CHAPTER (13)

FLOW MEASUREMENTS

SUMMARY

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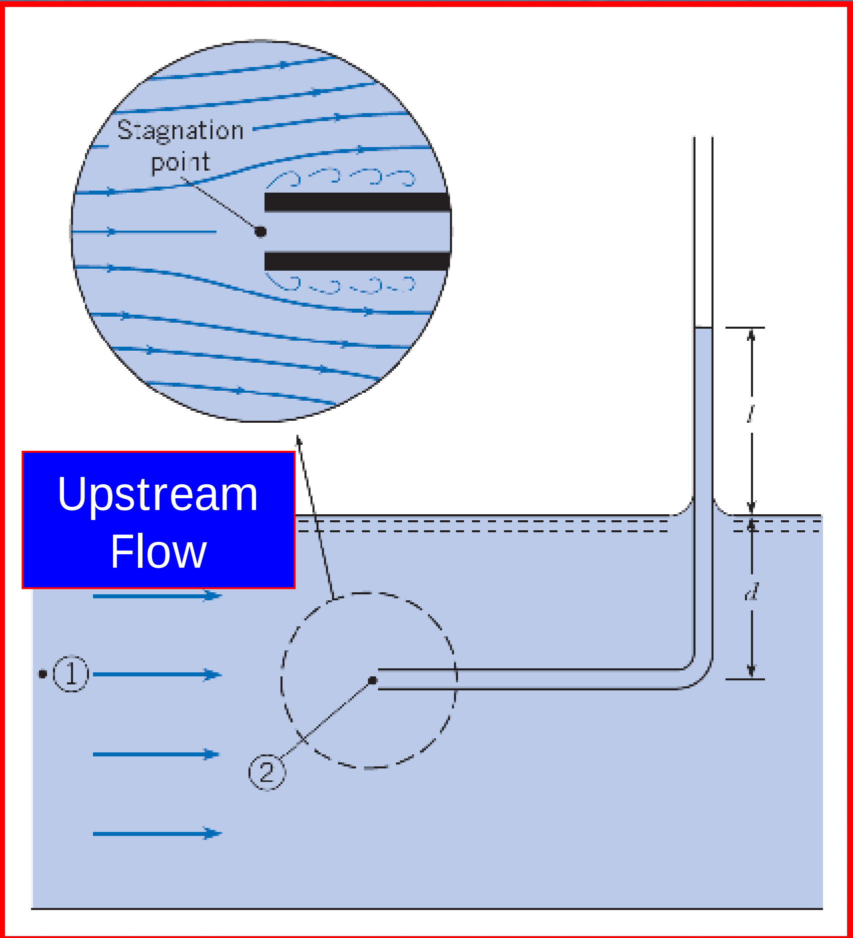
Instruments for the Measurements of Flow Velocity

1. Stagnation Tube.
2. Pitot Tube.
3. Vane or Propeller Anemometer.
4. Cup Anemometer for Measuring liquids & air Flows.
5. Hot-Wire and Hot Film Anemometers.
6. Laser-Doppler Anemometer.
7. Marker Methods.

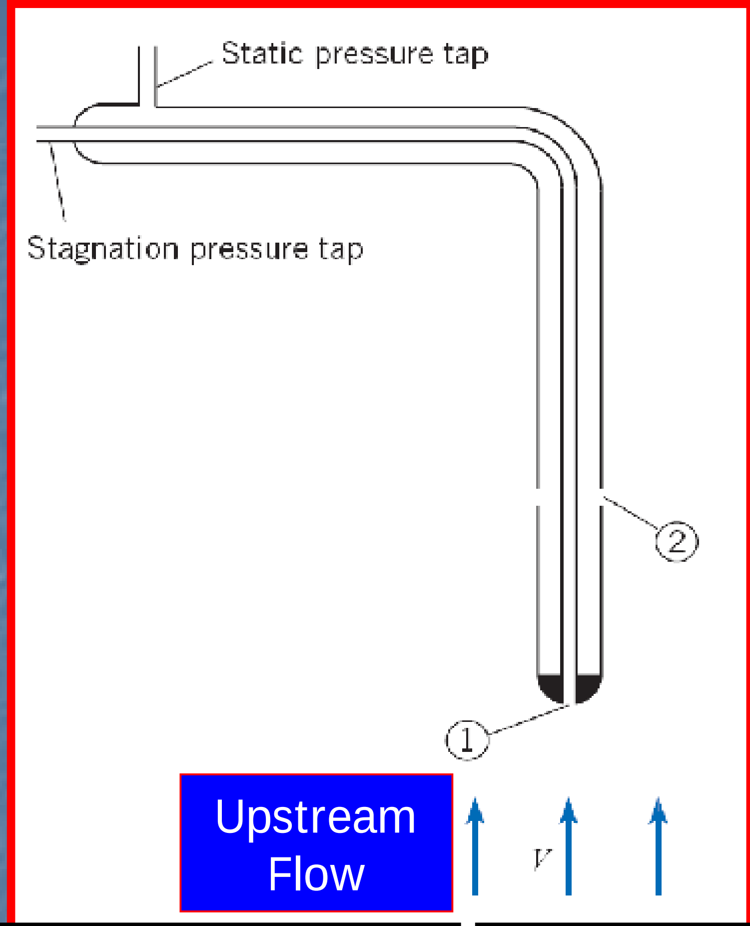
All are used for measuring velocity flows that are Steady or changes slowly with time.

1. Stagnation Tube
(Total head tube)



$$V_1 = \sqrt{2gl}$$

2. Pitot Static Tube



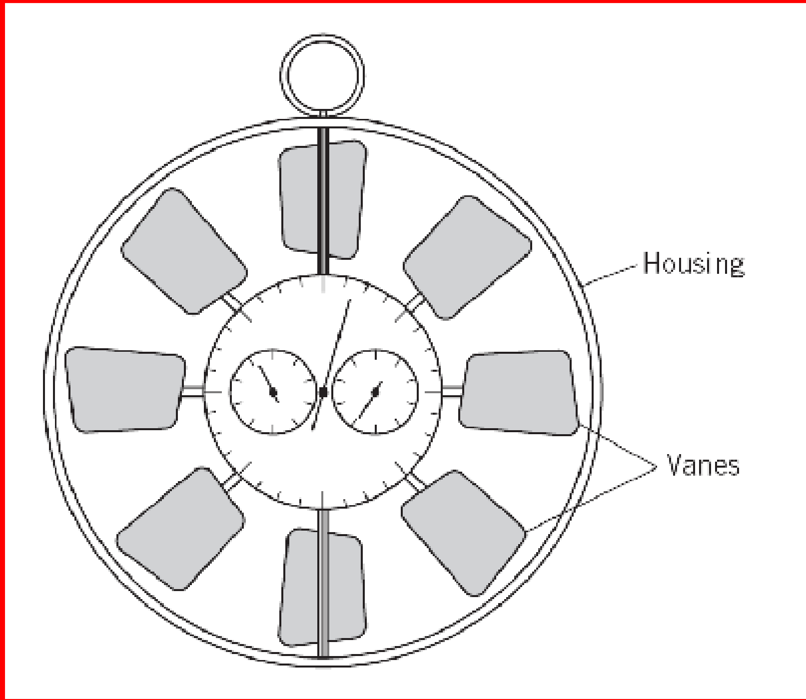
$$V_2 = \left[\frac{2}{r}\left(p_{z,1} - p_{z,2}\right)\right]^{1/2}$$

$$p_{z1} = p_1 + g z_1$$

$$p_{z2} = p_2 + g z_2$$

$V_2 = V$ *Where V is the stream velocity*

3(a).The Vane or Propeller Anemometer For Measuring Air Flow



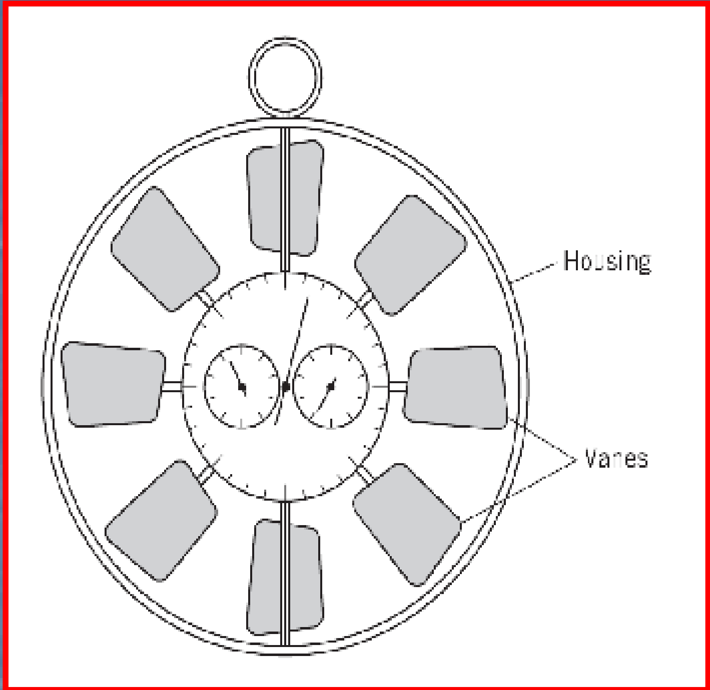
If the device is held for one minute in the air stream flow and the dial measures 300ft, then the velocity is 300ft/min

3(b). The Vane or Propeller Anemometer

For Measuring Wind Speed

The device is attached to the forward part of the wind vane, all of which is mounted on a mast. The propeller drives an electromagnetic generator, the voltage obtained is proportional to the wind speed.

