Fluid Mechanics

Fundamental Concepts

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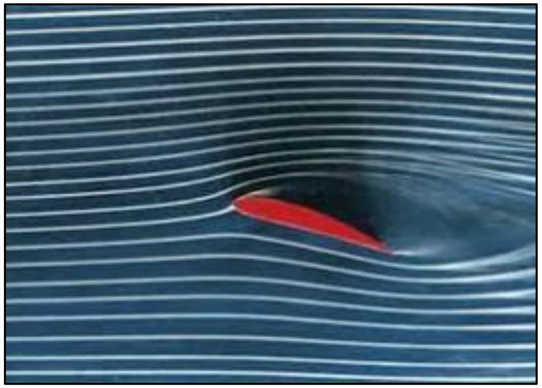
Outline

- Fundamental Concepts
- Viscosity
- Surface Tension





Office Hour: 9:00am~10:00am Friday, my office / online

Fundamental Concepts

- Fluid

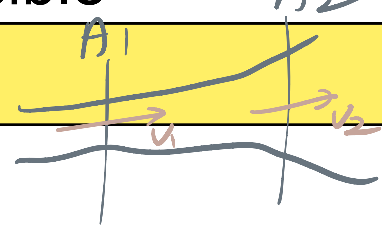
連續的變形

- Continuum model (古典力學)

