Chemical Engineering 374

Fluid Mechanics

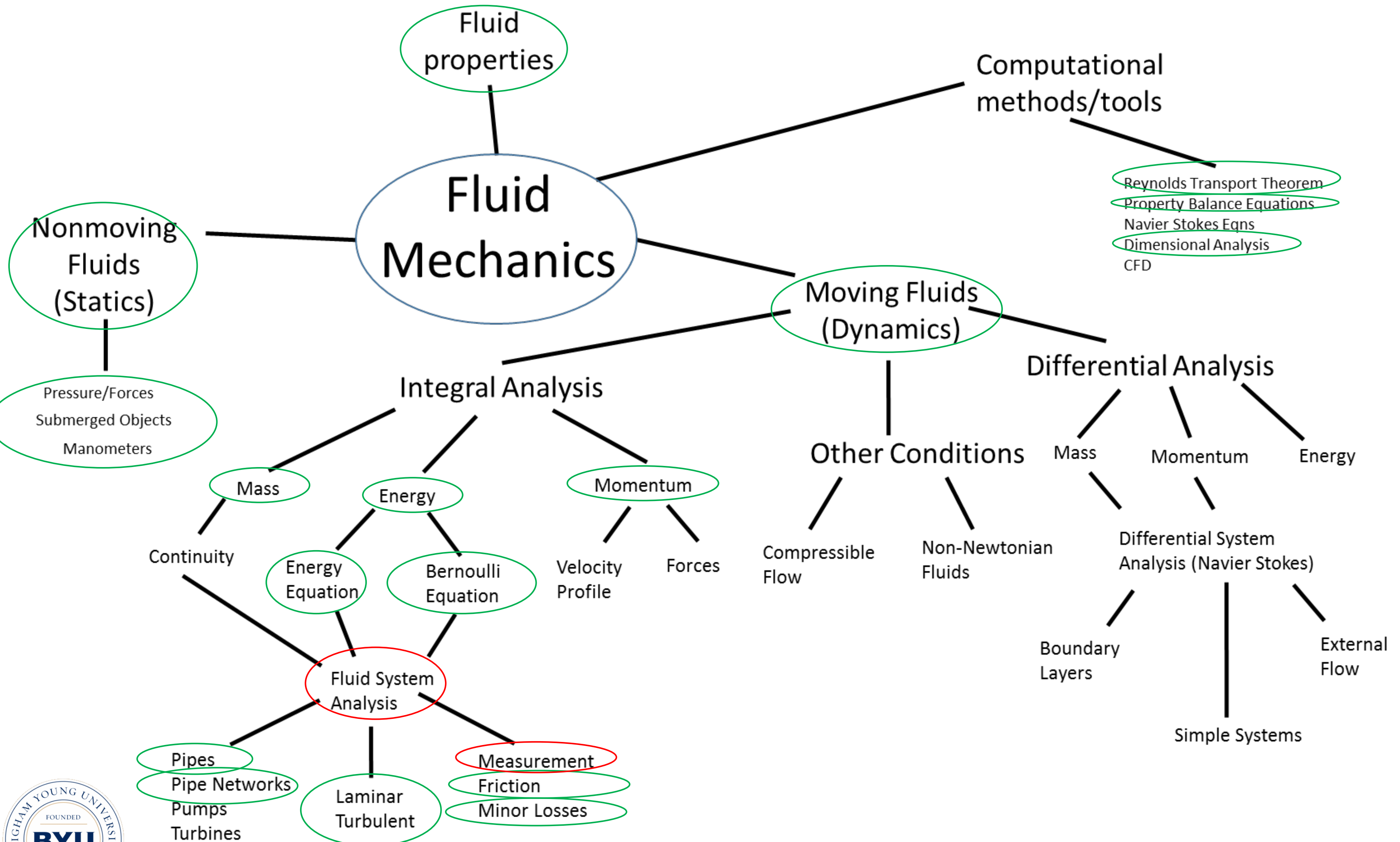
Flow Measurement

Spiritual Thought

"Every discovery in science and art, that is really true and useful to mankind has been given by direct revelation from God, though but few acknowledge it. It has been given with a view to prepare the way for the ultimate triumph of truth, and the redemption of the earth from the power of sin and Satan. We should take advantage of all these great discoveries, the accumulated wisdom of ages, and give to our children the benefit of every branch of useful knowledge, to prepare them to step forward and efficiently do their part in the great work"

