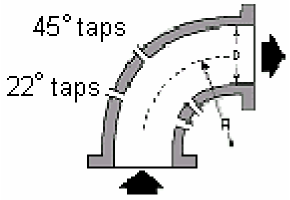
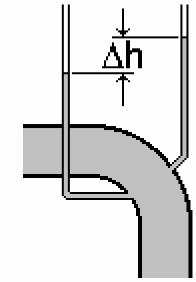
Lecture 14

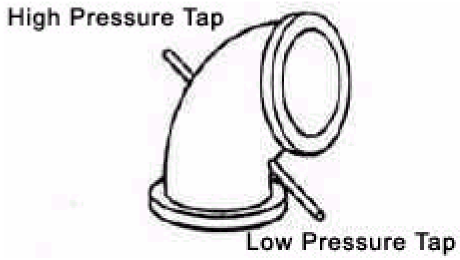
Flow Measurement in Pipes

I. Elbow Meters

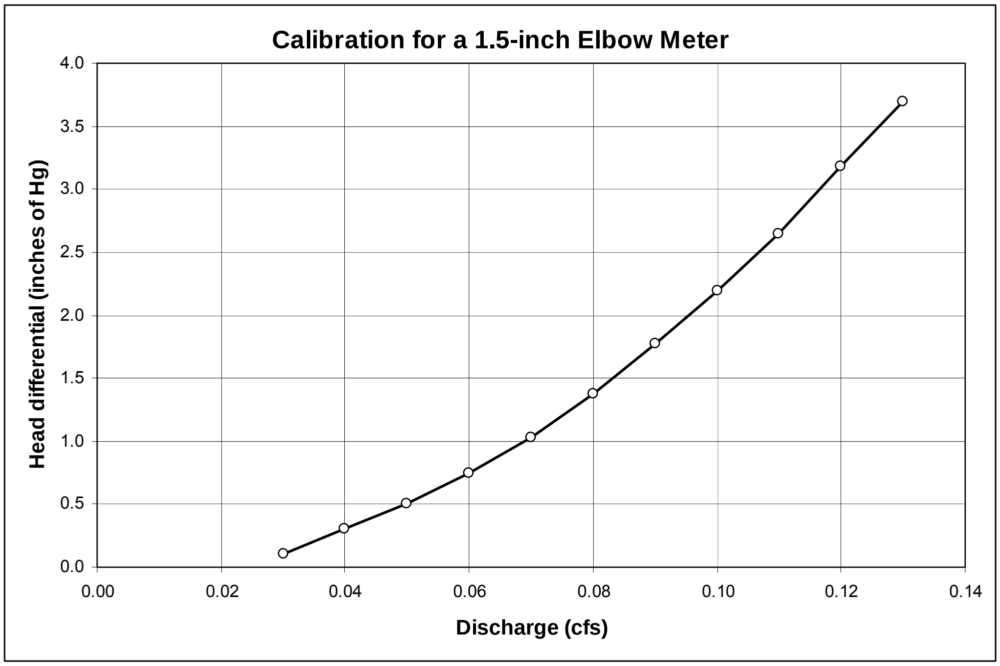




- An elbow in a pipe can be used as a flow measuring device much in the same way as a venturi or orifice plate
- The head differential across the elbow (from inside to outside) is measured, and according to a calibration the discharge can be estimated
- The taps are usually located in the center of the elbow (e.g. at a 45° angle for a 90° elbow), but can be at other locations toward the upstream side of the elbow
- Some companies manufacture elbow meters for flow measurement, but almost any pipe elbow can be calibrated
- Elbow meters are not as potentially accurate as venturi, nozzle, and orifice meters
- Typical accuracy is about ±4% of Q

