity

- Newton found that

$$F \propto A\frac{v}{h}$$

A is the plate area, h is the height, and v is the plate velocity



Viscous force experiment

Differential Form:

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

Newton's law of viscosity

τ - shear stress (an applied force per unit area needed to produce deformation in a fluid) [Pa]

μ - dynamic viscosity [N•s/m²]

v - fluid velocity

y - distance from solid surface

Unit

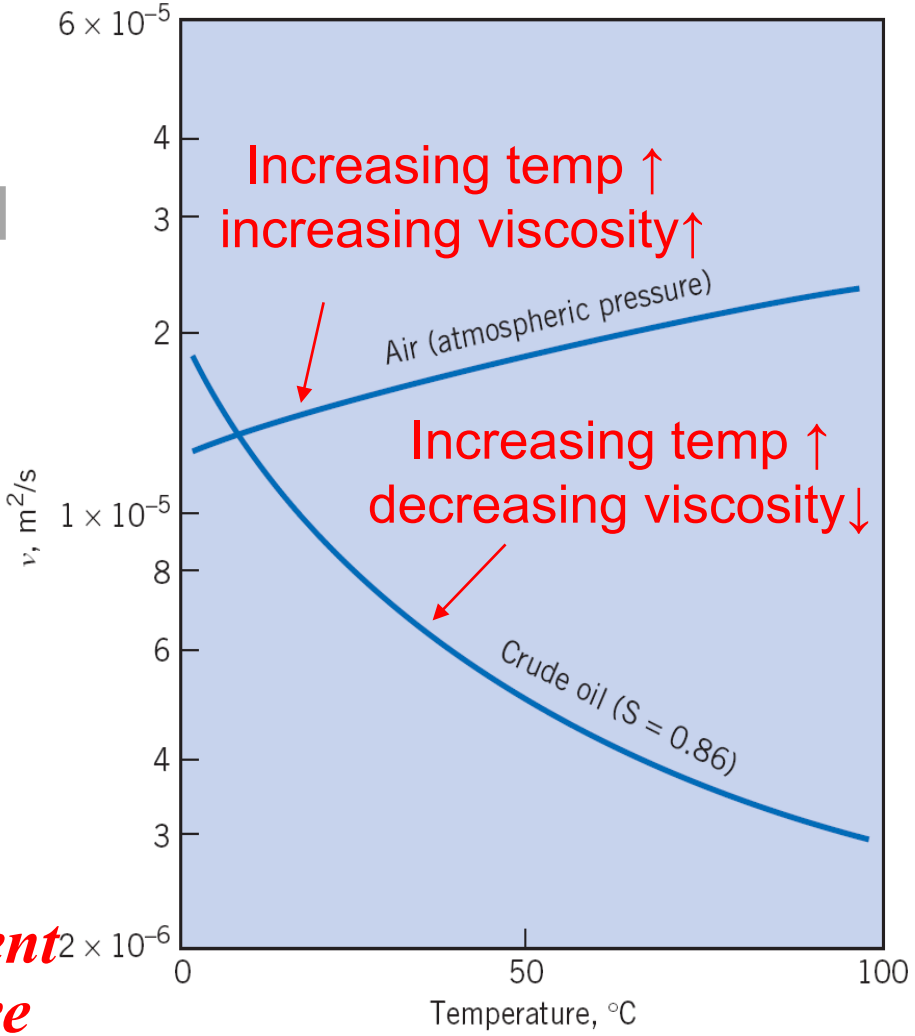
- Dynamic vicosity
  - Symbol μ
  - SI Unit Pa•s
- Kinematic viscosity
  - Symbol v
  - SI Unit m^2/s
  - $v = \mu / \rho$

Pitch has a viscosity approximately 230 billion (2.3×10^{11} Pa•s) times that of water (Year1927- now)

Note: 46# hydraulic oil means its kinematic viscosity is 46×10^{-6} m^2/s at 40 °C