3(c). The Vane Anemometer For Measuring Water Flow

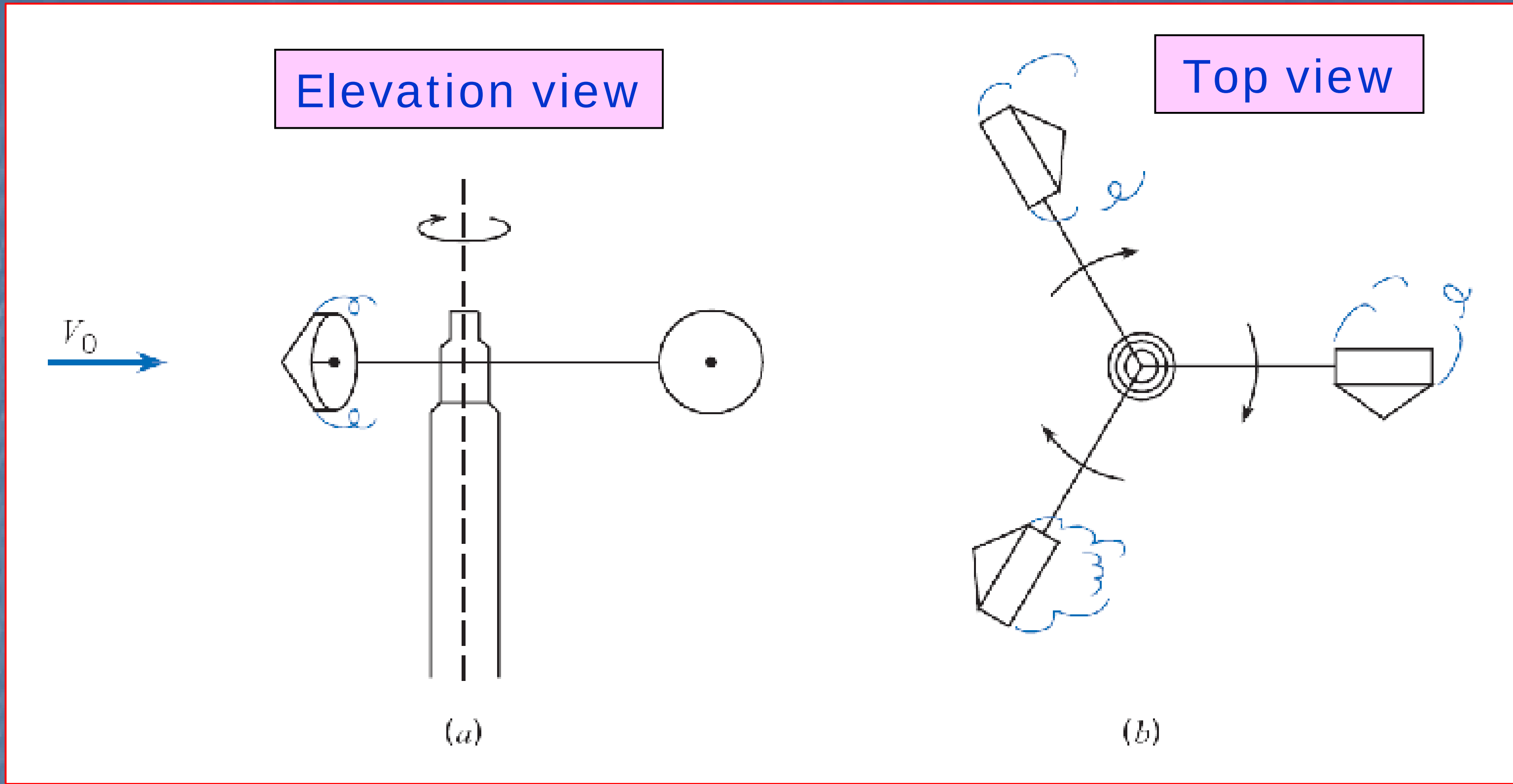


The device is connected to an electrical circuit in such a manner that an electrical signal is triggered for a given number of revolutions. Thus the frequency of rotation of the vane is obtained, which is directly converted to velocity by a calibration curve.

3(d). The Propeller Anemometer For Measuring Flow Rate (Liquid) Inside Pipes

The device is calibrated to indicate the flow rate directly in cubic meters per second

4. Cup Anemometer For Measuring Wind Velocity



Frequency of rotation is directly proportional to velocity flow by appropriate calibration data.

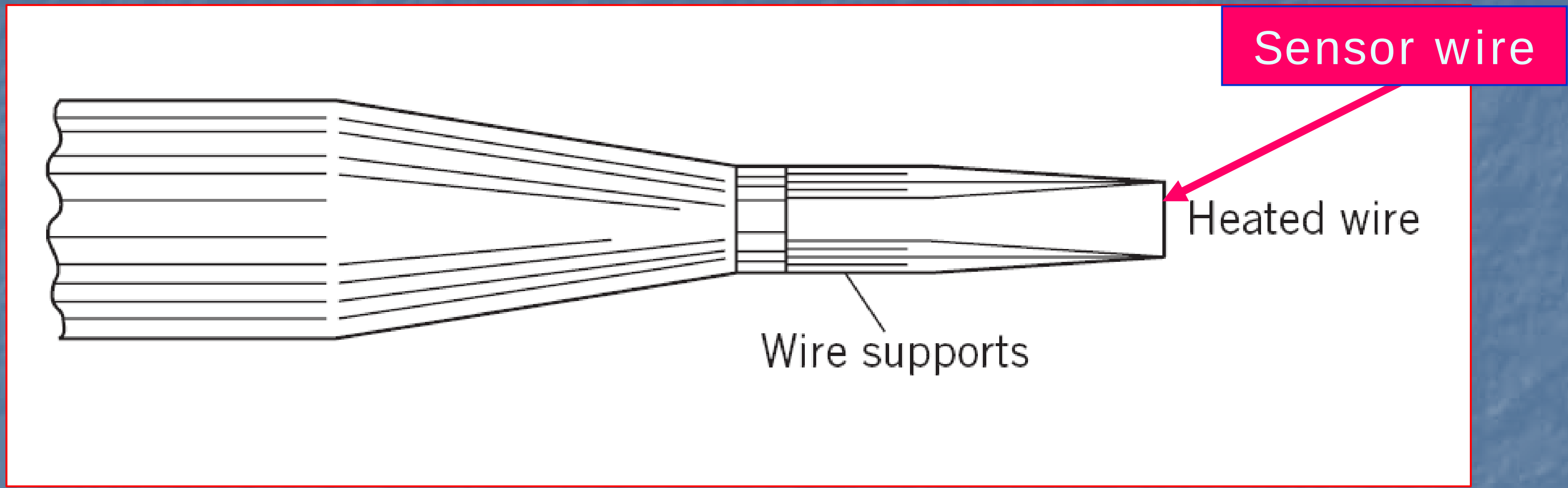
Important Note

1. Stagnation Tube.
2. Pitot Tube.
3. Vane or Propeller Anemometer.
4. Cup Anemometer for Measuring liquids & air Flows.

All the devices (1-4) are used for measuring velocity flows that are <u>Steady or changes slowly with time</u>.

5(a). Hot wire Anemometer

Used to measure <u>velocity fluctuations</u> due to eddies as in <u>turbulent flows.</u>



Probe for hot-wire anemometer (enlarged).

Main Disadvantages	Main Advantages
Sensor wire is easily broken.	**Measure Low velocities from** $(30\,cm/s - 150\,m/s)$
Relatively high cost.	**Fluctuating velocities with Frequencies from** $f = 100{,}000\,Hz$

In operation, the wire used is (1-2 mm in Length) is heated (150 degree) by two methods:

1. Constant Current Anemometer.
2. Constant Temperature Anemometer.

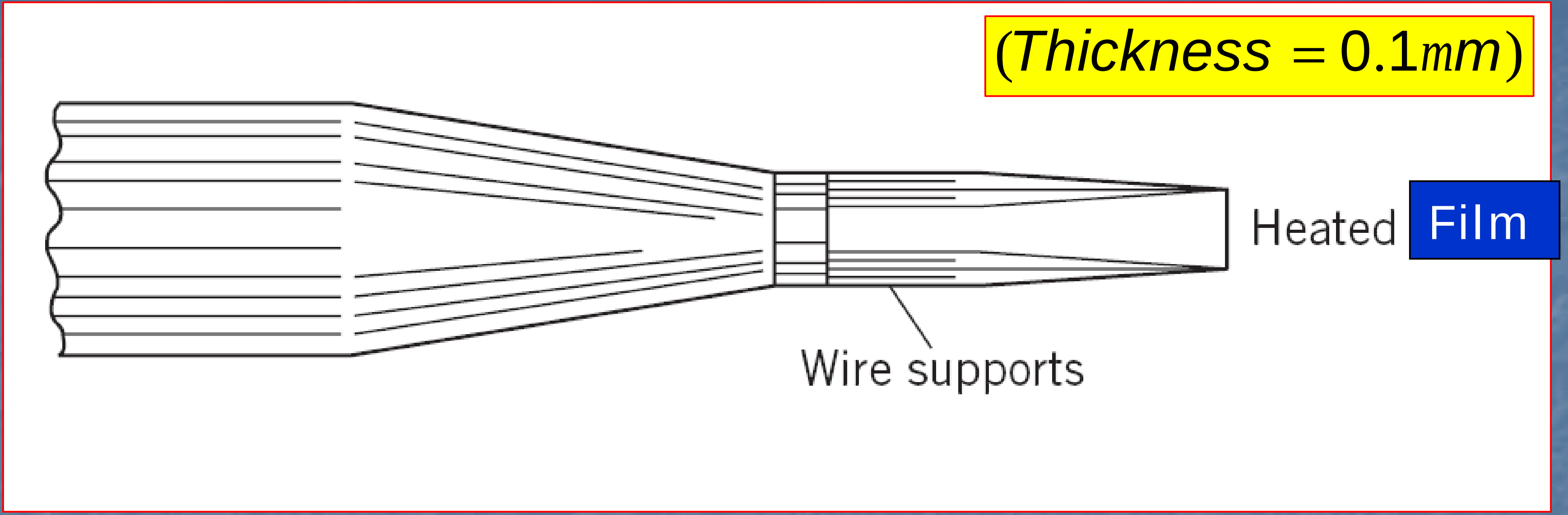
Principle of Operation $V = IR$

A flow of fluid past the hot wire causes the wire to cool because of convective heat transfer. In the constant-current anemometer, the cooling of the wire causes its resistance to change, and a corresponding voltage change occurs across the wire. Because the rate of cooling is a function of the speed of flow past the heated wire, the voltage across the wire is correlated with the flow velocity. The more popular type of anemometer, the constant-temperature anemometer, operates by varying the current in such a manner as to keep the resistance (and temperature) constant. The flow of current is correlated with the speed of the flow: the higher the speed, the greater the current needed to maintain a constant temperature. Typically, the wires are 1 to 2 mm in length and heated to 150°C. The

