

Properties of Fluids

What Are Fluids? – Lesson 2



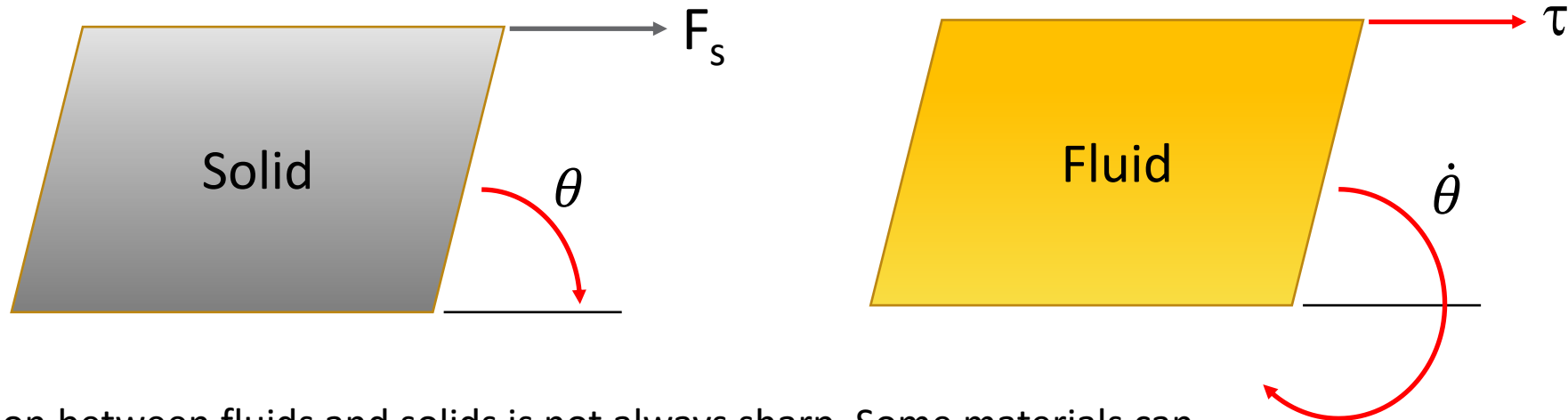
Before We Begin...Units

- Students taking this course should be familiar with units and unit conversion in science and engineering.
- We will adopt **SI** (metric) units for this course. However, real-world applications often employ other unit systems (e.g., English, CGS, etc.). Time units will be seconds unless otherwise indicated.

Quantities	SI	English
Mass	Kilogram (kg)	Pound-mass (lbm)
Length	Meter (m)	Foot (ft)
Velocity	m/s	ft/s
Acceleration	m/s ²	ft/s ²
Force	Newton (N)	Pound-force (lbf)
Pressure	Pascal (N/m ²)	lbf/ft ²
Temperature (absolute)	Kelvin (K)	Rankine (R)
Density	kg/m ³	lbm/ft ³
Viscosity	N · s/m ²	lbf · s/ft ²

What Is a Fluid?

- A fluid is a material that cannot resist a shear force without moving.
- Fluids vs. Solids
 - A **solid** deforms by an amount proportional to the applied shear stress, which is proportional to strain (Hooke's Law).
 - In contrast, a **fluid** deforms continuously when shear (tangential) forces (F_s) are exerted on it (**shear stress** is proportional to **strain rate**).



