Fluid Properties of State

This lecture focuses on the key "Properties of State", which are defined as properties that can be measured at a single point in time. They require no knowledge of past or future conditions.

Properties of state describe the state of the substance right now.

Primary Dimensions

In fluid mechanics, there are only four primary dimensions, from which all other dimensions can be derived. All other variables in a fluid mechanics can be expressed in terms of these units.

Some notes about units....

- Standard units vary widely within industry
- While SI is most common, Imp units are quite common and must be well understood
- People can die when units are not converted properly

1. **Temperature (T)** - Related to the internal energy of a fluid. A measure of the atomic scale vibration.
    - SI Unit - Kelvin (K)
    - Imp Unit - Rankine (°R)
    - Conversion factor - 1 K = 1.8 °R
    - °R = °F + 459.69
    - K = °C + 273.16

2. **Length (L)** - The distance from one end of something to the other
    - SI Unit - meter (m)
    - Imp Unit - foot (ft)
    - Conversion factor - 1 ft = 0.3048 m

3. **Mass (*m*)** - How much inertia can it have? A measure of an object's resistance to changing it's state of motion when a force is applied.
    - SI Unit - kilogram (kg)
    - Imp Unit - slug
    - Conversion factor - 1 slug = 14.59 kg

4. **Time (t)** - The measured or measurable period during which an action, process, or condition exists or continues. How long does it take?
    - SI Unit - second (s)
    - Imp Unit - second (s)

Secondary Dimensions

1. **Force (F)** - The time rate of change of momentum. Newton's 2nd Law.
   - F = ma
   - SI Unit - N = 1 kg · 1 m/s^2
   - Imp Unit - lbf = 1 slug · 1 ft/s^2
   - Conversion factor - 1 lbf = 4.4482 N

2. **Area (A)** - The quantity that expresses the extent of a two-dimensional figure or shape, or planar lamina, in the plane.
   - SI Unit - meter (m^2)
   - Imp Unit - foot (ft^2)
   - Conversion factor - 1 m^2 = 10.764 ft^2

3. **Volume (V)** - The amount of space that a substance or object occupies, or that is enclosed within a container.
   - SI Unit - m^3
   - Imp Unit - ft^3
   - Conversion factor - 1 m^3 = 35.315 ft^3

4. **Velocity (*v*)** - Physical vector quantity; both magnitude and direction are needed to define it. The magnitude of velocity is called "speed".
   - SI Unit - m/s
   - Imp Unit - ft/s
   - Conversion factor - 1 ft/s = 0.3048 m/s

5. **Acceleration (*a*)** - The rate of change of velocity
   - SI Unit - m/s^2
   - Imp Unit - ft/s^2
   - Conversion factor - 1 ft/s^2 = 0.3048 m/s^2

6. **Pressure or Stress (p)** - Compression stress at a point in a static fluid. Differences in pressure often drive a fluid flow, especially in ducts.
   - SI Unit - Pa = N/m^2
   - Imp Unit - lbf/ft^2
   - Conversion factor - 1 lbf/ft^2 = 47.88 Pa

7. **Density (ρ)** - Mass per unit volume. Density in liquids is nearly constant but highly variable in gasses. Density of water is about 1000 kg/m^3. Liquids are often treated as "incompressible", meaning density does not change with pressure.
    - SI Unit - kg/m^3
    - Imp Unit - slugs/ft^3
    - Conversion factor - 1 slugs/ft^3 = 515.4 kg/m^3

8. **Specific volume (υ)** - The amount of volume occupied by 1 unit mass in a substance.
    - $\upsilon = \frac{1}{\rho}$
    - SI Unit - m^3/kg
    - Imp Unit - ft^3/slugs

9. **Energy (E)** - The ability to do work.
    - SI Unit - J = N · m
    - Imp Unit - ft · lbf
    - Conversion factor - 1 ft · lbf = 1.3558 J

10. **Power (P)** - The amount of energy put out or produced in a given amount of time.
    - SI Unit - W = J/s
    - Imp Unit - ft · lbf/s
    - Conversion factor - 1 ft · lbf/s = 1.3558 W

11. **Volume flow rate ($\dot{Q}$)** - The volume of fluid which passes per unit time
    - $\dot{Q} = \frac{V}{\Delta t}$
    - SI Unit - m^3/s
    - Imp Unit - ft^3/s
    - Conversion factor - 1 m^3/s = 35.3147 ft^3/s

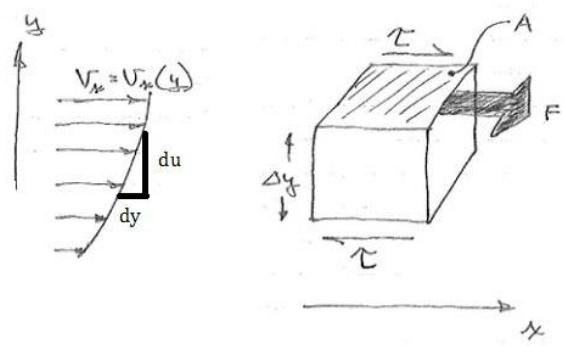
12. **Volume flow rate ($\dot{m}$)** - The volume of fluid which passes per unit time
    - $\dot{m} = \frac{m}{\Delta t}$
    - SI Unit - m^3/s
    - Imp Unit - ft^3/s
    - Conversion factor - 1 m^3/s = 35.3147 ft^3/s

13. **Viscosity (μ)** - Quantitative measure of a fluid's resistance to flow. We can easily move through air, which as very low viscosity. Movement is more difficult in water, which has 50 times higher viscosity than air. SAE 30 oil is 300 times more viscous than water.

- SI Unit - kg / (m · s)
- Imp Unit - slugs / (ft · s)
- Conversion factor - 1 slug / (ft · s) = 47.88 kg / (m · s)

Determines the fluid strain rate that is generated by a given applied **shear stress (τ)**.

Shear stress (τ) = F / A, N/m²



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

Where:

- $u = V_x$
- $\frac{du}{dy}$ = slope of the velocity distribution up the y-axis

Therefore, the applied shear stress is proportional to the velocity gradient for common linear fluids. The constant of proportionality is the viscosity coefficient, μ.

Dimensionless Analysis:

$$\left[\frac{\tau}{\frac{dU}{dy}} \rightarrow \frac{N/m^2}{\frac{m/s}{m}} = \frac{N-s}{m^2} = Pa-s \right]$$

UNITS OF VISCOSITY

14. **Kinematic Viscosity (υ)** - A measure of the resistance to flow, equal to the absolute viscosity divided by it's density.

- $\upsilon = \frac{\mu}{\rho}$

Units:

$$\frac{\frac{N-s}{m^2}}{kg/m^3} \quad \text{or} \quad \frac{\frac{kg-m}{s^2} \times s \times m^3}{kg \times m^2}$$

$$\rightarrow \frac{m^2}{s}$$

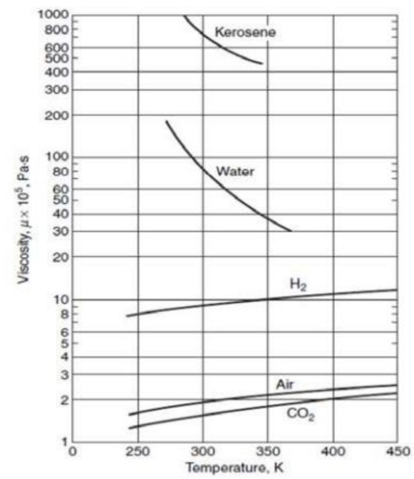


Figure 7.5 Viscosity–temperature variation for some liquids and gases.