Time response is improved with decreasing wire diameter

$d = 1mm$ or Less

5(b). Hot Film Anemometer



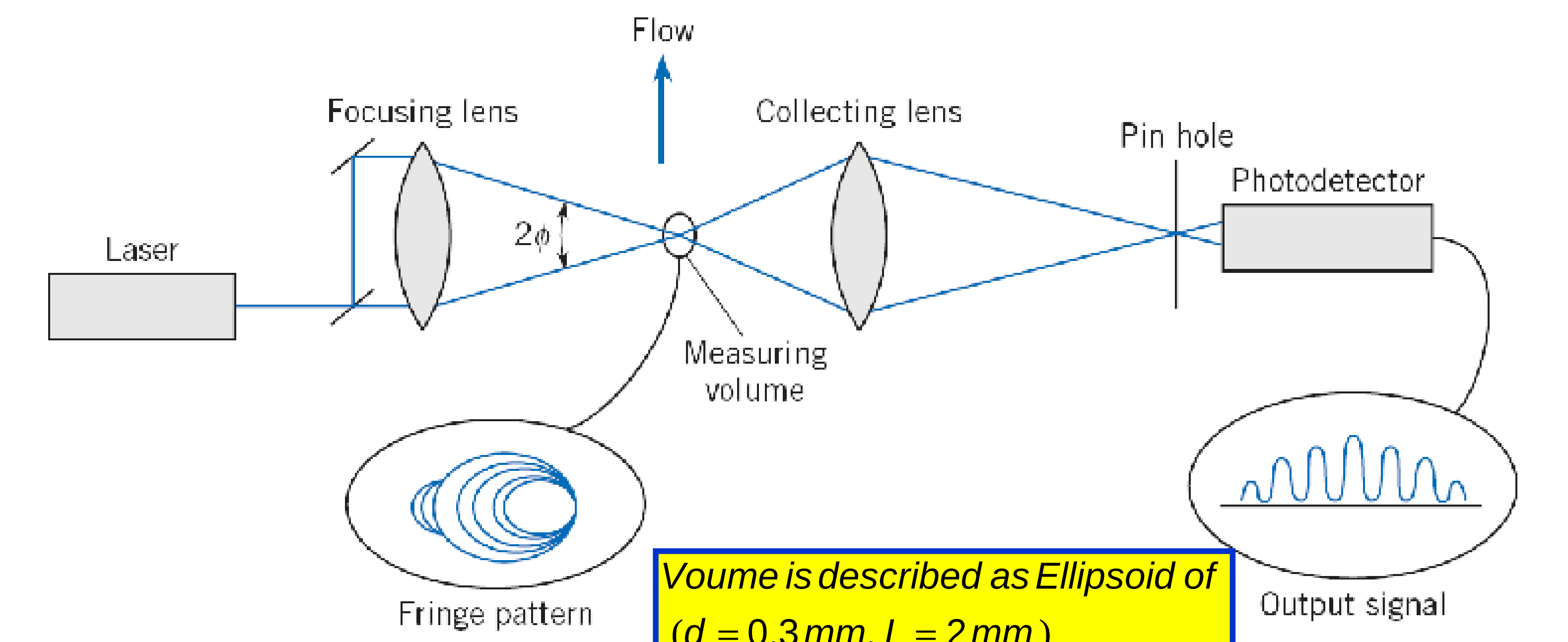
Probe for hot-wire anemometer (enlarged).

Same principle of operation as hot wire anemometer but its advantage that is used for Liquids and dirty Gases.

6. Laser -Doppler Anemometer (LDA)

Main Advantages:

1. Small volumes of flows.
2. Flow field is not disturbed by the presence of the probe compared to Pitot Tube or Hot Wire Anemometer.



Voume is described as Ellipsoid of $(d = 0.3\,mm, L = 2\,mm)$

Dual-beam laser-Doppler anemometer (Dual Beam)

Principle of Operation

There are several different configurations for the LDA, depending on the properties and accessibility of the flow. One configuration, known as the dual-beam mode, is shown in Fig. 13.7. The laser beam, which is a highly coherent, monochromatic light source, is first split into two parallel beams and then passed through a converging lens. The point where the two beams cross is the measuring volume, which might best be described as an ellipsoid that is typically 0.3 mm in diameter and 2 mm long, illustrating the excellent spatial resolution achievable. The interference of the two beams generates a series of light and dark fringes in the measuring volume perpendicular to the plane of the two beams. As a particle passes through the fringe pattern, light is scattered and a portion of the scattered light passes through the collecting lens toward the photodetector. A typical signal obtained from the photodetector is shown in the figure.

The operation of the laser-Doppler anemometer depends on the presence of particles in the flow to scatter the light, particles sufficiently small that they always move at the fluid velocity. In liquid flows, the impurities of the fluid typically serve as scattering centers. In gaseous flows, however, it is sometimes necessary to "seed" the flow with small particles. Smoke is often used for this seeding.

It can be shown from optics theory that the spacing between the fringes is given by

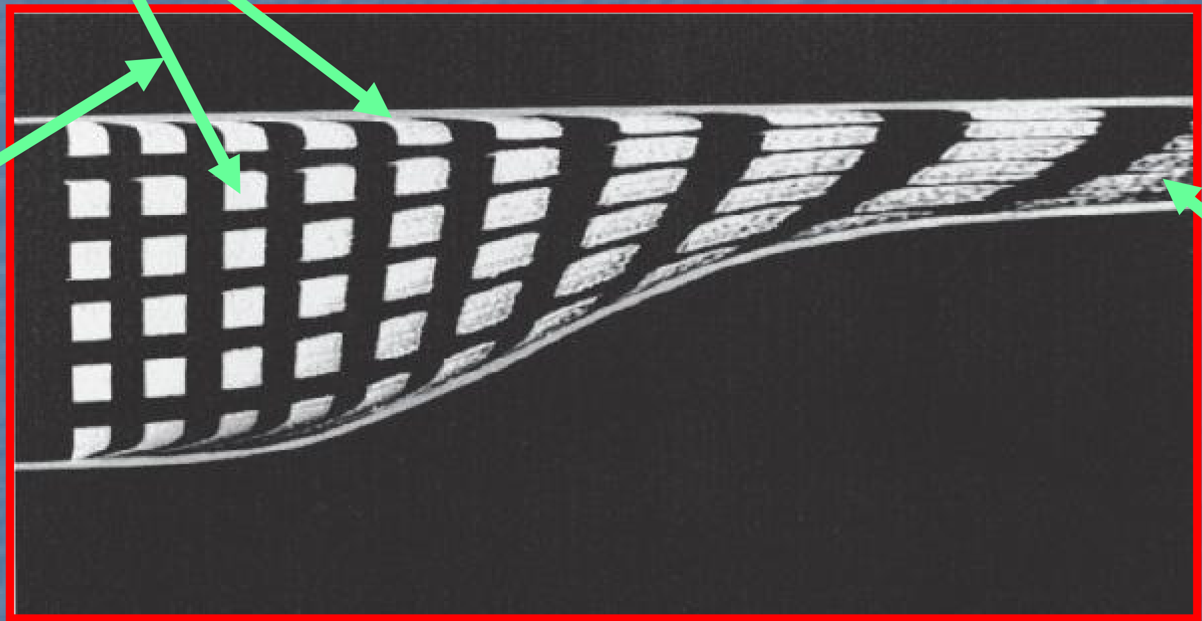
$$\Delta x = \frac{l}{2 \sin f}$$

where λ is the wavelength of the laser beam and ϕ is the half-angle between the crossing beams. By suitable electronic circuitry, the frequency of the signal (f) is measured, so the velocity is given by

$$U = \frac{\Delta x}{\Delta l} = \frac{l}{2 \sin f}$$

7. Marker Methods

(7.1) Hydrogen Bubbles Marker Method produced by Using Electrodes

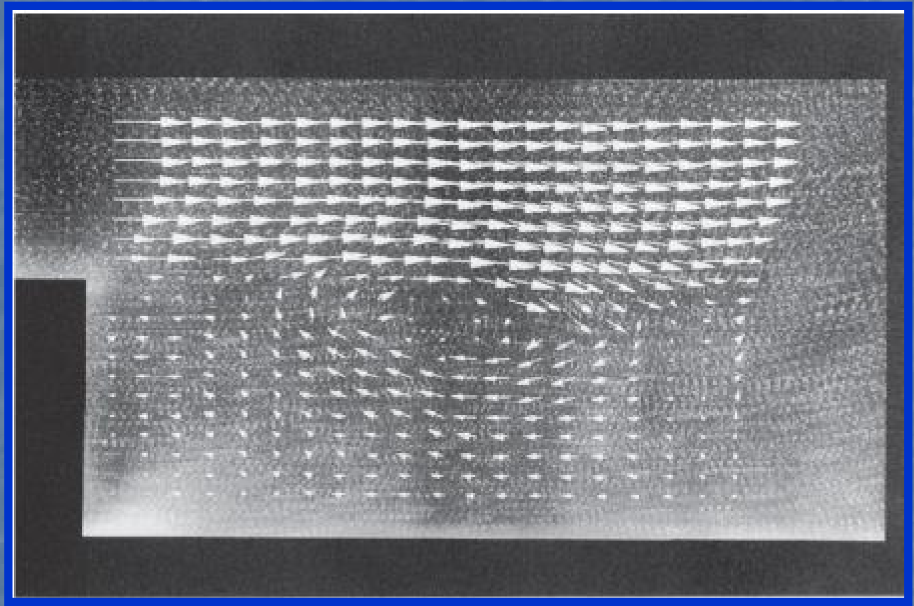


Note: The marker must have the same density as the water flow. An electrode is placed in a flowing fluid causes small bubbles to be formed and swept downstream, thus revealing the motion of the fluid.