President Brigham Young

Fluids Roadmap



Key Points

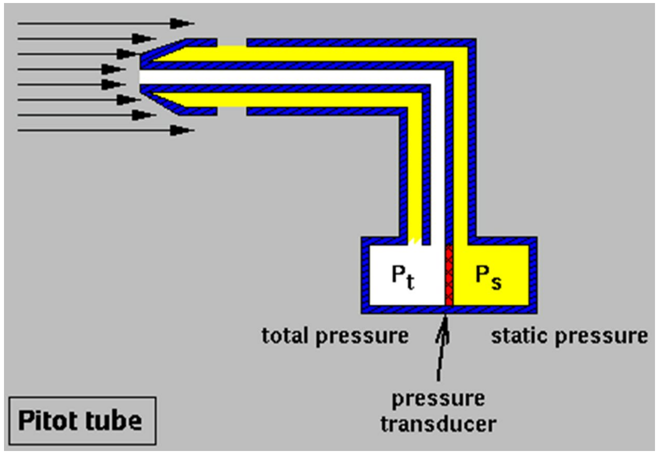
- Velocity/Flow measurement
- Types
  - Obstruction
    - Kinds
    - Calculations
    - Values
  - Drag Types
  - Cumulative Flow Measurement
  - Others

- Flow meters and velocity measurement
- Measure
  - Velocity (instantaneous)
  - Flow rate (~integral)
- Primitive to complex
  - Bucket and watch
  - Particle Image Velocimetry (laser sheet → full planar velocity field.)
- Many measurement types.
  - Operate on various physical principles

- Types
  - Bernoulli Effects
  - Drag Effects
  - Fluid Displacement
  - Heat Transfer
  - Vortex Shedding
  - Wave Disturbence
  - Magnetic Flow meters
  - Intertial Effects
  - Particle Imaging
  - Cumulative flow
- Examples
  - Pitot tubes
  - Orifice meters
  - Nozzles
  - Venturi meters
  - Rotameters
  - Rotors/turbines/paddles
  - Hot wire/film aneometers
  - Vortex flowmeter
  - Laser Doppler velocimetry
  - Electromagnetic
  - Ultrasonic flowmeters
  - Bellows
  - Nutating disk

Bernoulli Effects

- Pitot probes
  - Gases and Liquids
  - Higher velocities needed for gases
  - Simple, inexpensive, reliable
  - Need good alignment



$$v = \sqrt{\frac{2(P_1 - P_2)}{\rho}}$$

$$v = \sqrt{2gh}$$

Obstruction Flowmeters

No Losses:

$$v = \sqrt{\frac{2(P_1 - P_2)}{\rho(1-\beta^4)}}$$

$$\beta = d/D$$

Know How to Derive

With Losses

$$v = C_d\sqrt{\frac{2(P_1 - P_2)}{\rho(1-\beta^4)}}$$

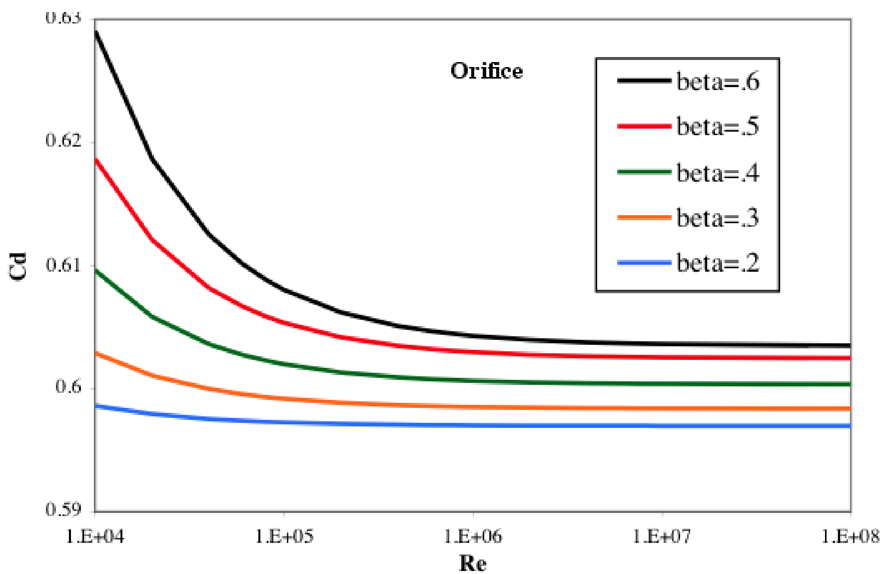
Sign, Size of C_d?

