南方科技大学
SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

MAE5009
Continuum Mechanics B
Session 09: Introduction of Fluid Mechanics

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Introduction

Mechanics
- **Rigid body mechanics**
- **Nonrigid body mechanics (continuum mechanics)**
  - **Elasticity (solid elastic bodies)**
  - **Fluid mechanics**

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Introduction

- Fluid mechanics studies the statics and dynamics of fluid, i.e. flow of **fluid**
- A fluid is a substance which cannot resist a shear force or stress without moving as can a solid
- Any shear stress applied to a fluid, no matter how small, will result in motion of that fluid

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Characteristics of a fluid

Fluid

- **Liquid**
  - Intermolecular forces, possess volume but no definite shape
  - Light compressibility
  - Density varies little with temperature/pressure
- **Gas**
  - no definite volume/shape, fill any container into which it is placed
  - Large compressibility
  - Density may vary significantly with temperature/pressure

Water takes the shape of the vessel containing it

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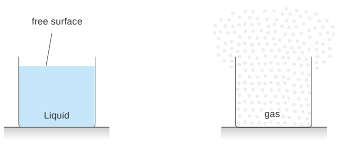
Characteristics of a fluid

- Important characteristics of fluid from fluid mechanics viewpoint: compressibility and viscosity
  - Compressibility: a fluid increases its pressure against compression, trying to retain its original volume
  - Viscosity: a fluid shows resistance when two layers slide over each other
- In general: liquids are called incompressible fluids and gases are compressible



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Characteristics of a fluid

- Density: mass per unit volume of material

$$\rho = \lim_{\Delta V \to 0} \frac{\Delta m}{\Delta V} = \frac{dm}{dV}$$

The density of a gas changes according to the pressure, while that of a liquid may be considered unchangeable in general

- Specific gravity: $s = \frac{\rho}{\rho_w}$
- Specific volume: $\upsilon = \frac{1}{\rho}$
- Specific weight: $\gamma = \rho g$

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Compressibility

- Compressibility: the volume of fluids decrease with increasing pressure
- The bulk modulus of a fluid:

$$K = \frac{\Delta p}{\Delta V / V} = -V\frac{dp}{dV}$$

- Compressibility:

$$\beta = \frac{1}{K}$$ indicates how compressible the fluid is

  - Water of normal pressure/temperature: K = 2.06×10^9 Pa, β = 4.85×10^{-10} 1/Pa, it shrinks only by ~0.005% if the atmospheric pressure is increased by 1 atm
  - For air, K = 1.4×10^5 Pa, β = 7.14×10^{-6} 1/Pa

- Incompressible fluid: β=0, no volume change under changing pressure and temperature
- Liquid can be approximated as in incompressible fluid

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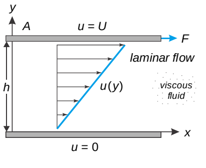
Viscosity

- Viscosity:
  - The internal stickiness of a fluid
  - A quantitative measure of a fluid's resistance to flow

- Viscosity experiments between two parallel plates:

$$F = \mu\frac{AU}{h}$$

$$\tau = \frac{F}{A} = \mu\frac{U}{h}$$



Newton's law of viscosity

- where μ is the coefficient of viscosity, or **dynamic viscosity**, Pa·s or N·s/m^2 (1 poise = 0.1 Pa·s), depends on the fluid property, temperature, and pressure
- It measures how well a fluid resists deformation
- Dynamic viscosity can also be used to distinguish solid and fluid

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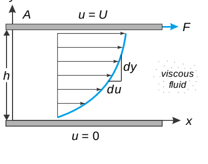
Viscosity

- Viscosity:

$$\tau = \mu\frac{du}{dy} = \mu\dot{\varepsilon} \qquad \dot{\varepsilon} = \frac{d\theta}{dt} = \frac{du \cdot dt}{dy}\Big/ dt = \frac{du}{dy}$$

  - The shear stress between fluid layers is proportional to the gradient of flow velocity
  - When du/dy=0, no relative movement between fluid layers, τ=0
  - Friction of fluid depends on velocity gradient; friction of solid depends on pressure



- **Newtonian fluids**: the shear stress τ is proportional to the velocity gradient/shear strain rate du/dy
  - Newtonian fluids: air, water, gasoline, alcohol, etc.
  - Non-Newtonian fluids: toothpaste, paint, etc.

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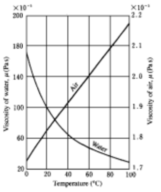
Viscosity

- Gases: increased temperature makes the molecular movement more vigorous and increases mixing so that viscosity increases
- Liquids: molecules separate from each other with increasing temperature and the attraction between them decreases, and thus results in a decreasing viscosity



  - Under high pressure, the viscosity of gases and liquids increase with increasing pressure
  - Ordinary pressure has minor influence on the viscosity of fluids
- Kinematic viscosity:

$$\nu = \frac{\mu}{\rho} \qquad \text{unit: } m^2/s$$

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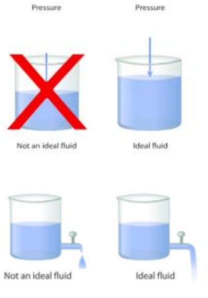
Ideal fluid or perfect fluid

- An ideal fluid is a fluid that has no internal friction or viscosity
- Ideal fluid do not actually exist in nature, but sometimes used for in particular fluid flow problems in order to simplify the problem



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Fluidity of fluid

- The most fundamental difference between fluid and solid is that the fluid can flow
- Fluid is easy to deform and flow; no specific shape; for gas, there is even no specific volume
- Solid can sustain compression, tension, bending, shear, torsion forces; fluid can only sustain compression and shear forces
- When fluid is static, it cannot sustain shear stress
- Fluid can continuously deform when subjected to constant shear stress

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