忽略不連續的行為、不考慮奈米粒子、連續行為

體積不變

- Incompressible vs compressible

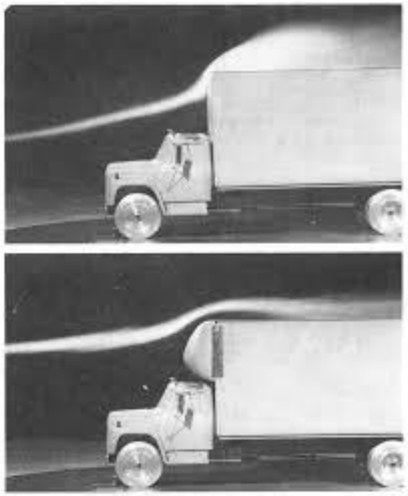


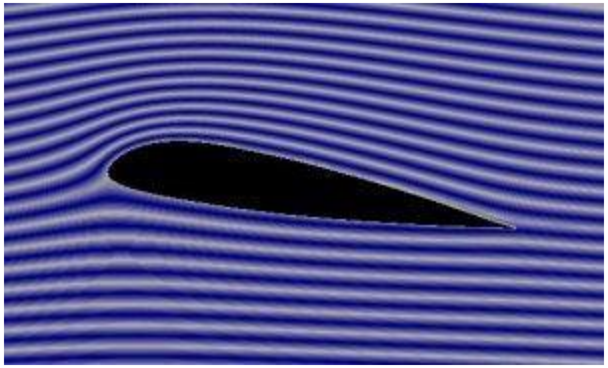
$A_1V_1 = A_2V_2 = \frac{dV}{dt}$

- Steady or unsteady

Fundamental Concepts

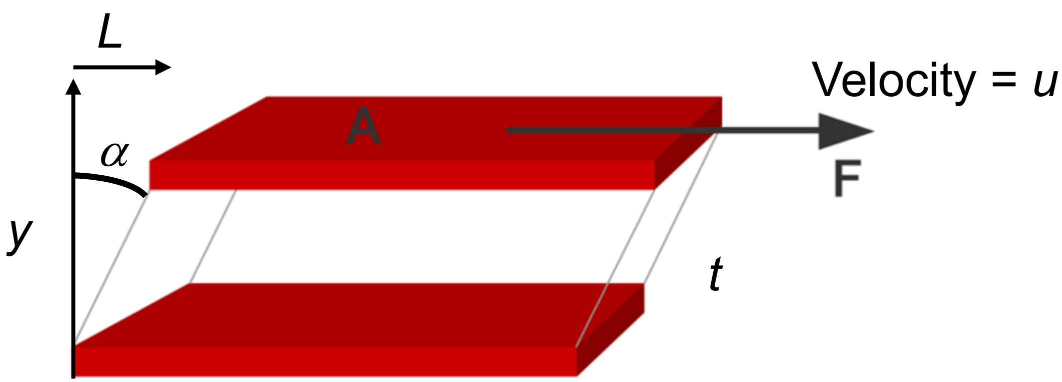
- External flow





- Internal flow
- No-slip
- Boundary layer

- Flow between two plates



$$\frac{d\alpha}{dt} = \frac{du}{dy}$$ (Shear rate) 剪變率 ⇨ Shear stress : $\tau = \mu \frac{du}{dy}$

$\mu \rightarrow \left(\frac{M}{Lt}\right)$

Viscosity 黏度

$\frac{g}{cm \cdot \sec} = \mathrm{cP}$

Poise (泊)

水= 1cP

Fundamental Concepts

- Laminar flow
  - Organized, in layers
- Turbulent flow
  - Disorganized, random

Fundamental Concepts

- Reynolds number, Re
  - Ratio inertia to viscous
  - The Reynolds Number and Flow around Objects:
    - https://www.youtube.com/watch?v=0ThQ_nD97hY
    - Start @ 0:30~
- Mach number, Ma
  - Ratio speed of object/fluid to speed of sound
  - Subsonic, sonic, supersonic, hypersonic
  - Sonic Boom (https://www.youtube.com/watch?v=OEmiTYtW5cs)

Fundamental Concepts

- System
- Surroundings
- Boundary
- Closed system = control mass
- Open system = control volume

Fundamental Concepts

- Mass
- Specific gravity vs specific weight
- Pressure
  - Measurement
  - Unit

Fundamental Concepts

- Ideal Gas Model
- Vapor Pressure
- Cavitation:
  - Cavitation is a phenomenon in which the static pressure of a liquid reduces to below the liquid's vapor pressure, leading to the formation of small vapor-filled cavities in the liquid.

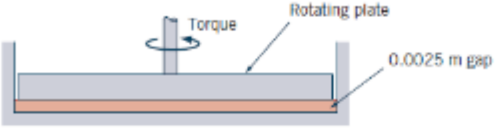
TABLE 18–2 Saturated Vapor Pressure of Water

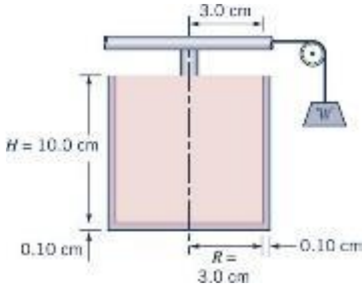
Temperature (°C)	Saturated Vapor Pressure torr (= mm-Hg)	Pa (= N/m²)
−50	0.030	4.0
−10	1.95	2.60×10^2
0	4.58	6.11×10^2
5	6.54	8.72×10^2
10	9.21	1.23×10^3
15	12.8	1.71×10^3
20	17.5	2.33×10^3
25	23.8	3.17×10^3
30	31.8	4.24×10^3
40	55.3	7.37×10^3
50	92.5	1.23×10^4
60	149	1.99×10^4
70†	234	3.12×10^4
80	355	4.73×10^4
90	526	7.01×10^4
100‡	760	1.01×10^5
120	1489	1.99×10^5
150	3570	4.76×10^5

†Boiling point on summit of Mt. Everest.
‡Boiling point at sea level.