Cost, Losses?

Standard Geometries—C_d

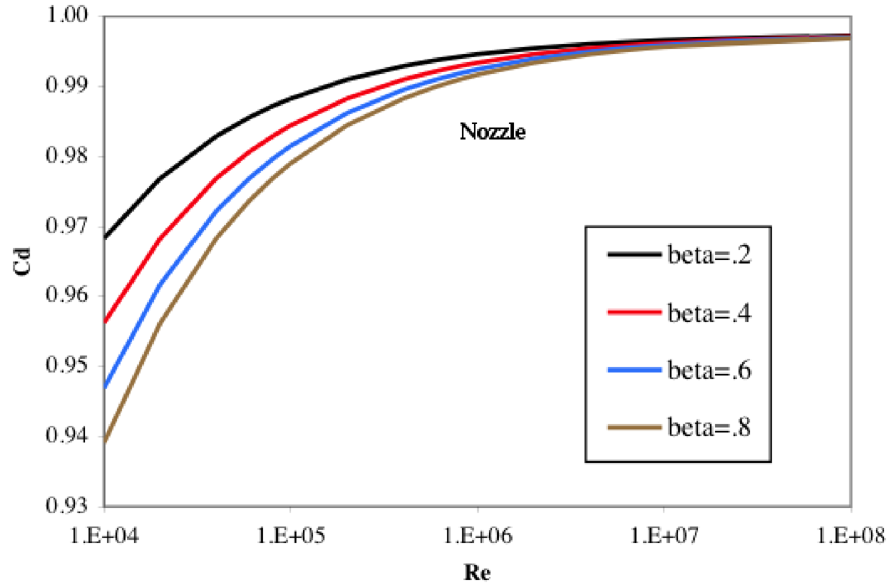
Orifice

$$C_d = 0.5959 + 0.0312\beta^{2.1} - 0.184\beta^8 + \frac{91.71\beta^{2.5}}{Re^{0.75}}$$



Nozzle

$$C_d = 0.9975 - \frac{6.53\beta^{0.5}}{Re^{0.5}}$$



Venturi

$$C_d \approx 0.95 - 0.99$$

$$C_d \approx 0.98$$

- Cd is Re dependent (velocity)
- Requires iteration
  - Guess C_d → v → Re → C_d → repeate
- C_d doesn't change too much though for nozzles and venturies (or orifices at high Re)

Notes

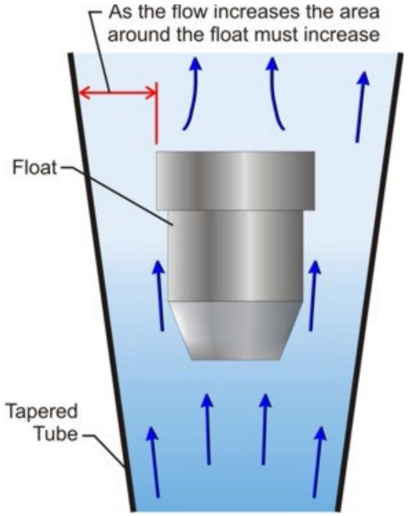
- Similarity to K_L
  - C_d corrects the velocity for losses
  - K_L is a pressure/head loss coefficient
  - Both are emperical.
  - Depends on throat velocity
- Manufacturer's provide C_d
  - Or correlate yourself
- Pressure monitored electronically, so flow rates can be displayed remotely.
  - Basis of a control system
- To get flow, measure velocity at the average position
  - Laminar: average velocity is half the centerline velocity.
  - More difficult for turbulent flows.

$$v = C_d\sqrt{\frac{2(P_1 - P_2)}{\rho(1-\beta^4)}} \qquad K_L = \frac{(P_1 - P_2)}{\frac{1}{2}\rho v^2} \qquad K_L = \frac{1-\beta^4}{C_d^2}$$