(7.2) Particle Image Velocimetry (PIV) Marker Method

This method is considered as a whole-field technique because it measures the velocity at locations throughout a cross section of the flow. Typically performed using digital hardware and computers.

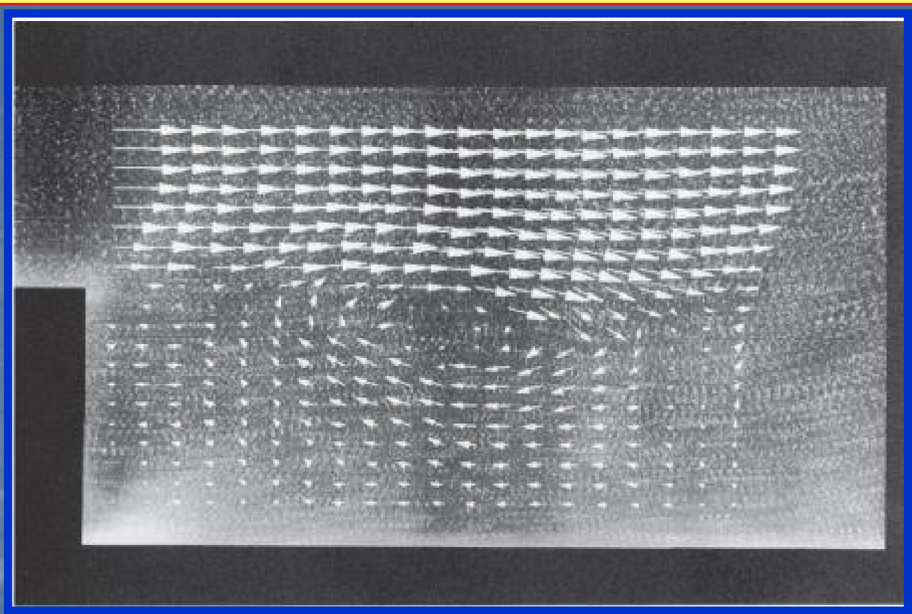
Silver coated hollow spheres as seeding particles.



The Seeding Particles are:

1. Small spheres of Aluminum, glass or polystyrene.
2. Oil droplets or oxygen bubbles (Liquid Only).
3. Smoke particles (Gases Only).

(7.2) Particle Image Velocimetry (PIV) Marker Method



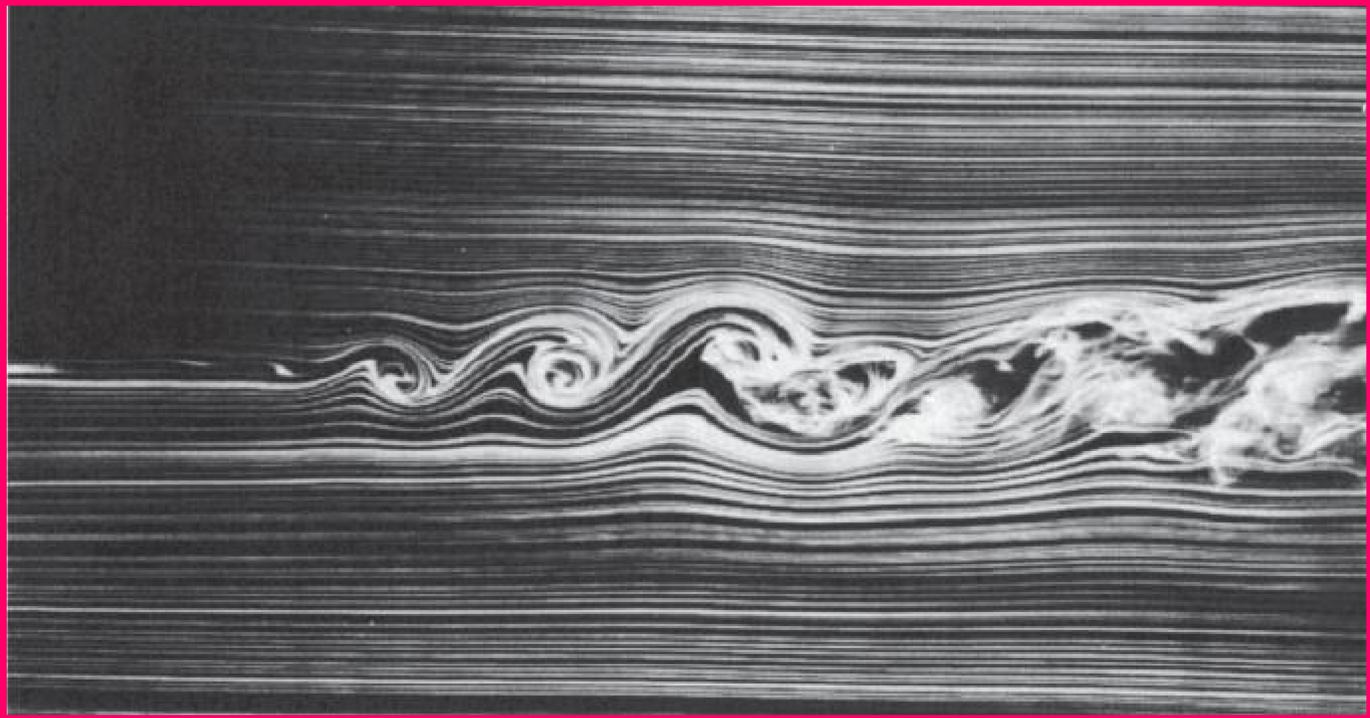
How it works

A sheet of light is passing through a cross section of the flow is pulsed on twice, and then scattered light from particles is recorded by a camera.

The first pulse of light records the position at time (t), and the second pulse of light records at time $(t+\Delta t)$. Thus, the displacement (Δr) of each particle is recorded on the photograph.

$$V = \frac{\Delta r}{\Delta t}$$

(7.3) Smoke particles Marker (Gases Only)



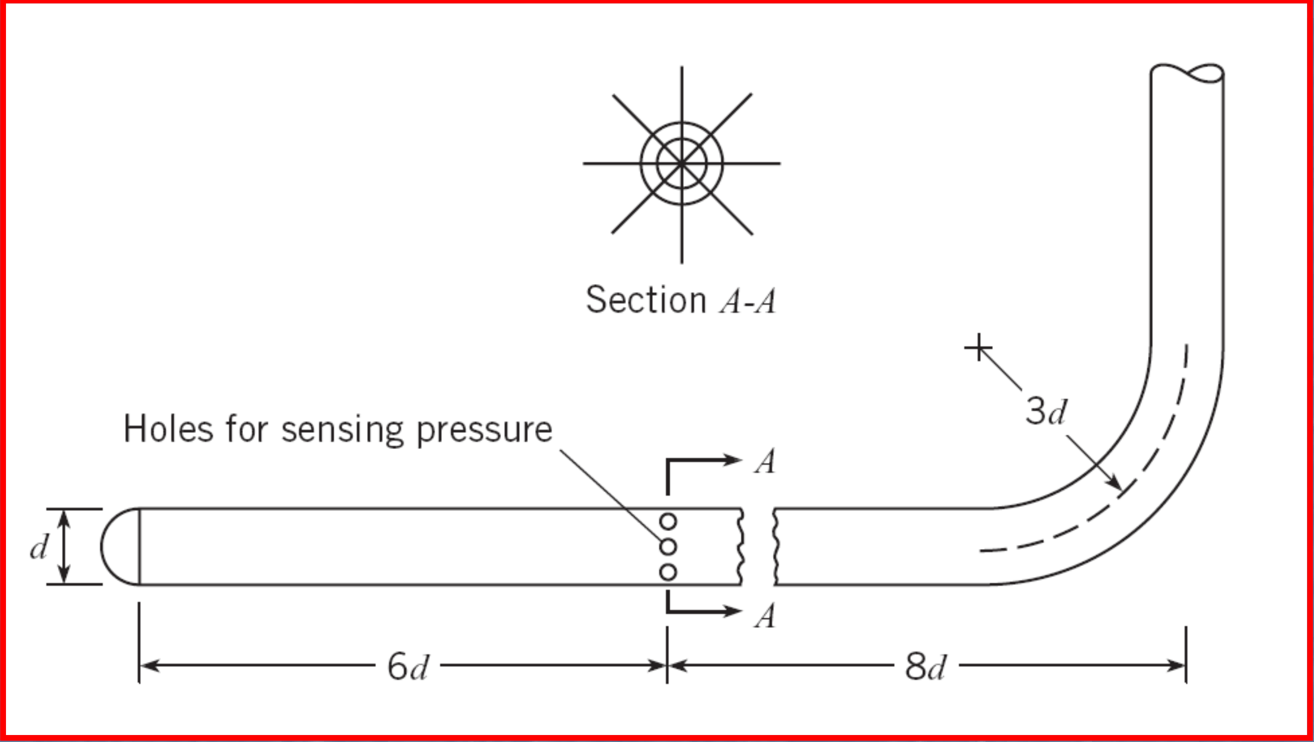
Flow pattern in the wake of a flat plate.

One technique is to suspend a wire vertically across a flow field and allow oil to flow down the wire. The oil tends to accumulate in droplets along the wire. Applying a voltage across the wire creating streaks from the droplets.

