Flow Measurement (Part II)

Prof. A. Agrawal
IIT Bombay

Why need flowmeter?

Measurement of Volume Flow Rate

- Sometimes flow rate in a duct or pipe needs to be measured and/or controlled
- Sometimes total flow occurring during a given time interval is of interest
  - e.g. Petrol filled in tank of vehicle
  - Cooking gas consumed in a house
- Integration of instantaneous flow rate is required
- Integrating unit may be part of flowmeter itself or done remotely from the flowmeter

Introduction

- Flow meters should have
  - high turn down (maximum to minimum Reynolds number) ratio
  - low irrecoverable pressure loss
  - insensitivity to fluid properties and temperature
  - high immunity to external noise (vibrational, electrical, etc.)
  - accuracy
  - low maintenance and low purchase cost

Introduction

- Traditional flow measuring devices include venturimeter, orificemeter, differential manometers, etc., which work on the principle of differential pressure measurements
- These flowmeters have small turn down ratio (1:10)
- Regular calibration of the device is required.
- Of late, flowmeters based on unconventional technologies such as Coriolis, Ultrasonic, Electromagnetic and Vortex flowmeters have become popular.

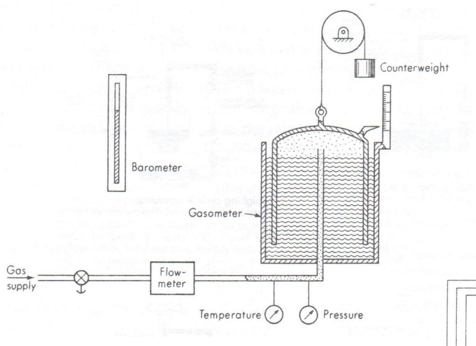
Calibration and Standards

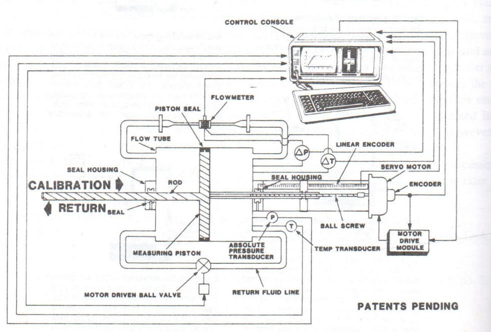
- Calibration of volume or mass flow rate depends on standards of volume (length) and time or mass and time
- Establish steady-state. Measure volume (or mass) accurately in an accurately timed interval
- Possible sources of errors: variation in fluid properties (density, viscosity) due to change in temperature, orientation of flowmeter, any upstream (or downstream) flow disturbances

Calibration and Standards

- Calibration of flowmeter with gases can be carried out with liquids (maintaining same Reynolds number, etc)
- Direct calibration for gas is also available if the above is perceived to be inaccurate
- In a *gasometer* system, gas flowing through flowmeter over a time interval is trapped and its volume measured. Knowing temperature and pressure, its mass can be determined
- The bell, along with weights, can be used to drive the gas through the flow meter. Here the drop rate of bell needs to be measured and related to gas flow rate

Calibration for Gas Flowmeter





Constant-Area, Variable-Pressure-Drop or Obstruction Meters

- Involves placing a fixed-area flow restriction in pipe or duct
- Flow restriction causes pressure drop, which varies with flow rate
- Measure pressure drop and relate it to flow rate
- Common practical devices: orifice, flow nozzle, venturi tube, Dall flow tube, laminar-flow element

Square-edge Orifice

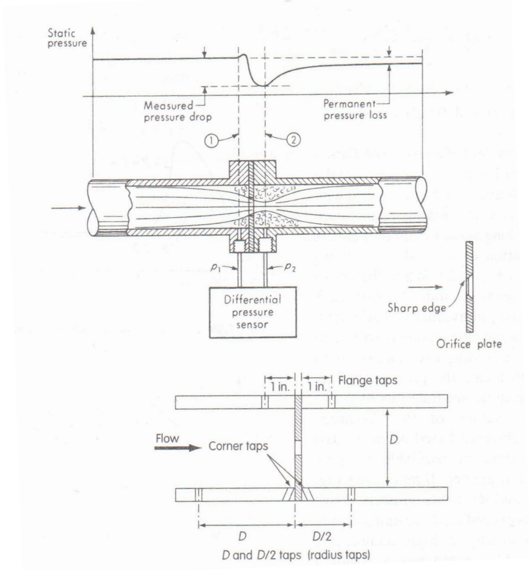
- Most widely used flow metering element due to its simplicity, low cost, and great volume of data available about its behavior
- Assuming one-dimensional, incompressible, inviscid flow without work, heat transfer, and elevation change, we obtain theoretical flow rate (Q_t) as:

$$Q_t = \frac{A_{2f}}{\sqrt{1-(A_{2f}/A_{1f})^2}}\sqrt{\frac{2(p_1-p_2)}{\rho}}$$