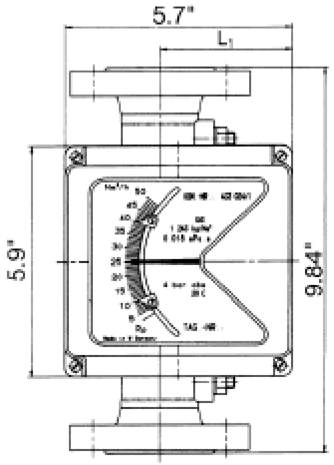


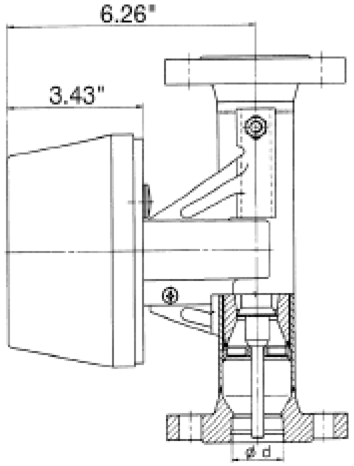
- One advantage of elbow meters is that there need not be any additional head loss in the piping system as a result of flow measurement
- The graph below is a sample calibration curve for a 1½-inch elbow meter in a USU hydraulic lab where the head differential (inside to outside tap) is measured in inches of mercury, using a manometer (data are from Dr. L.S. Willardson)



II. Variable Area Meters

- These are vertical cylinders with a uniformly expanding cross-section in the upward direction
- A float inside the cylinder stabilizes at a certain elevation depending on the flow rate through the cylinder





- Note that the outside walls are usually transparent to allow direct readings by eye

III. Horizontal Trajectory Method

- From physics, an accelerating object will travel a distance x in time t according to the following equation (based on Newton's 2nd law):

$$x = v_o t + \frac{a t^2}{2} \tag{1}$$

where x is the distance; v_o is the initial velocity at time 0; t is the elapsed time; and a is the acceleration

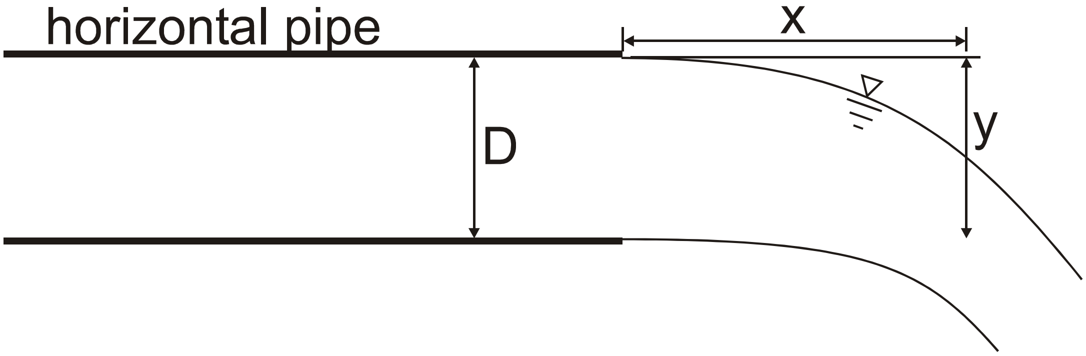
- Flow emanating from a horizontal pipe will fall a height y over a distance x
- The horizontal component (x-direction) has almost no acceleration, and the vertical component (y-direction) has an initial velocity of zero
- The vertical acceleration is equal to the ratio of weight to mass, or g = 9.81 m/s^2 (32.2 ft/s^2)
- Therefore,

$$x = v_o t \qquad \text{and,} \quad y = \frac{g t^2}{2} \tag{2}$$

- Then by getting rid of t, knowing that Q = VA, and the equation for the area of a circle, the flow rate is calculated as follows:

$$Q = \frac{\pi D^2 x}{4\sqrt{\frac{2y}{g}}} \tag{3}$$

where D is the inside diameter of the circular pipe



- This equation is approximately correct if x and y are measured to the center of mass of the discharge trajectory
- Errors occur because in practice it is difficult to measure exactly to the center, and because of possible wind and other turbulent effects
- Also, the pipe might not be exactly horizontal (although a correction could take this into account, according to the same analysis given above)
- Tables of coefficient values derived from experiments allow x and y to be measured from the top of the trajectory
- However, measurements can be difficult because the flow is often very turbulent at a distance from the pipe end

- The previous equation can be simplified as:

$$Q = 3.151 C D^2 \frac{x}{\sqrt{y}} \tag{4}$$

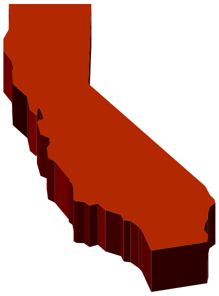
where C is a coefficient to adjust the calculated discharge value when the ratios of x/D or y/D are smaller than 8 and 5, respectively (otherwise, C equals unity)