But P_1-P_2 are not the same for flow and K_L

Drag Type—Rotameters

- Variable Area Flow
  - Velocity Changes
- Drag on float depends on velocity
- Balance drag, weight, bouyancy.
- ~5% accuracy
- Need clear liquids
- Direct visual reading
- Don’t break the glass!
- Gas/liquid
- Vertical, else use a spring type



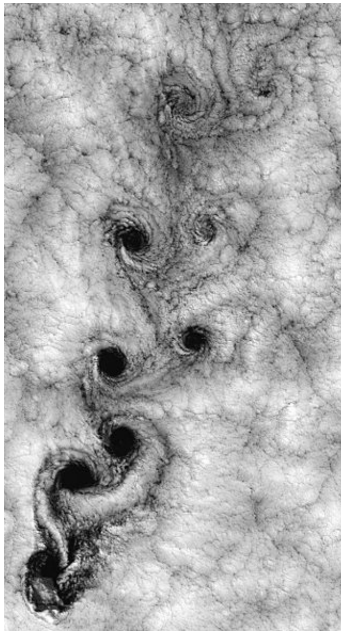
$$Q_{G1} = Q_{G2}\left(\frac{M_{G2}}{M_{G1}}\right)^{1/2}$$

Rotameters

Others

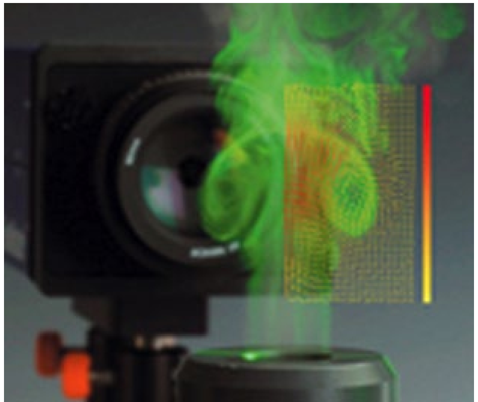
- Turbines
  - Accurate, simple, low cost
  - Blade speed proportional to v
- Paddle wheels
  - Even lower cost, lower pressure drop
  - Cover only a portion of flow
- Hot wires/films
  - Maintain wire at const. T
    - Higher v → higher heat transfer
    - Higher v → higher current (voltage)
  - Accurate, high resolution (time/space)
  - Delicate
  - Common in research
  - 1, 2, or 3D

- Vortex Shedding
  - Rod across the flow
  - Shedding freq prop. to vel.
  - Wake/vorticies detected
    - Ultrasonic, etc.
  - Accurate, wide range of fluids, higher head loss.

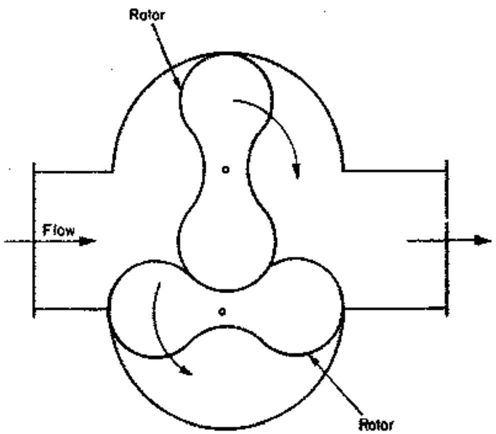


Others

- Wave Disturbances
  - Ultrasonic (Doppler Effect)
  - Fluid needs impurities (tap water)
  - Sound or laser light
  - Frequency shift related to vel.
  - Nonintrusive, no pressure drop
  - Wide range of fluids
  - accurate, easy to install
- Magnetic Flowmeters
  - Electrically conductive fluids
  - Electrodes inserted in fluid
  - Magnetic coils aligned with flow.
  - Flow of charge through Mag. Field produces current, measured by electrodes.
  - High cost
- Inertial effects
  - Flow through a "U" tube
  - Measure forces on the tube, which correlate with velocity.
- Particle Image Velocimetry
  - Laser sheet
  - Two quick photos → illuminate particles
  - Compare positions → time
  - 2D or 3D
  - Full field
  - Expensive, but high space/time resolution (research, cfd validation)



Cumulative Flow Rates



- Provides total volume passed over some time period.
  - Water meters
  - Gasoline pumps
  - Natural gas meters