A_{1f}, A_{2f} is flow area where p_1 and p_2 are measured
p_1 and p_2 are static pressures

- Note requires measurement of flow areas A_{1f}, A_{2f} which are different from cross sectional areas and function of flow rate.
- Also, fluid not inviscid. Therefore, corrections needed

Square-edge Orifice (contd)



Square-edge Orifice (contd)

- Experimental calibration to determine actual flow rate (Q_a) required. Defining discharge coefficient C_d as $C_d = Q_a/Q_t$
- Curves for variation of C_d versus Re available for different β ratio (orifice diameter/pipe diameter)
- Value of C_d can change with upstream flow disturbances – therefore certain minimum upstream (and downstream) length(s) are required
- If upstream/downstream lengths cannot be provided – use flow conditions

Square-edge Orifice (contd)

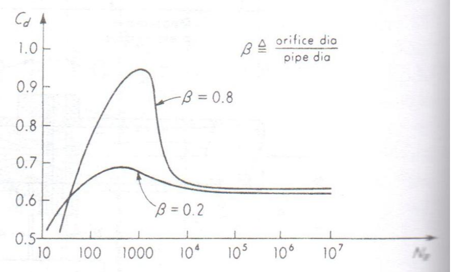


Fig. 7.29 *Variation in discharge coefficient.*

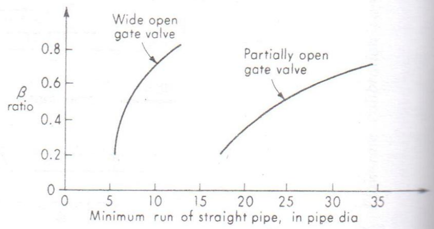
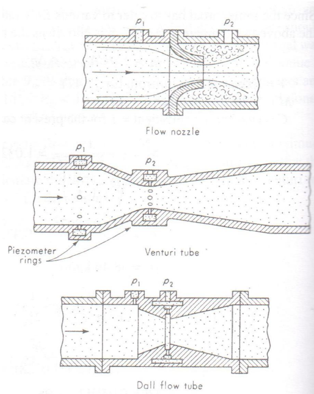


Fig. 7.30 *Effect of upstream disturbances.*

Flow nozzle, venturi tube, Dall flow tube

- Involves less abrupt change in area as compared to orifice.
- So have higher discharge coefficient, and smaller permanent pressure loss
- More expensive than venturi
- Used in high-flow situations



Flow nozzle, venturi tube, Dall flow tube (contd)

- Mass flow rate:

$$\dot{m} = C_d \rho A_t \sqrt{\frac{2(\Delta p)}{\rho(1-\beta^4)}}$$

Δp: pressure difference between throat and upstream

A_t: area of throat

C_d: discharge coefficient

β: throat diameter/pipe diameter

ρ: density of fluid

Laminar Flow Elements

- Involves flow through pipe in laminar regime. Mostly Re < 1000
- For fully-developed flow, we have

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

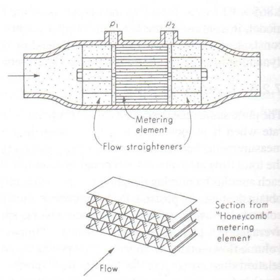


Fig. 7.32 Laminar-flow element.

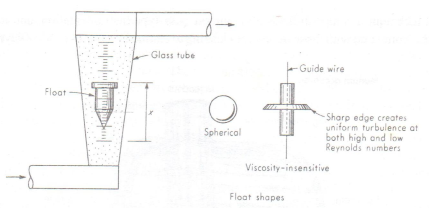
- Note linear relation between linear relation (rather than square root) between pressure drop and flow rate
- To measure larger flow rates, use large number of flow elements in parallel

Laminar Flow Elements (contd)

- Such devices have been used to measure flow rate of low pressure air
- Can be used for reversed flow also
- Usually less sensitive to upstream and downstream flow disturbances
- Limitations include: clogging from dirty fluid, high cost, large size, high pressure loss (all the measured pressure-drop is actually lost!)

Rotameter

- Consists of a vertical, tapered tube in which a "float" assumes a vertical position based on the flow rate in the tube
- When float is stationary (in equilibrium), balance of gravity, pressure, viscosity, and buoyancy forces
- Accuracy is typically +/-1% of full scale, with repeatability of 0.25% of reading
- Range of 10:1



Rotameter (contd)

$$Q = \frac{C_d (A_t - A_f)}{\sqrt{1 - [(A_t - A_f)/A_t]^2}} \sqrt{2gV_f \frac{\rho_f - \rho_{ff}}{\rho_{ff}}}$$

Q: volume flow rate
C_d: discharge coefficient
A_t: area of tube
A_f: area of float
V_f: volume of float
ρ_f: density of float
ρ_{ff}: density of fluid