Other Smoke Generators Methods are: Heating Oil, Introducing Titanium Tetrachloride (TiCl4) which react with water vapour.

Static Tube

Used to measure static pressure



Position of the holes (see Figure above) is important for measuring fluid static pressure and is selected at a location where both effects of the rounded nose (decrease pressure) and the downstream stem (increase pressure) cancel each other.

Instruments for the Measurement of Flow Rate

1. Direct Methods: Volume or weight measurements for a given time interval (W/t).
2. Indirect Methods: Venturi meters, Orifices, Flow nozzles, Electromagnetic Flow Meters.

1. Direct Volume or Weight Measurements

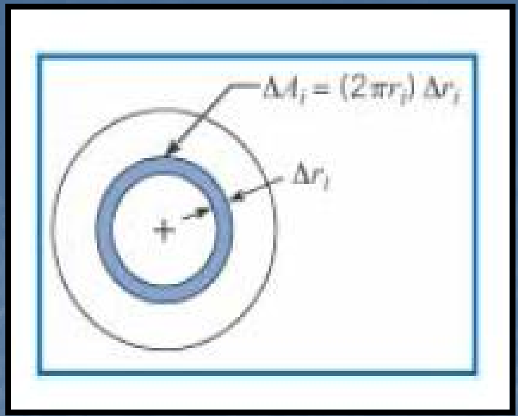
$$\frac{Weight}{t}, \frac{Volume}{t}$$

2. Velocity – Area Integration

Volume flow rate (Q) can be calculated in a pipe Only if the velocity distribution is Symmetrical.

$$Q = \int V dA = \int V (2pr \, dr)$$

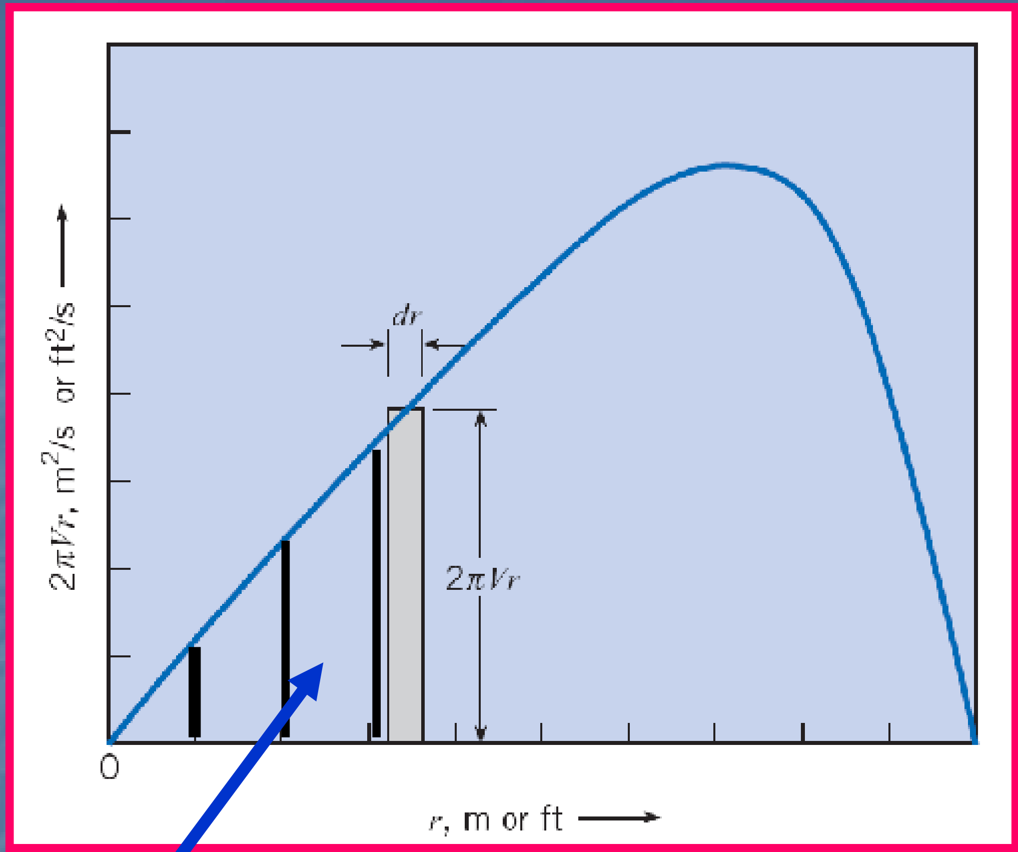
Velocity is measured by using Pitot Tube or hot wire Anemometer



$$dQ = \int V dA = \int V \left(2pr\ dr\right)$$

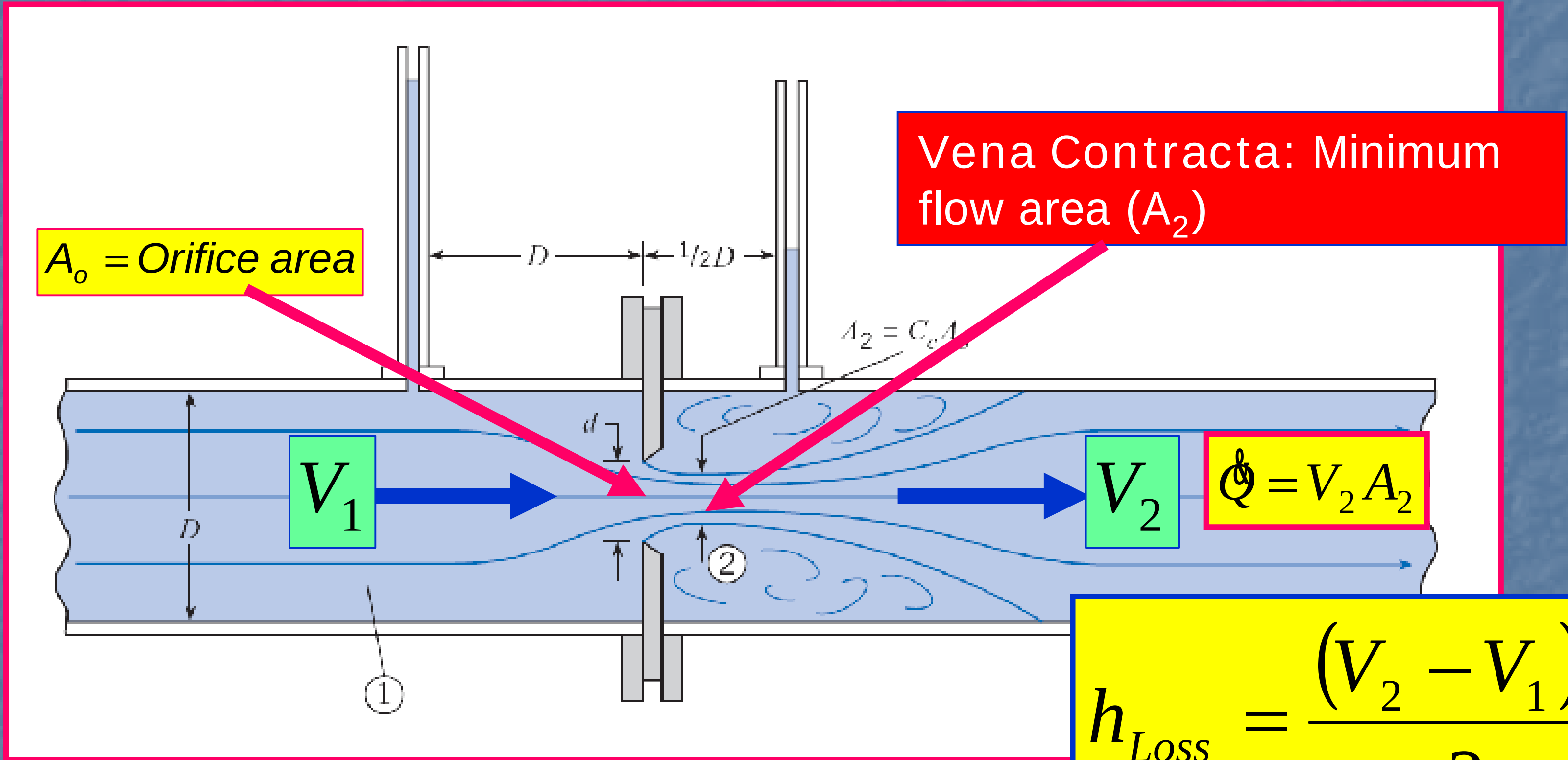
$$\dot{Q} = \int_0^r V\, dA = \int_0^r V\, 2p\, r\, dr$$