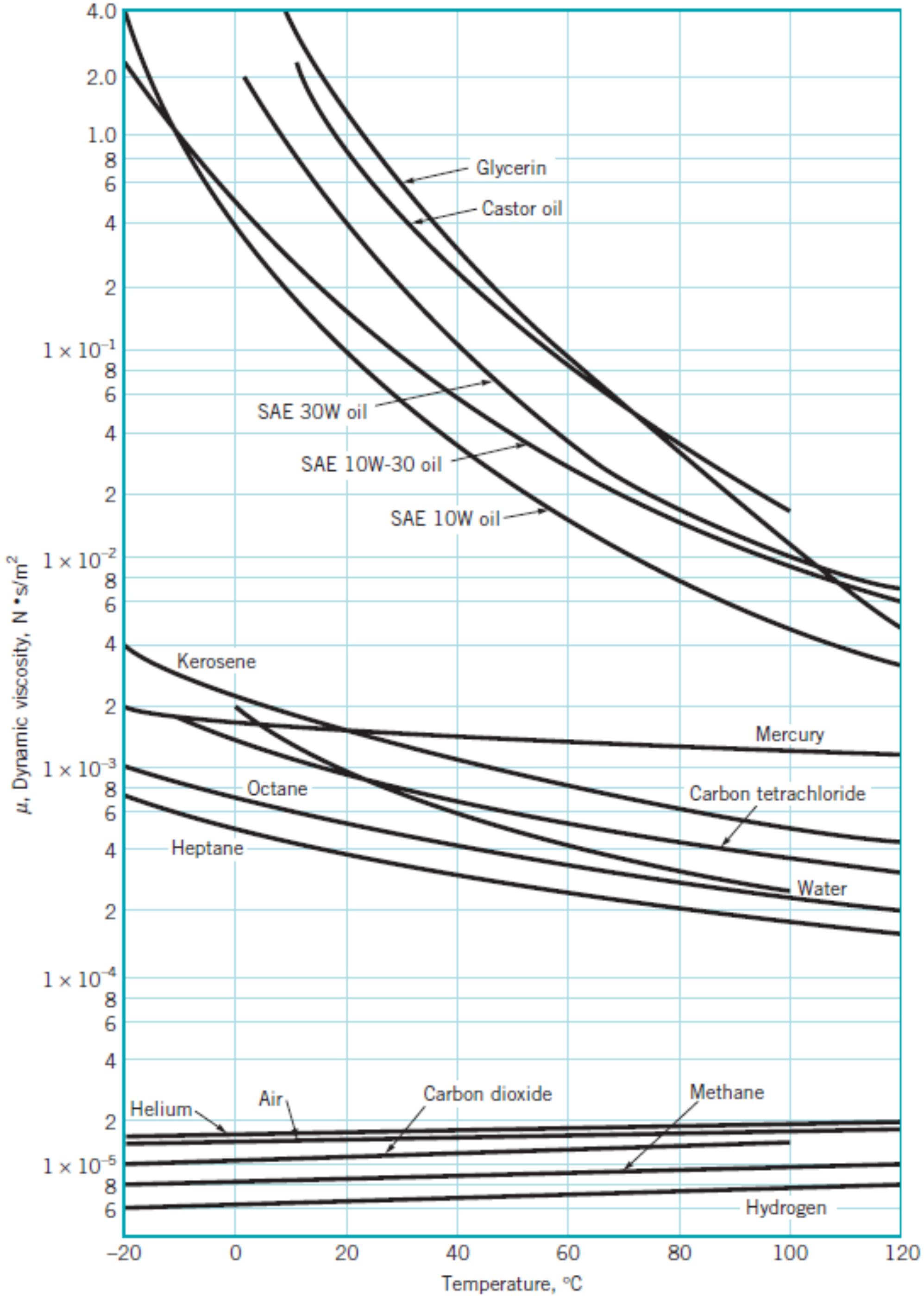
Viscosity

- Viscosity is a measure of a fluid’s resistance to shear – more viscous, more resistance
- Intrinsic property of a fluid (varies with temperature)
- Viscosity causes fluids to adhere to solid boundaries.
  - Engine oil
  - https://www.youtube.com/watch?v=V5a4kP-5Jiw
  - Example 2.2 (take home)
  - Two homework problems (HW1)



