Chemical Engineering 374

Fluid Mechanics

Flow Measurement

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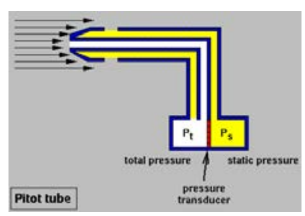
- Flow meters and velocity measurement
- Measure
  - Velocity (instantaneous)
  - Flow rate (~integral)
- Primitive to complex
  - Bucket and watch
  - Particle Image Velocimetry (laser sheet → full planar velocity field.
- Many measurement types.
  - Operate on various physical principles

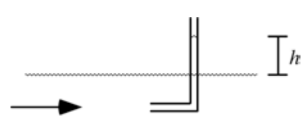
- Types
  - Bernoulli Effects
  - Drag Effects
  - Fluid Displacement
  - Heat Transfer
  - Vortex Shedding
  - Wave Disturbence
  - Magnetic Flow meters
  - Intertial Effects
  - Particle Imaging
  - Cumulative flow
- Examples
  - Pitot tubes
  - Orifice meters
  - Nozzles
  - Venturi meters
  - Rotameters
  - 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

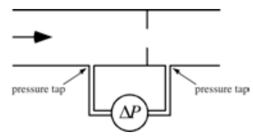
With Losses

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

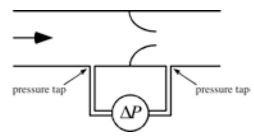
Sign, Size of C_d?

Cost, Losses?

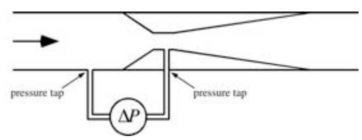
Orifice Meter



Nozzle



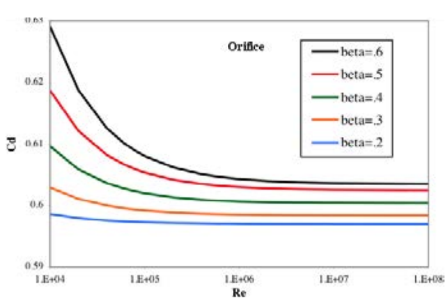
Venturi Meter



Standard Geometries—C_d

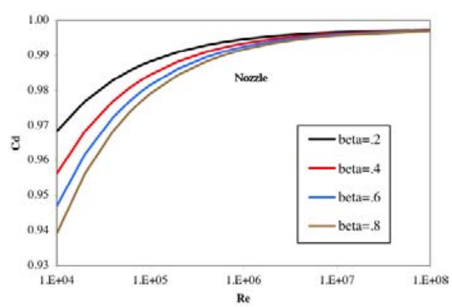
Orifice

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



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

Notes

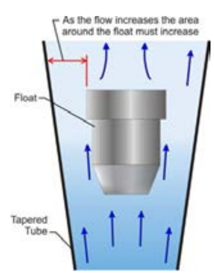
- Similarity to K_L
  - C_d corrects the velocity for losses
  - K_L is a pressure/head loss coefficient
  - Both are emperical.
  - Depends on throat velocity
- Manufacturer's provide C_d
  - Or correlate yourself
- Pressure monitored electronically, so flow rates can be displayed remotely.
  - Basis 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



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

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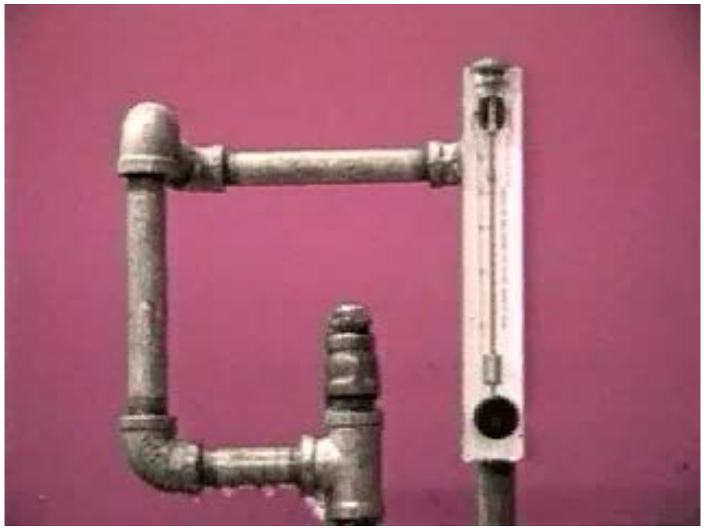
Rotameters



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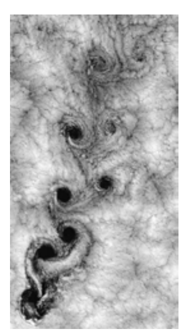
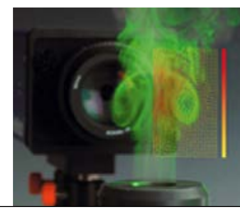
Others

- 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.

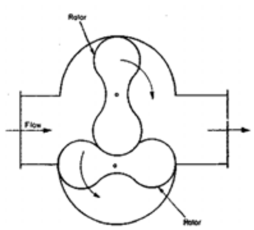


Others

- 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