$$Trapezium\ Area = \frac{y_1 + y_2}{2}\left(x_2 - x_1\right)$$



INDIRECT METHODS FOR MEASURING FLOW RATE

1. ORIFICES: A restricted opening through which fluid flows



$$\dot{Q} = V_2 A_2$$

$$h_{Loss} = \frac{(V_2 - V_1)^2}{2}$$

$$Q = K A_o \sqrt{2 g \Delta h}$$

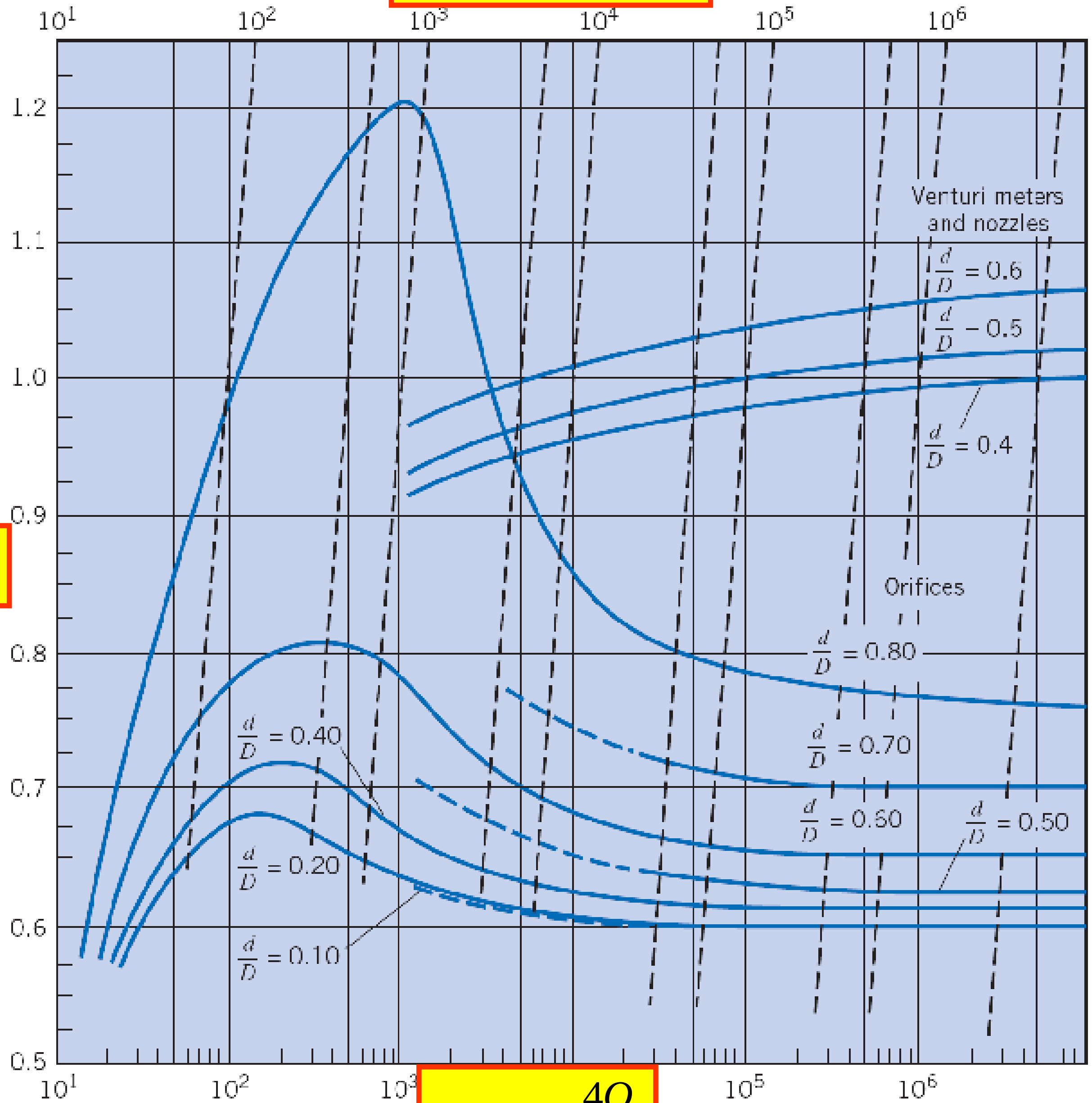
$$Q = K A_o \sqrt{2 \frac{\Delta p_z}{\rho}}$$

Δh *is known*

$$\frac{(\mathrm{Re})_d}{K} = \sqrt{2g\Delta h}\,\frac{d}{u}$$

If Q is not known

K



$$(\mathrm{Re})_d = \frac{4Q}{pdu}$$

If Q is known

Mass Flow Rate For Gases

$$Q = KA_o\sqrt{2g\Delta h}$$

If a differential pressure transducer is connected across the orifice, it will sense a piezometric pressure change that is equivalent to $\gamma\Delta h$, so the orifice equation becomes

$$Q = KA_o\sqrt{2\frac{\Delta p_z}{\rho}}$$

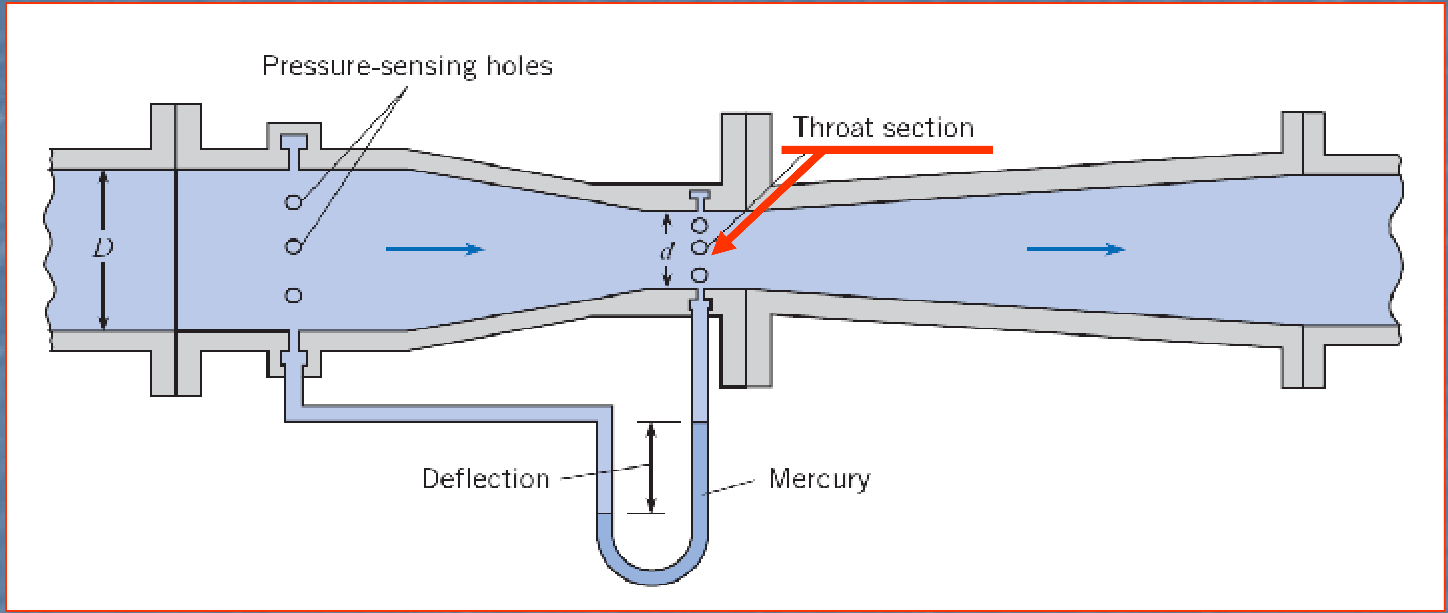
$$\dot{m} = \rho_1 \dot{Q} = Y\,K\,A_0\sqrt{2\,\rho_1(p_1 - p_2)}$$

$$Y = 1 - \left\{\frac{1}{k}\left(1 - \frac{p_2}{p_1}\right)\left[0.41 + 0.35\left(\frac{A_o}{A_1}\right)^2\right]\right\}$$

(Y) account for Compressibility Effect.

2. Venturi Meter

Smaller head loss than the orifice

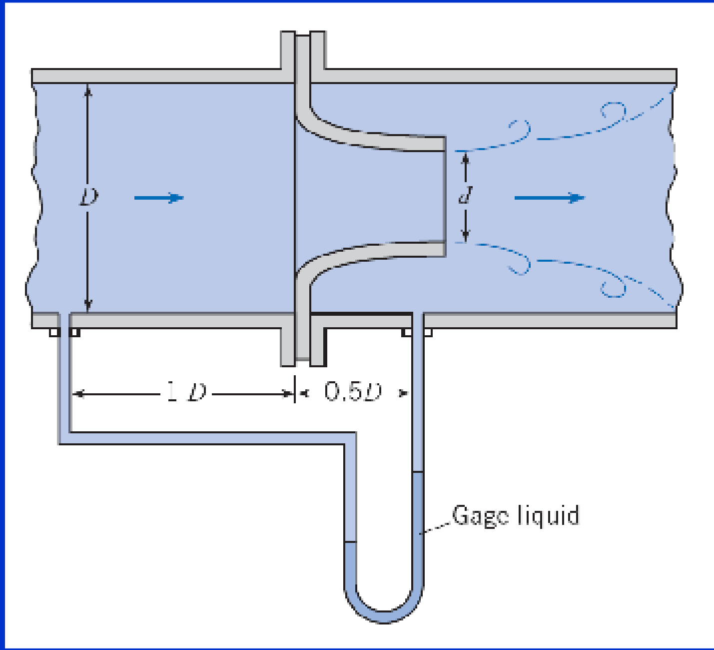


Venturi Eqn. is given by: $C_C = 1$

$$Q = \frac{A_t C_d}{\sqrt{1-(A_t/A_p)^2}} \sqrt{2g(h_p - h_t)} \qquad (13.5)$$

$$Q = K A_t \sqrt{2g\Delta h} \qquad (13.6)$$

3. Flow Nozzles



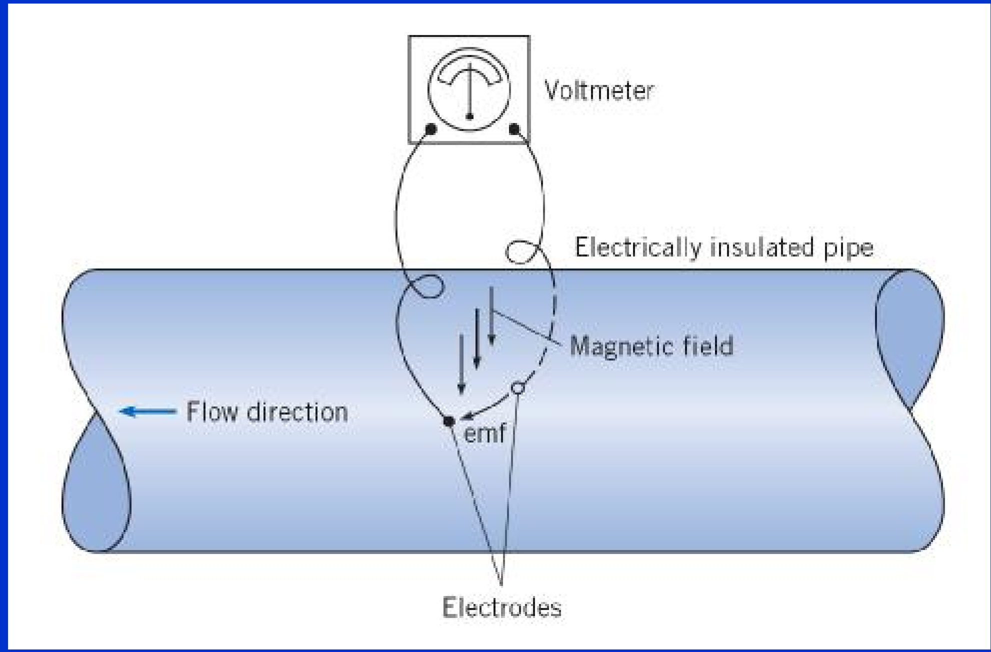
[Advantages:]

1. Less susceptible to wear compared with Orifice device.
2. Same Flow coefficient (K) as Venturi if the pressure taps are located as shown in the figure.