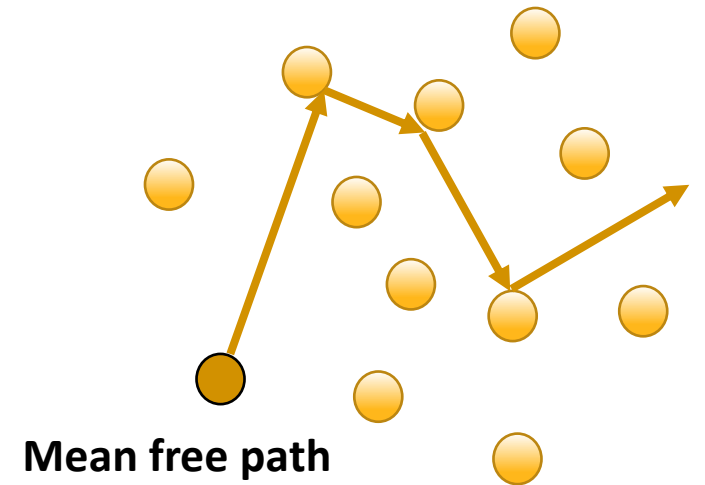
- The distinction between fluids and solids is not always sharp. Some materials can behave as liquids or solids under different conditions:
 - Granular solids in many aspects behave like fluids.
 - Metals under extreme pressures, like in a shaped charge, behave like fluids.

Fluids as a Continuum

- In order to formulate governing equations related to fluid motion, we will assume that fluids behave as a **continuous medium**, or **continuum**.
- **Continuum**: the properties at a point represent an average over a small volume whose dimension is large compared to the distance between **individual fluid molecules** (or, in gases such as helium, **atoms**), but small enough to be a point in space.
- Under the assumption of continuum, the molecular structure of the medium is ignored, and the medium is assumed to fill all the space it occupies
- A measure of the continuum assumption is the **Knudsen number (Kn)**

$$Kn = \frac{\lambda}{L} = \frac{\text{Molecular mean free path}}{\text{Characteristic length}}$$

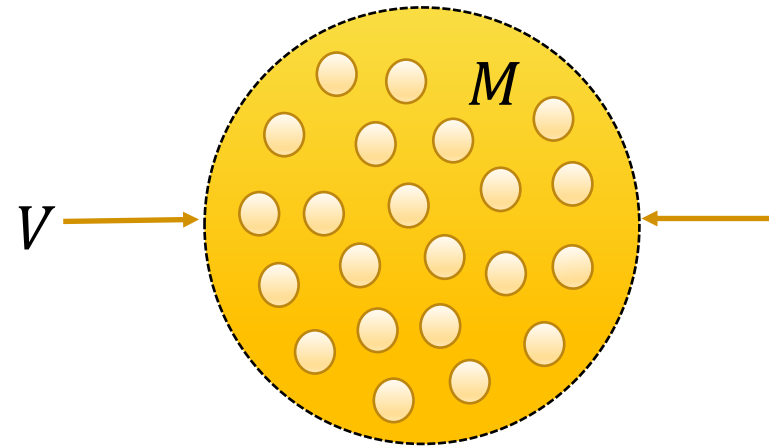
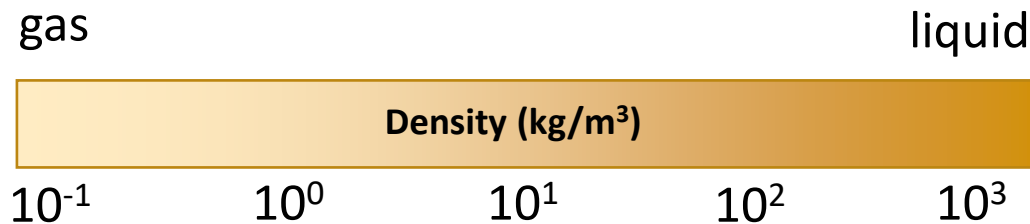
- ❖ $Kn \ll 1$ Continuum assumption is closely obeyed
- ❖ $Kn \gg 1$ Free molecule flow (rarefied gas flow)



Fluid Properties — Density

- All fluids are comprised of molecules (in gases such as Helium, atoms).
Gases – Molecules move freely, can be easily compressed
Liquids – Molecules are close together, not easily compressed
- The **mass** (M) of a fluid in a given **volume** (V) is related to the number of molecules in the volume and the molecular weight of the fluid material.
- The **density** (ρ) of the fluid is then defined as the ratio of mass of fluid to the volume as the volume shrinks to zero (continuum limit).