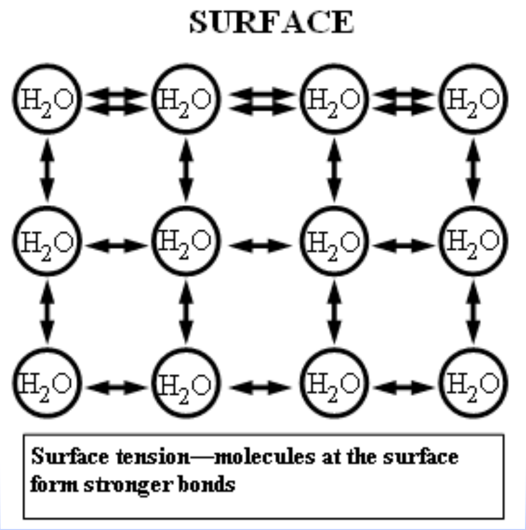


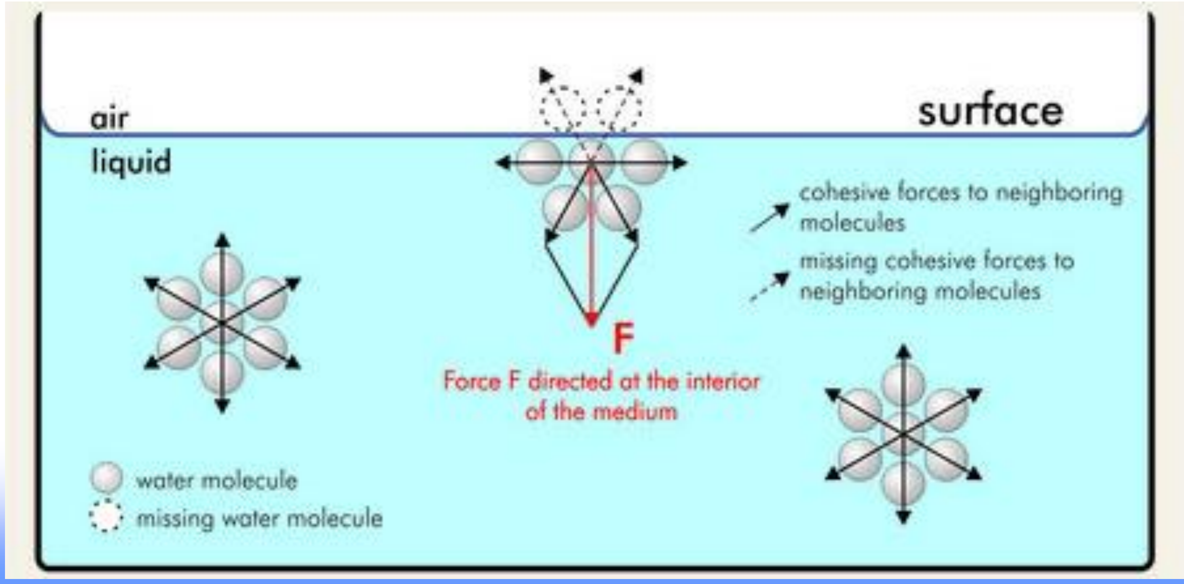
- Observations show shear stress is proportional to velocity gradient
- (Dynamic) viscosity (μ) is the constant or proportionality
- Kinematic viscosity ($\nu = \nu/\rho$) is also commonly used


Glycerin
Castor oil
SAE 30W oil
SAE 10W-30 oil
SAE 10W oil
Kerosene
Mercury
Octane
Carbon tetrachloride
Heptane
Water
Helium
Air
Carbon dioxide
Methane
Hydrogen
μ, Dynamic viscosity, N•s/m²
Temperature, °C
4.0
2.0
1.0
1 × 10⁻¹
1 × 10⁻²
1 × 10⁻³
1 × 10⁻⁴
1 × 10⁻⁵
–20
0
20
40
60
80
100
120