Disadvantages:

Same head loss as Orifice plate.

4. Electromagnetic Flow Meter



Principal of operation is that a conductor moves in electromagnetic field produces an electromotive force. Hence liquids having a degree of conductivity generate a voltage between electrodes as shown above and this voltage is proportional to the velocity of flow in the conduit.

4. Electromagnetic Flow Meter

Applications

1. Measuring blood flow.
2. Measuring the flow of liquid metal in nuclear reactor.

Advantages

1. The output signal varies linearly with the flow rate.
2. The meter causes no resistance to the flow.
3. The meter does not require pressure taps.

Disadvantages

1. High cost.
2. Its unsuitability for measuring gas flow.

5. Ultrasonic Flow Meter

It is used for a diverse applications ranging from blood pressure to open channel flow.

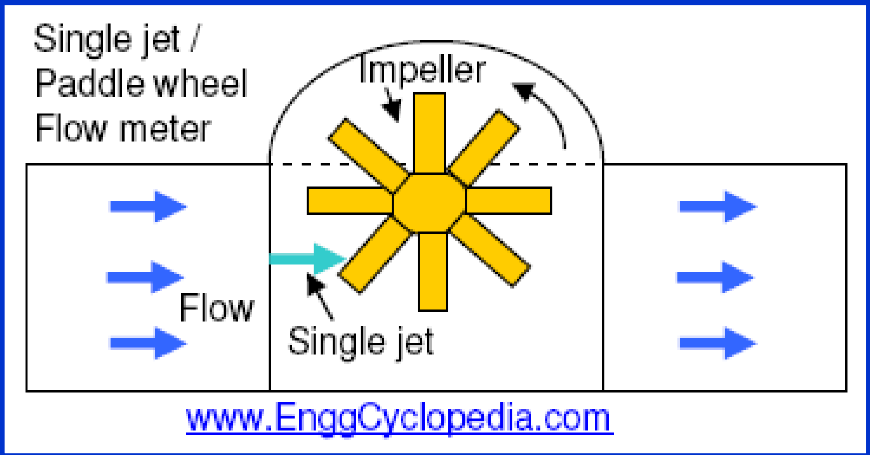
Modes of Operation

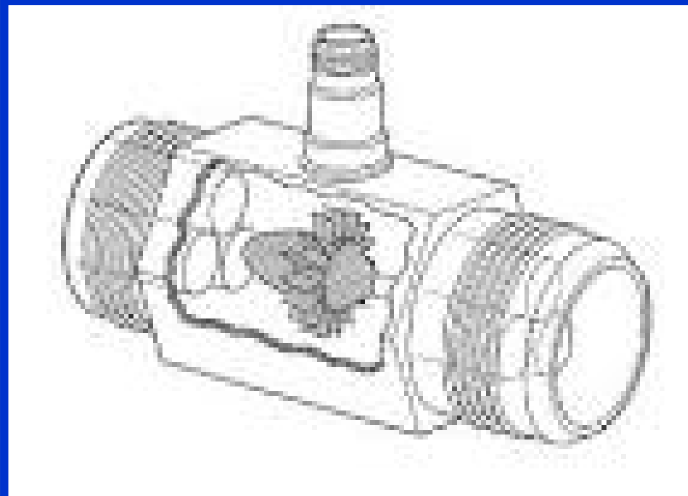
1. First mode involves measuring the difference in travel time for a sound wave traveling upstream and downstream between two measuring stations. The difference in travel time is proportional to flow velocity.

2. Second mode is based on the Doppler effect. When an ultrasonic beam is projected into an inhomogeneous fluid, some acoustic energy is scattered back to the transmitter at a different frequency. The measured frequency difference is related directly to the flow velocity.

6. Turbine Flow Meter

Consists of a wheel with a set of blades mounted inside a duct. Volume flow rate through the meter is related to the rotational speed of the wheel.



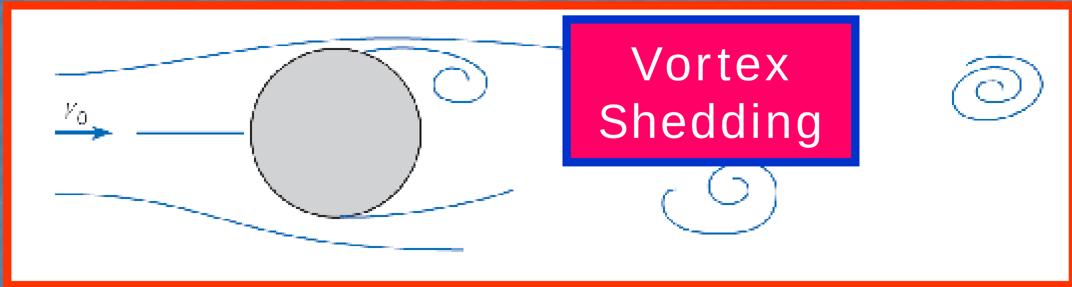


Advantages

1. It can be used for either liquids or gases and monitoring flow rate in fuel supply systems.
2. High accuracy .
3. It operates with small head loss.
4. Very compact.
5. Ideally for low viscosity.
6. Fast time response.

7. Vortex Flow Meter

Consists of a cylinder mounted inside a duct. The cylinder sheds vortices and give rise to oscillatory flow field. The velocity and volume flow rate are directly proportional to the frequency of oscillation.



$$St = \frac{nd}{V_0} \qquad (11.7)$$

n = Frequency

d = Pipe Diameter

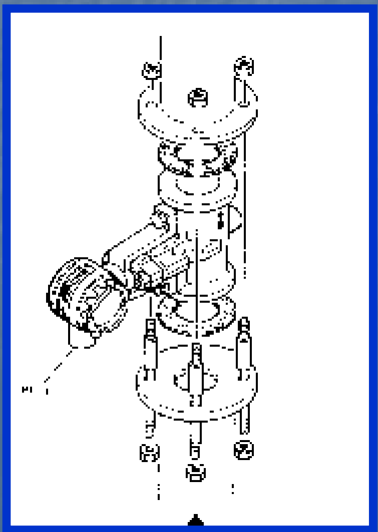
V = Velocity of Flow

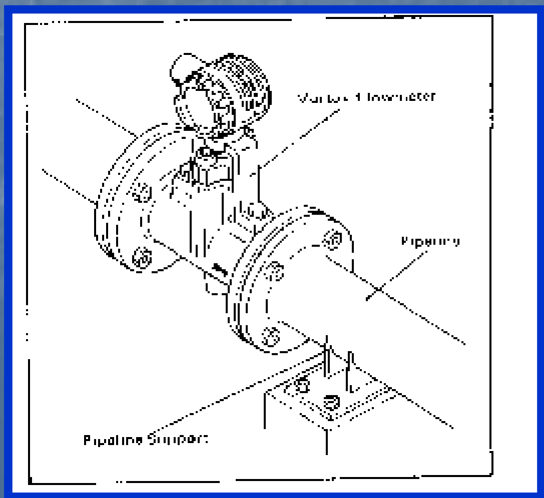
Advantages

No moving parts

Disadvantages

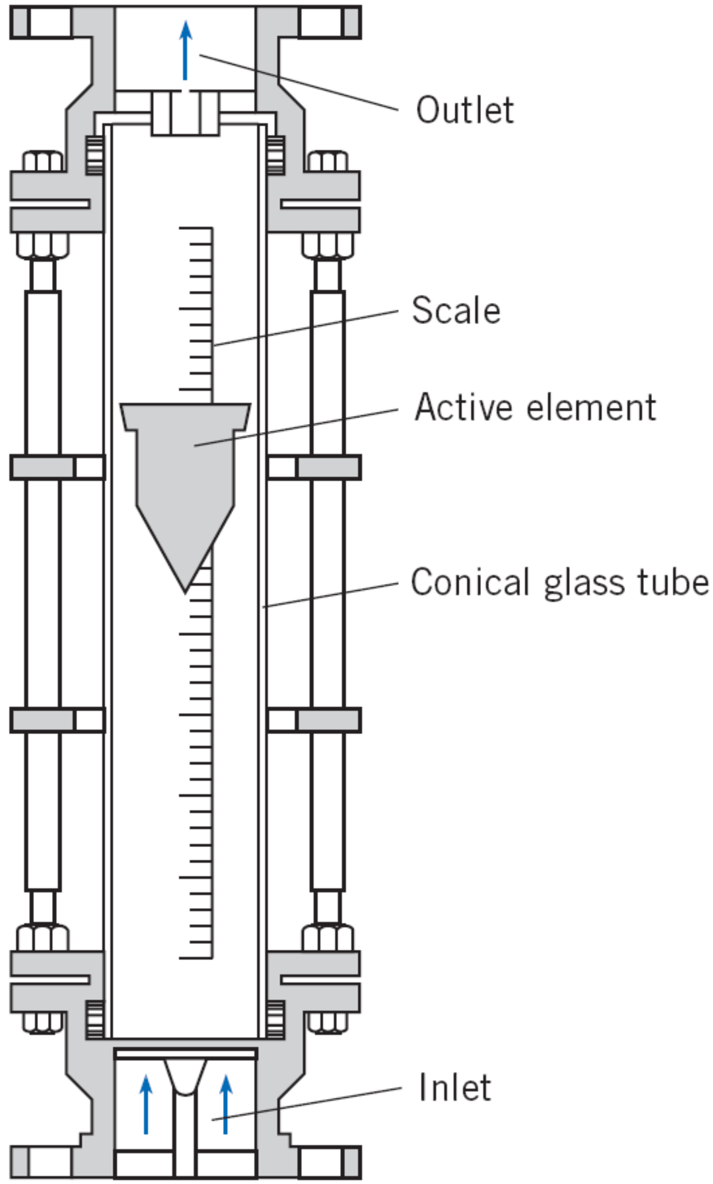
High head loss





8. Rotameter

The rotor (active element) moves up and down against the calibrate scale as shown, <u>the scale measures the volume flow rates</u>.