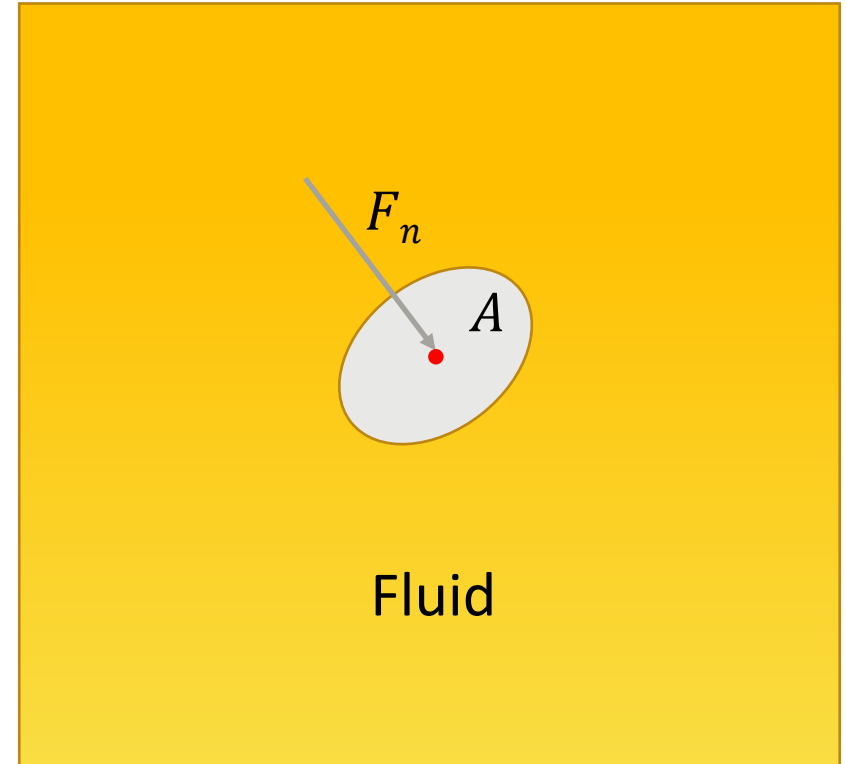
$$\rho = \lim_{V \rightarrow 0} \frac{M}{V} \quad \left[\frac{kg}{m^3} \right]$$



Fluid Properties — Pressure

- Consider a small surface (A) centered at a point within a fluid at rest.
- If the surface is at rest, the fluid will exert a **normal force** (F_n) on the surface.
- In the continuum limit as the area shrinks to zero, the normal force/area tends to a fixed value. This is how we define the fluid **pressure** (P).

$$P = \lim_{A \rightarrow 0} \frac{F_n}{A} \quad \left[\frac{N}{m^2} \right]$$



💡 Note that pressure is a **point property**, and for compressible fluids is related to the density and temperature through an **equation of state**.

Fluid Properties — Viscosity

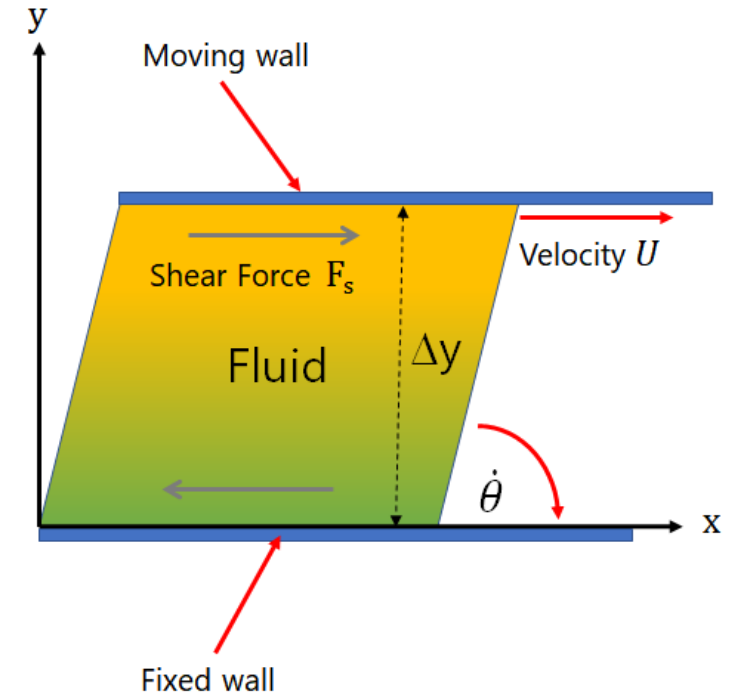
- A fluid's viscosity is a measure of its resistance to deformation due to the internal friction of a moving fluid.
- Consider a fluid layer between two walls of height Δy . The top wall is in motion with velocity U relative to the lower fixed wall.
- For a fluid, it is found that the shear force per unit area (τ) is proportional to the velocity gradient as follows:

$$\tau = \frac{F_s}{A} = \mu \frac{U}{\Delta y}$$

- This relation also holds in differential form at any point in the fluid:

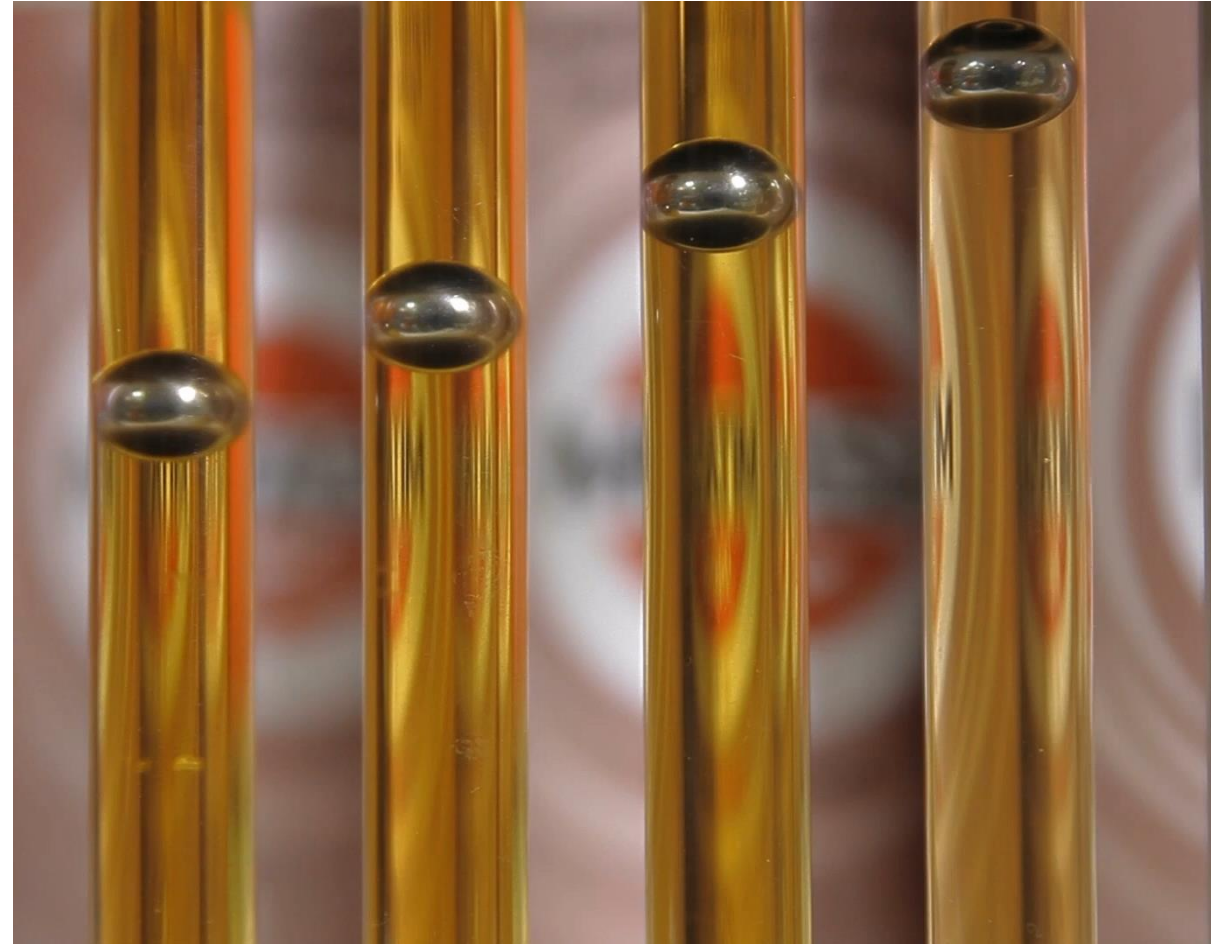
$$\tau = \mu \frac{\partial U}{\partial y}$$