Surface Tension

- Is a property of fluid that is important at interfaces between different fluids. The different molecular dynamics on each side of the interface lead to surface tension.
- Sensitive to changes in chemical composition (i.e. you can change surface tension easily by dissolving a solute in a fluid)
- How insects walk on water; how droplets form in a specific shape

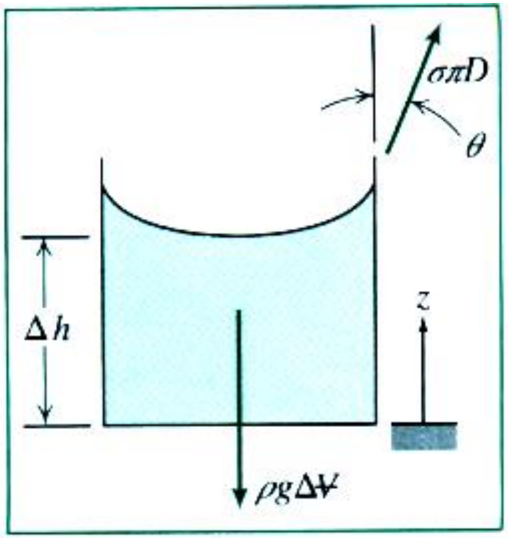




Capillary Rise

Example 2.3 ANALYSIS OF CAPILLARY EFFECT IN A TUBE

Create a graph showing the capillary rise or fall of a column of water or mercury, respectively, as a function of tube diameter D. Find the minimum diameter of each column required so that the height magnitude will be less than 1 mm.



Given: Tube dipped in liquid as in Fig. 2.12

Find: A general expression for Δh as a function of D.

Solution: Apply free-body diagram analysis, and sum vertical forces.

Governing equation:

$$\sum F_z = 0$$

Assumptions:

1 Measure to middle of meniscus,

2 Neglect volume in meniscus region,

Summing forces in the z direction:

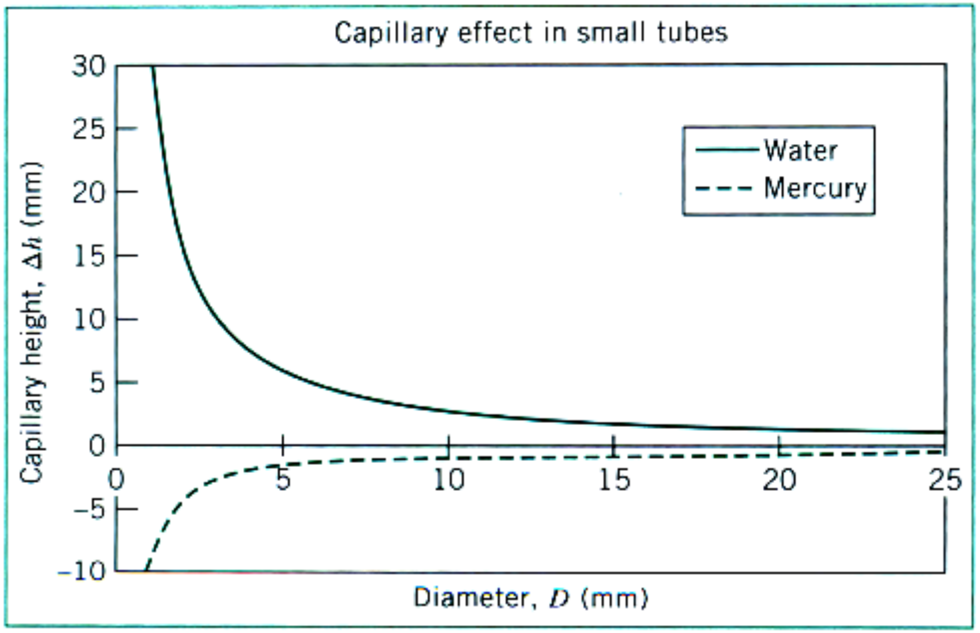
$$\sum F_z = \sigma\pi D \cos\theta - \rho g \Delta V = 0 \qquad (1)$$