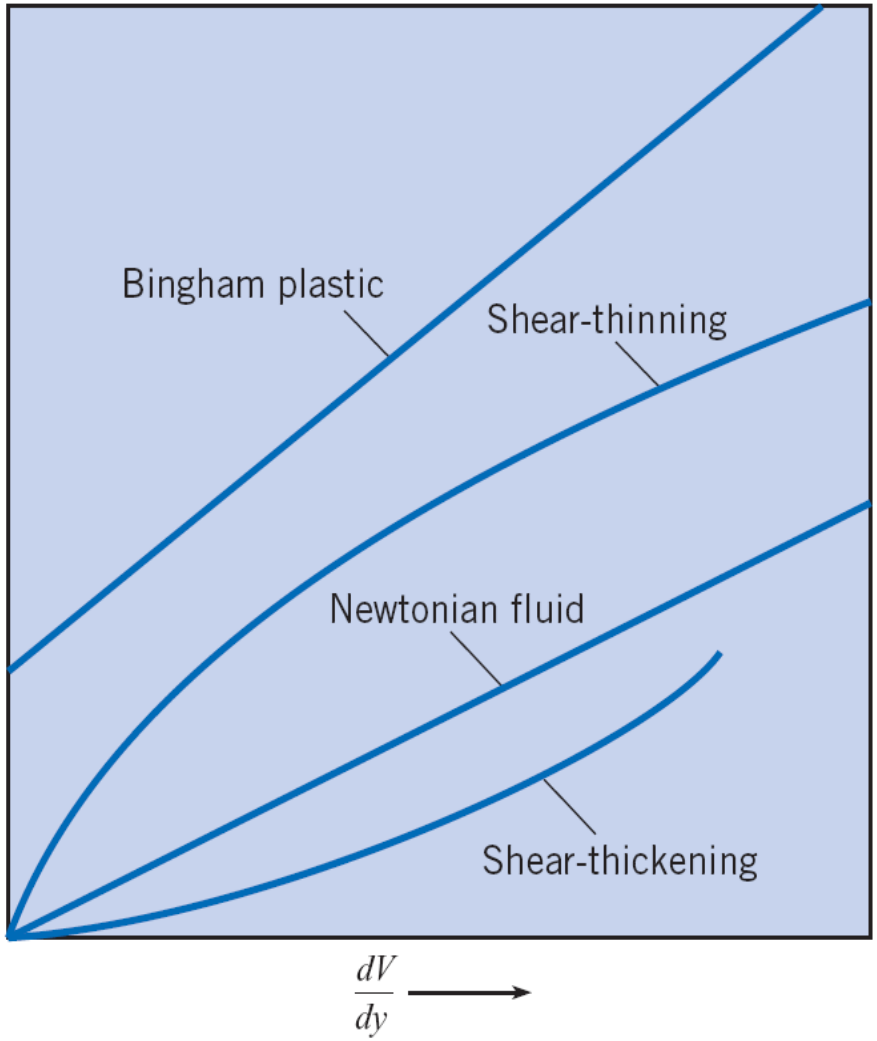
Why the fluid is viscous?

- In gases, molecular collisions transfer momentum between fluid layers
- In liquids, friction between fluid layers comes from the interattractive force of molecules sliding past each other



