1. Flow Regime Classification
   - Newtonian vs Non-Newtonian

\[ \tau_w = \mu \left( \frac{\partial u}{\partial y} \right) \]

- Viscosity Measurement
  - Co-cylinder viscometer

- Density Measurement
• Compressible vs Incompressible

\[ M \equiv \frac{u}{a} \]

\[ a^2 \equiv \left( \frac{\partial p}{\partial \rho} \right)_s = \begin{cases} \gamma RT & \text{ideal gas} \\ \frac{E}{\rho} & \text{liquid} \end{cases} \]

\[ M \leq 0.2 - 0.3 \quad \text{Incompressible} \]
\[ M > 0.3 \quad \text{Compressible} \]

• Laminar vs Turbulent
  o Critical \( R_{cr} \)
  o Turbulent “eddy” transport

• Flow Separation and Reverse flow

2. Flow Pattern Measurement

• Tracer & Flow representation
  o Tracers:
    - Aerosols
    - Bubbles (in liquid)
    - Solid Particles (in liquid)
    - Radioactive solids
  o Slip velocity (error margin in velocity)
    - By gravity (terminal velocity)
    - By inter-particle or wall collisions

\[ F_D = C_D \frac{1}{2} \rho A (u - u_i) |u - u_i| \]

\[ C_D \]

\[ R_c \]
Optical Image
  - Optical reflection and deflection

Parallel window

Spatial resolution (by pixel numbers)
Time resolution
  - Refreshment frequency
  - D/A sampling frequency

Trajectory vs Streamline
  - “Laminar & Steady state”
  - “Turbulent & unsteady state”; time averaged

Effect of diffusion
  - Brownian diffusion
  - Turbulent diffusion

3. Flow Rate Measurement
   - Absolute method
     - Weigh tank

For incompressible and inviscid fluids
  - Venturi
Orifice

\[ Q_{th} = \frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{\frac{2\Delta p}{\rho}} \]

\[ \dot{Q} = C \cdot Q_{th} \]

Where, C: Discharge coefficient

- For Viscous fluid
  - Rotameter
$F_D - F_p = mg$

- Representative probe in fully-developed flow

- Viscous friction in pipe flow

Moody Chart
Laminar:

\[ Q = \frac{\pi D^4 \Delta p}{128 \mu L} \]

4. Flow Velocity Measurement

- Incompressible and invicid fluid
  - Pitot tube
    \[ \Delta P = P_T - P \]
    \[ P_T - P = \frac{1}{2} \rho u^2 \]

- Hot-wire anemometer

- Laser – Doppler anemometer

- PIV (Particle Image Velocimetro) (double exposure)
5. Flow Friction in Pipes

- \[ \left( \frac{p + \frac{u^2}{2} + qz}{\rho} \right)_1 = \left( \frac{p + \frac{u^2}{2} + qz}{\rho} \right)_2 + W + gl_f \]

- Total pressure \( p_o = p + \frac{1}{2} \rho u^2 \)

\[ \Rightarrow \frac{\Delta p_o}{\rho g} + \Delta z = \frac{W}{g} + l_f \]

Special case: \( \Delta z = 0, \ W = 0 \)

\[ l_f = f \frac{L u^2}{D g} \quad \quad \bar{u} = \frac{\dot{Q}}{A} \]

OR \[ \rho g \bar{u}^2 l_f = f \left( \frac{L}{D} \right) \left( \frac{1}{2} \rho u^2 \right) \]

In general,

\[ l_f = \sum l_{fi} \]

Including valves, bends, connections….