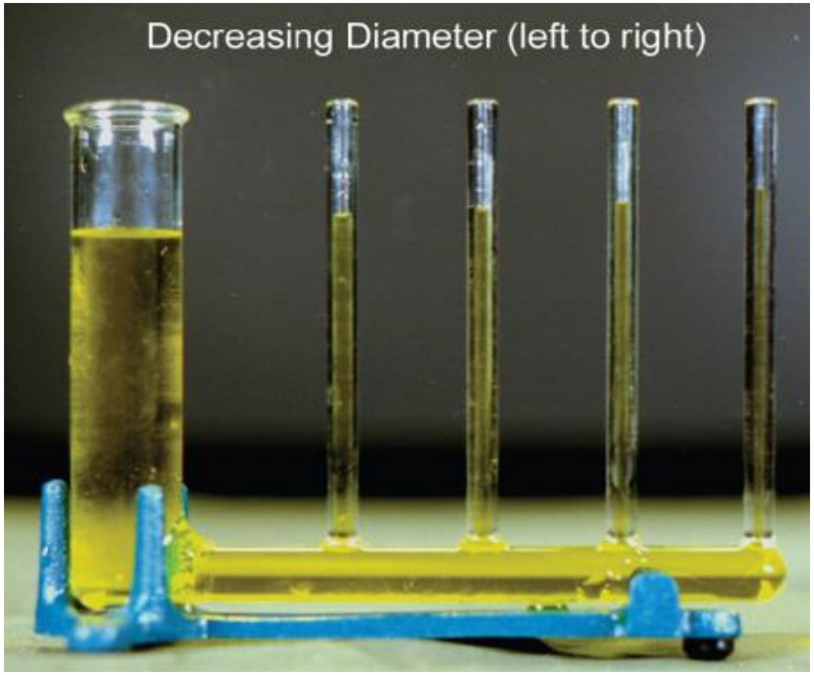
$$\Delta h = \frac{4\sigma\cos\theta}{\rho g D}$$

Δl

For water, $\sigma = 72.8$ mN/m and $\theta \approx 0°$, and for mercury, $\sigma = 484$ mN/m and $\theta = 140°$

Capillary Rise



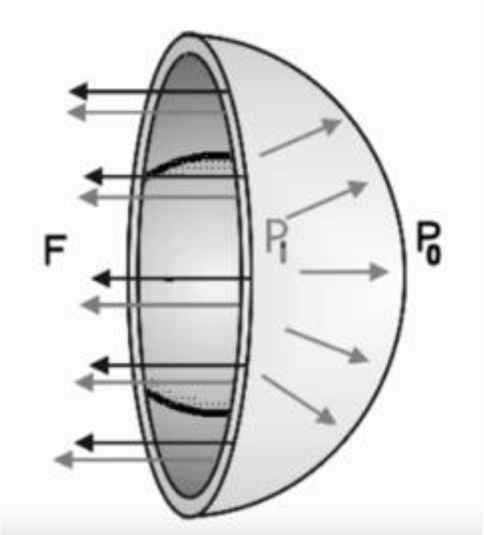


Using the above equation to compute $D_{\min}$ for $\Delta h = 1$ mm, we find for mercury and water

$$D_{M_{\min}} = 11.2 \text{ mm} \quad \text{and} \quad D_{W_{\min}} = 30 \text{ mm}$$

Surface Tension

Liquid	Surface tension (N/m)
Water (20C)	0.073
Water (100C)	0.059
Soapy water (20C)	0.025
Alcohol	0.022
Glycerine	0.063
mercury	0.513