Note: Gas and liquid show different trends for increasing temperature

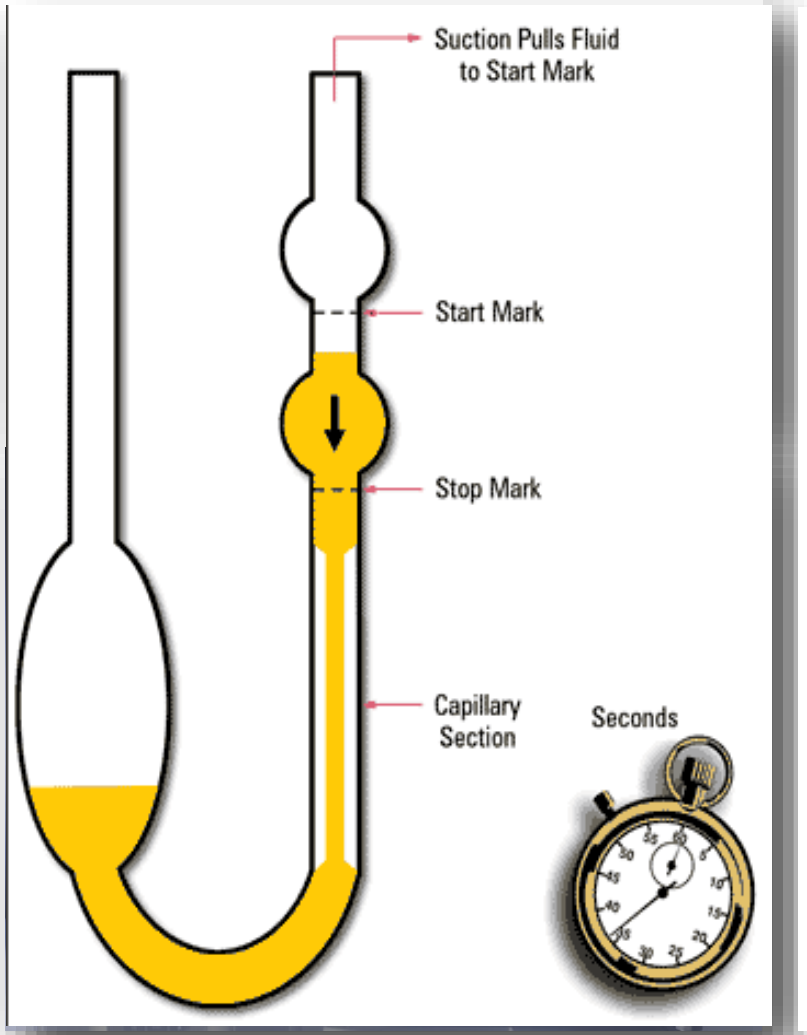
Newtonian vs. Non-Newtonian Fluids



Slope of line is dynamic viscosity

- *Newtonian fluid*:
  Shear stress is proportional to shear strain
- *Non-Newtonian fluid*:
  Shear stress is not proportional to shear strain (*not linear to shear strain or not through the zero point*),such as toothpaste, catsup, paint, gypsum-water mixtures

How to measure viscosity?



- Capillary viscometer :(*for kinematic viscosity measurement*)

  is used for those fluids which has a single value of viscosity and not sensitive to temperature

  The time taken for the level of the liquid to pass between these marks is proportional to the kinematic viscosity.

- Characteristics

  Simple, Low price

Compressible or not?

- All real fluids are compressible - even water
- If the density change of fluids in pressure is small, it can be regarded as incompressible, otherwise compressible
- In most steady conditions liquids are treated as incompressible, on the contrary gases are treated as compressible, but not always
- Incompressible fluid means ρ *is constant*

Viscous or not?

- All real fluids are viscous
- Ideal fluid is inviscid

Terminology

Compressible fluid	ρ is not constant
Incompressible fluid	ρ is constant
Ideal fluid	μ is zero
Real fluid	μ is not zero

The Continuum Assumption

- Fluids are composed of many finite-size molecules with finite distance between them. These molecules are in constant random motion and collisions
- This motion is described by statistical mechanics (Kinetic Theory)
- Within the continuum assumption there are no molecules. *The fluid is continuous*
- Fluid properties as density, velocity etc. are continuous and differentiable in space & time
- A fluid particle is a volume large enough to contain a sufficient number of molecules of the fluid to give an average value for any property that is continuous in space, independent of the number of molecules

The Continuum Assumption

- Characteristic scales for standard atmosphere:
  - atomic diameter ~ 10^{-10} m
  - distance between molecules ~ 10^{-8} m
  - mean free path, λ (sea level) ~ 10^{-7} m
- Knudsen number: $Kn = \lambda / L$

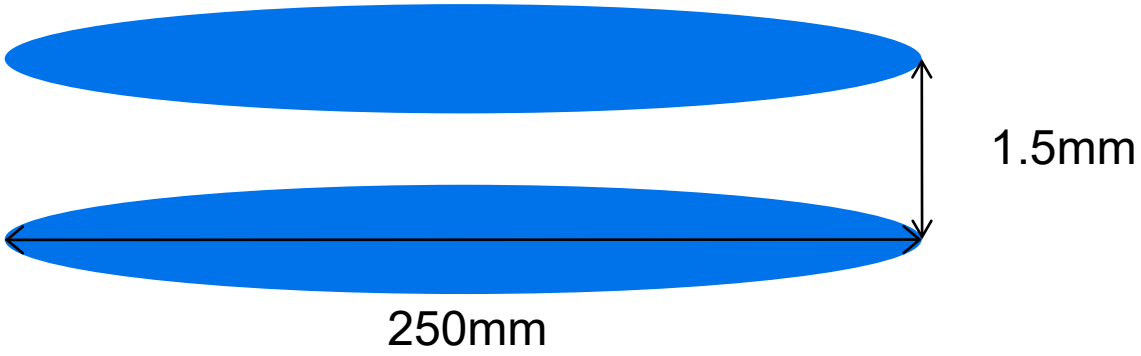
  λ - mean free path

  L - characteristic length
- L is the size of investigated object, in most cases, ~ 10^{-3}

Continuum assumption: $Kn \ll 1$

Example

- Two discs of 250 mm diameter are placed 1.5 mm apart and the gap is filled with an oil. A power of 500 W is required to rotate the upper disc at 500 rpm while keeping the lower one stationary. Determine the viscosity of the oil.



[0. 71 kg/ms]

Example

- Newton fluid is linear to du/dy, if shear stress is linear to du/dy , is it Newton fluid?