- It is known as **Newton's law of viscosity**, and the parameter μ is called the **viscosity** (which is referred to as **dynamic viscosity**) with the units of $\text{N} \cdot \text{s}/\text{m}^2$.
- For many fluids, the viscosity μ is approximately constant. However, it can be a function of temperature and chemical composition. For some materials, the viscosity is highly variable and a function of the velocity; and these are classified as **non-Newtonian fluids**.



Physical Effect of Viscosity

- Steel spheres of equal size are dropped simultaneously into tubes filled with engine oils of different viscosities.
- The spheres sink due to the gravitational force acting on them.
- The friction force (**drag**) acting on a sphere's surface is greatest for the tube filled with the highest viscosity liquid — hence, that sphere falls more slowly than the others.



Lowest Viscosity

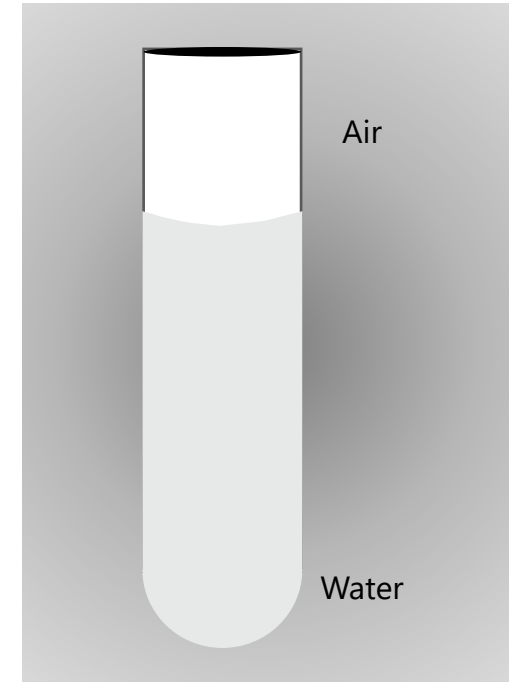
Highest Viscosity

Fluid Properties — Surface Tension

- Another fluid property that is important for free surface physics is the **surface tension** (σ) with units of $\text{N} \cdot \text{m}$.
- Physically, the surface tension represents the tendency of a fluid surface to shrink into the minimum surface area possible.
- The surface tension force acts tangential to a fluid-fluid interface and gives rise to a pressure difference across the interface.
- The surface tension force exists at an interface between two immiscible fluids. The most common is a liquid-gas interface. In a narrow tube, this interface exhibits a concave or convex shape depending on whether the tube wall is hydrophilic or hydrophobic, respectively.
- Surface tension can even induce motion in narrow tubes. This effect is known as **capillary action**.
- The capillary pressure difference across the interface between two static fluids is described by the Young-Laplace equation:

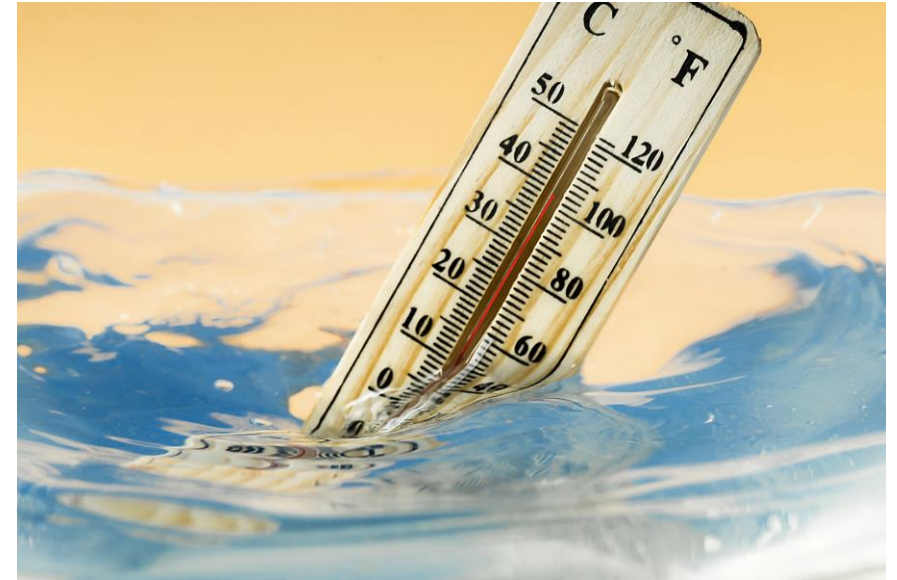
$$\Delta p = \sigma \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

where R_1 and R_2 are principal radii of the surface



Fluid Properties — Temperature

- Temperature is a measure of the internal thermal energy in the system.
- The temperature of any body (solid or fluid) is defined by the **zeroth law of thermodynamics**, which states:
Two bodies which are in thermal equilibrium with a third body are in thermal equilibrium with each other.
- Thus, we can measure **temperature** by observing how the fluid's thermal energy causes changes in another body — for example, how the mercury level in the bulb of a thermometer reacts to the fluid surrounding it.
- Like other properties, temperature is a function of space and time in a fluid and can be linked to density and pressure through a **thermodynamic equation of state**.
- Temperature has SI units of Kelvin (K).




Thermodynamics of Fluids

- For a pure, compressible substance, it is known from observations that the **state** of the substance can be defined by three properties: density, pressure and temperature.
- If two properties are known, the third can be determined from an **equation of state**:

$$P = f(\rho, T)$$

- It should be noted that the thermodynamic state also implies the **phase** of the substance (solid, liquid, gas). The associated 3D plot is called a **phase diagram**.

 NOTE: In basic fluid mechanics, we concern ourselves primarily with fluids in the liquid or gaseous phases, since the behavior of these fluid phases conform to our definition of a fluid given earlier. We also exclude, for now, mixtures of phases such as bubbles in a liquid, which is the subject of multiphase fluid dynamics (and thus beyond the scope of our current course).

Thermodynamic Properties

- From thermodynamics, there are several fluid properties that become important when compressibility and/or heat transfer effects are important.
 - **Specific Heat (C_p, C_v)** – Ratio of heat absorbed by a substance per unit mass to the change in temperature ($J/kg \cdot K$)
 - **Speed of Sound (c)** – Speed at which pressure waves propagate through a fluid (m/s)
 - 💡 At standard sea level, the speed of sound in still air is 340.9 m/s.
 - **Thermal expansion coefficient (β)** – Measure of volume change of a substance with respect to temperature, important in the study of natural convection (1/K).
 - **Thermal Conductivity (k)** - Ratio of the heat flow per unit area through a substance to the local temperature gradient ($W/(m \cdot K)$). Thermal conductivity will be very important in the study of **heat transfer** in fluids and solids.

Summary

- We have discussed what a fluid is in terms of its basic properties, specifically:
 - Continuum
 - Reaction to forces
 - Density
 - Pressure
 - Temperature
 - Surface tension
 - Thermodynamic properties
- These properties will be important when we begin to examine the physical laws which govern the motion of fluids.



 **Ansys**