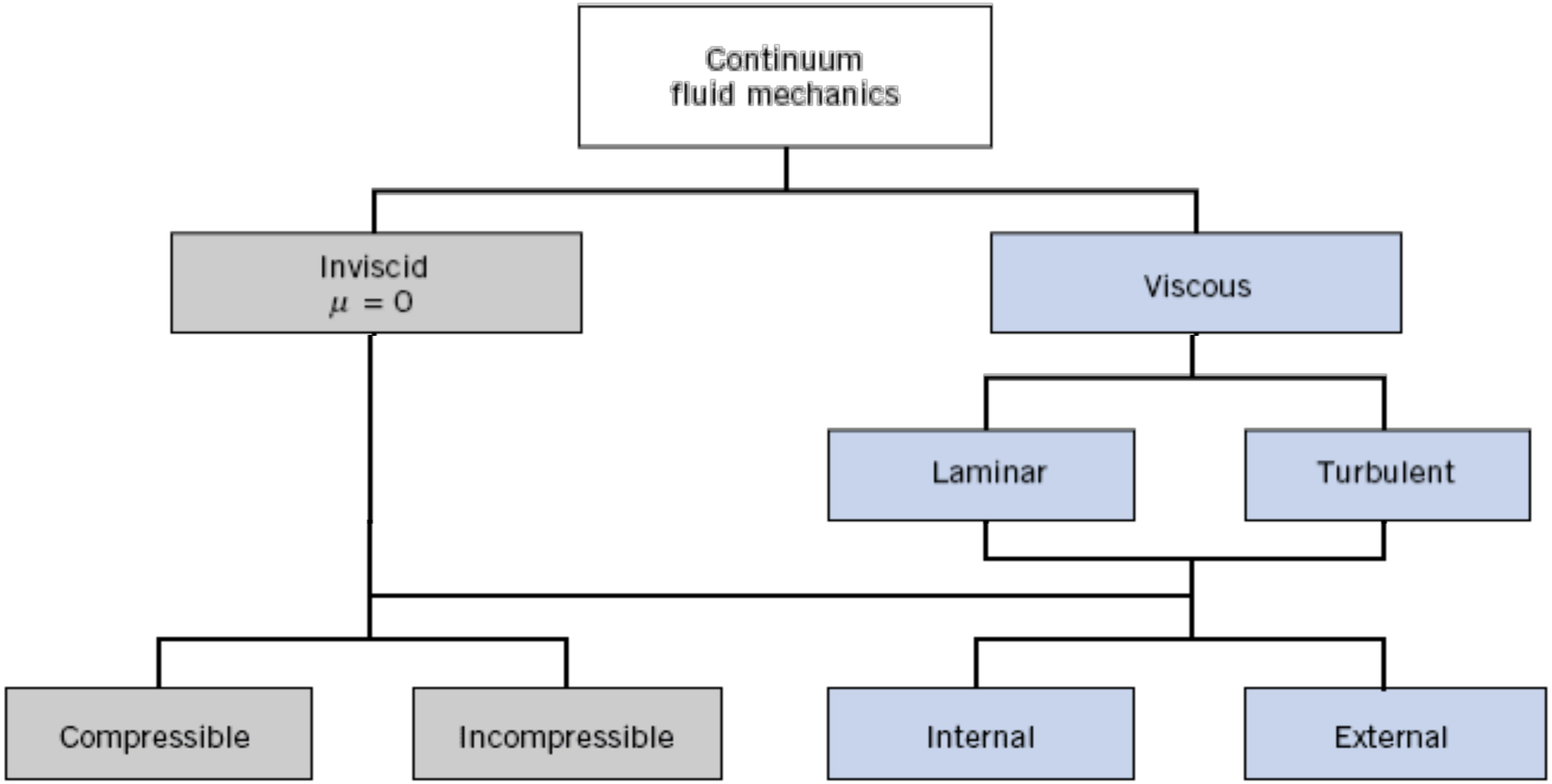


Fig. 2.13 Possible classification of continuum fluid mechanics.

Eng. Math & Fluidic Static Review

- Solve: $\frac{dy}{dt} = -ay + b$