Advantages

Simplicity of design.

Disadvantages

It is not accurate compared with venturi and orifices.

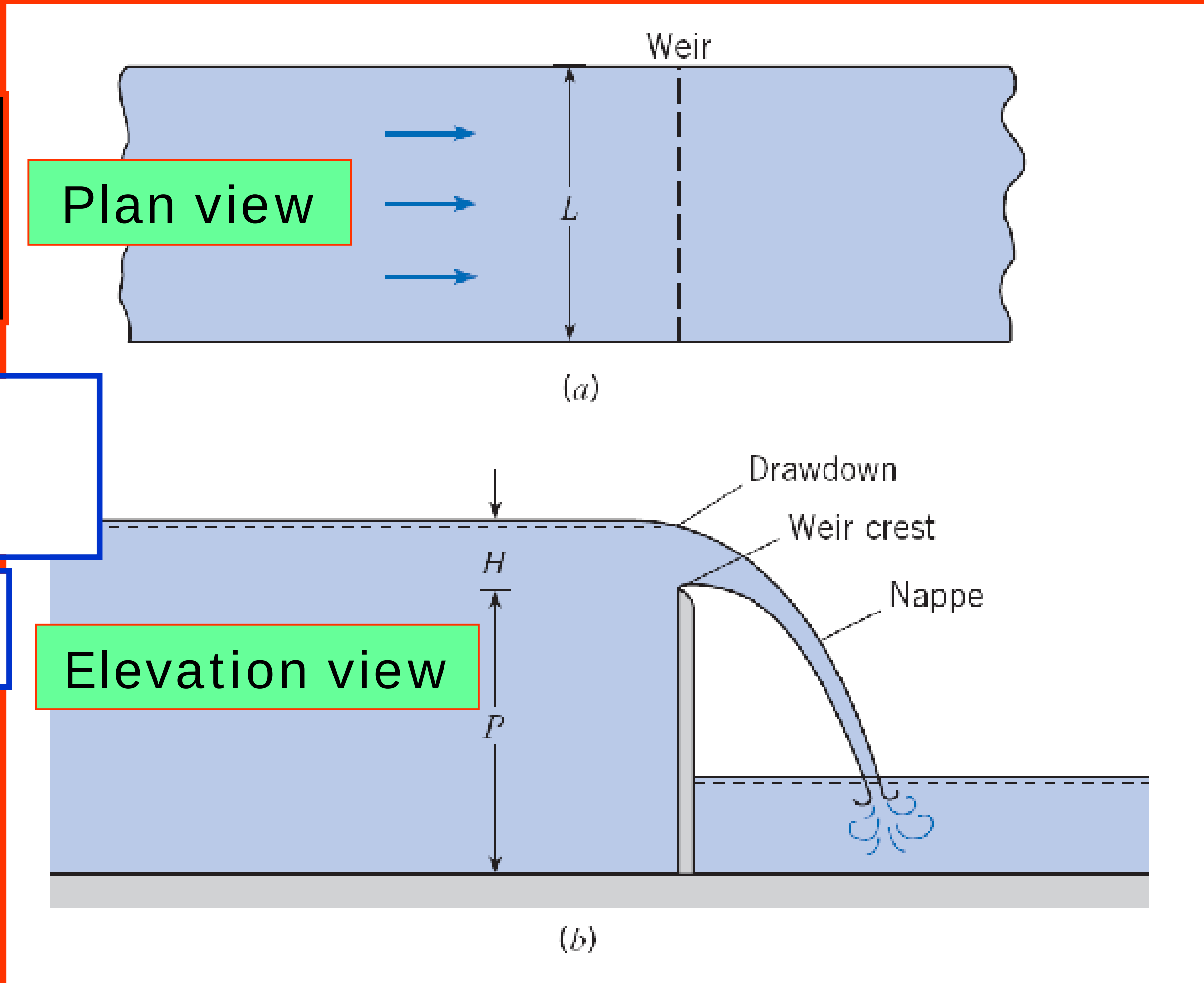
9. Rectangular Weir

To account for Viscous Effects, we introduce the Discharge Coefficient, so the actual flow rate is given by:

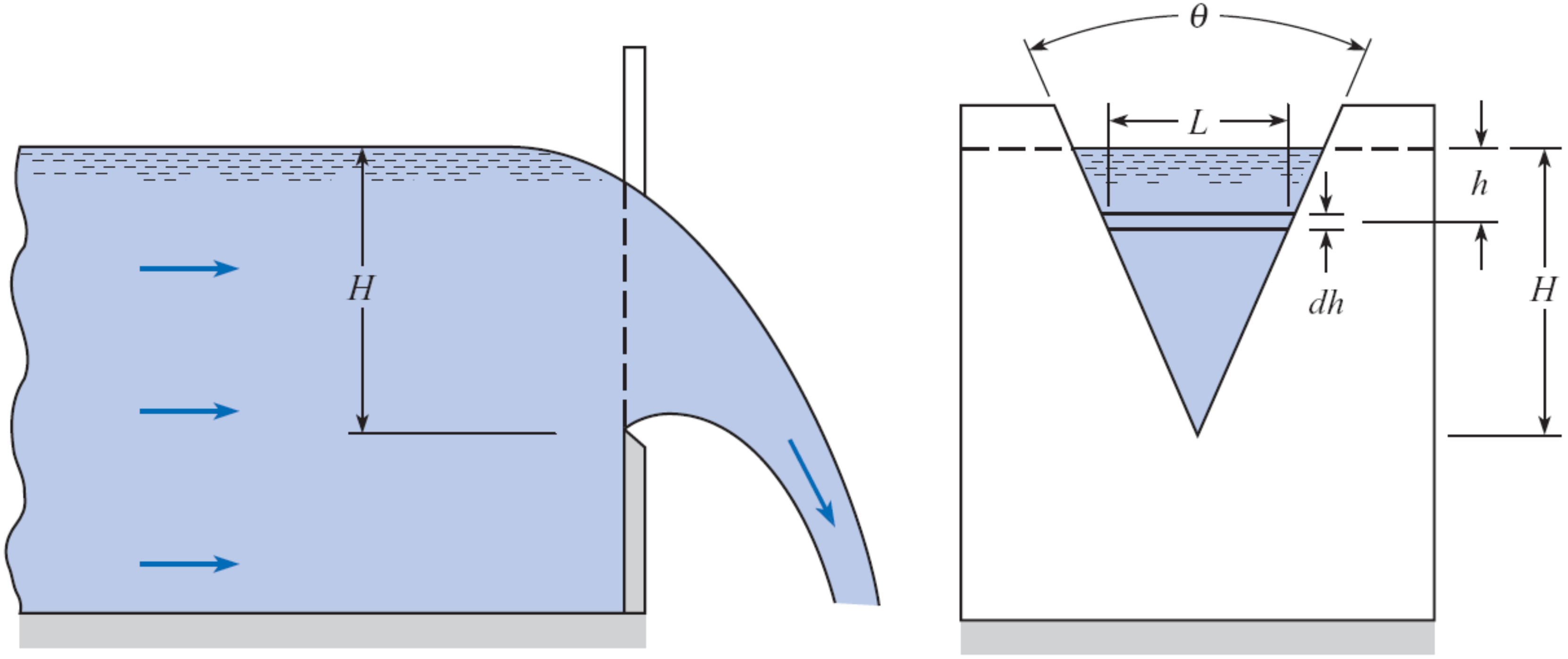
$$Q = \tfrac{2}{3} C_d \sqrt{2g} L H^{3/2}$$
$$= K \sqrt{2g} L H^{3/2}$$

$$K = 0.40 + 0.05 \frac{H}{P}$$

Where: (H/P) is the relative head on the weir



A weir is an obstruction in an open channel over which liquid flows as shown above.



The basic discharge equation for the triangular weir is derived in the same manner as that for the rectangular weir. The differential discharge $dQ = V\,dA = VL\,dh$ is integrated over the total head on the weir. Thus we have

$$Q = \int_0^H \sqrt{2gh}\,(H-h)2\tan\left(\frac{\theta}{2}\right)dh$$

$$Q = \frac{8}{15}\sqrt{2g}\,\tan\left(\frac{\theta}{2}\right)H^{5/2}$$

However, a coefficient of discharge must still be used with the basic equation. Hence we have

$$Q = \frac{8}{15}C_d\sqrt{2g}\,\tan\left(\frac{\theta}{2}\right)H^{5/2}$$

Experimental results with water flow over weirs with $\theta = 60°$ and $H > 2$ cm indicate that C_d has a value of 0.58. Hence the *triangular weir equation* with these limitations is

$$Q = 0.179\sqrt{2g}\,H^{5/2}$$

Discharge For a Triangular Weir

END OF SUMMARY

CHAPTER (13)