- Equation 4 is valid for x, y and D in ft, and Q in cfs
- The following table is for C values for use with Eq. 4

y/D	x/D							
	1.00	1.50	2.00	2.50	3.00	4.00	5.00	8.00
0.5	1.44	1.28	1.18	1.13	1.10	1.06	1.03	1.00
1.0	1.37	1.24	1.17	1.12	1.09	1.06	1.03	1.00
2.0		1.11	1.09	1.08	1.07	1.05	1.03	1.00
3.0			1.04	1.04	1.04	1.04	1.03	1.00
4.0			1.01	1.01	1.02	1.03	1.02	1.00
5.0			0.97	0.99	1.00	1.01	1.01	1.00

- This method can also be used for pipes flowing partially full (i.e. $A < \pi D^2/4$), and experimental data are available to assist in the estimation of discharge for these conditions

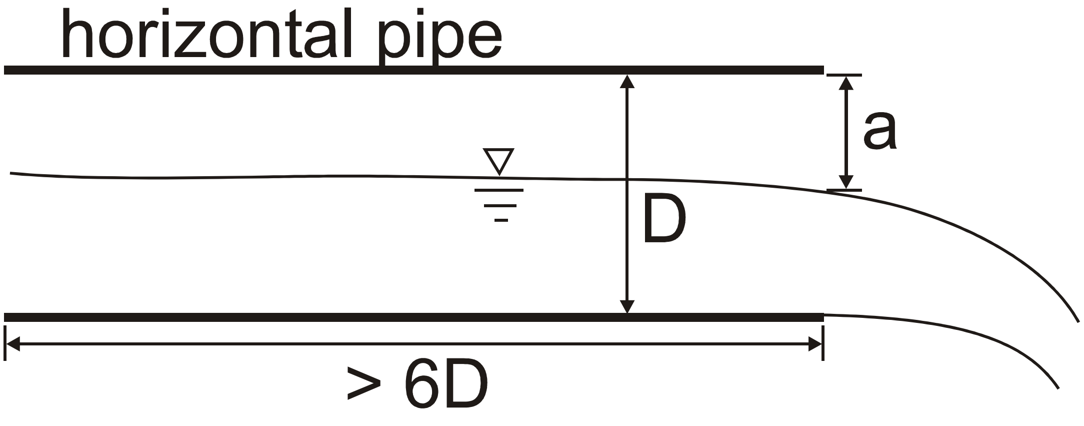
IV. California Pipe Method



- This is the horizontal pipe method for partially-full pipes
- It is somewhat analogous to the calibration for a weir or free overfall
- The following equation is in English units:

$$Q = 8.69\left(1 - \frac{a}{D}\right)^{1.88} D^{2.48} \tag{5}$$

where a and D are defined in the figure below (ft); and Q is discharge in cfs



- The ratio a/D is limited to: $a/D > 0.45$
- This method was published in the 1920’s
- Measurement accuracy is only ±10%, at best
- The pipe must be exactly horizontal (level), with circular cross section
- The pipe must discharge freely into the air, unsubmerged

V. Vertical Trajectory Method

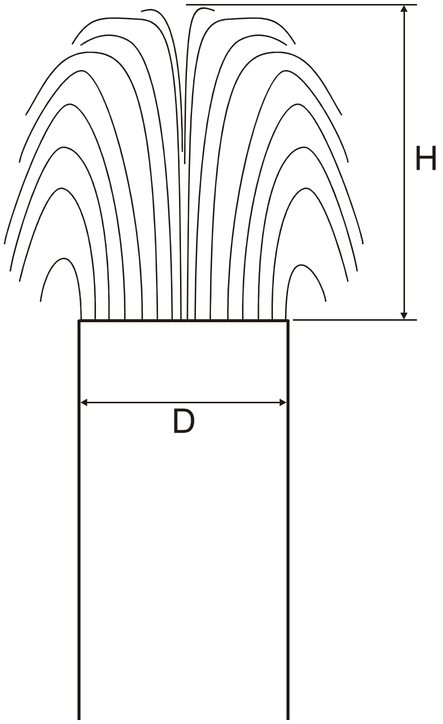
- As with pipes discharging horizontally into the air, there is a method to measure the flow rate from vertical pipes
- This is accomplished by assuming a translation of velocity head into the measurable height of a column of water above the top of the pipe
- Thus, to estimate the flow rate from pipes discharging vertically into the air it is only necessary to measure the:

1. inside diameter of the pipe, D; and,
2. the height of the jet, H, above the pipe

- This is a nice idea on "paper," but in practice, it can be difficult to measure the height of the column of water because of sloshing, surging, and splashing
- Also, the act of measuring the height of the column can significantly alter the measured value
- The table below gives flow rate values in gpm for several pipe diameters in inches

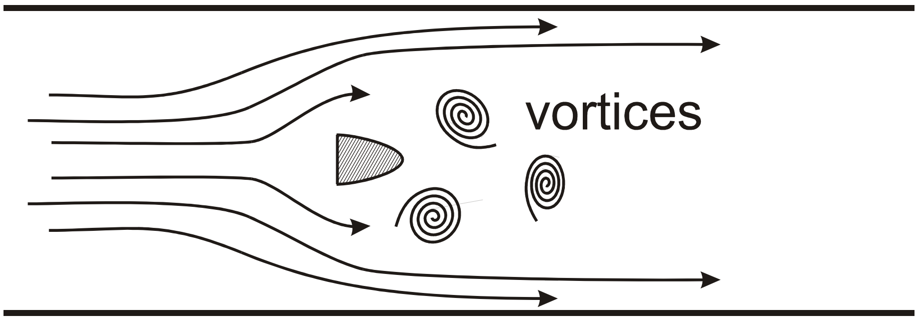
Jet Height (inch)	Pipe Diameter (inch)							
	2	3	4	5	6	8	10	12
	(gpm)	(gpm)	(gpm)	(gpm)	(gpm)	(gpm)	(gpm)	(gpm)
2	28	57	86	115	150	215	285	355
2½	31	69	108	150	205	290	385	480
3	34	78	128	183	250	367	490	610
3½	37	86	145	210	293	440	610	755
4	40	92	160	235	330	510	725	910
4½	42	98	173	257	365	570	845	1060
5	45	104	184	275	395	630	940	1200
6	50	115	205	306	445	730	1125	1500
7	54	125	223	336	485	820	1275	1730
8	58	134	239	360	520	890	1420	1950
9	62	143	254	383	550	955	1550	2140
10	66	152	268	405	585	1015	1650	2280
12	72	167	295	450	650	1120	1830	2550
14	78	182	320	485	705	1220	2000	2800
16	83	195	345	520	755	1300	2140	3000
18	89	208	367	555	800	1400	2280	
20	94	220	388	590	850	1480	2420	
25	107	248	440	665	960	1670	2720	
30	117	275	485	740	1050	1870	3000	
35	127	300	525	800	1150	2020		
40	137	320	565	865	1230	2160		

From Utah Engineering Experiment Station Bulletin 5, June 1955.
"Jet Height" (first column) is the height from the top of the pipe to the top of the jet.

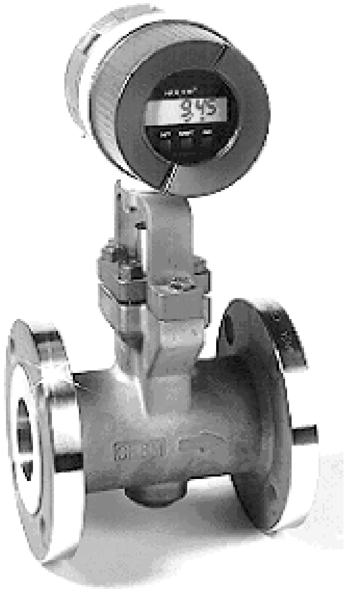


VI. Vortex Shedding Meters

- The vortex shedding meter can be accurate to within ±½% to ±1% of the true discharge
- The basic principal is that an object placed in the flow will cause turbulence and vortices in the downstream direction, and the rate of fluctuation of the vortices can be measured by detecting pressure variations just downstream



- This rate increases with increasing velocity, and it can be used to give an estimate of the discharge
- This requires calibration for a particular pipe material, pipe size, element shape and size, fluid type, and temperature
- It is essentially a velocity-area flow measurement method, but it is calibrated to give discharge directly



- Vortex shedding meters are commercially available and are used with a variety of fluids, not only with water, and can operate well over a large pressure range and high flow velocities
- Size selection for these meters is important in order to avoid cavitation
- There need not be any moving parts in the meter
- This meter can be used for velocities up to approximately 50 m/s, or 180 kph
- The response of the device is linear for Reynolds numbers of 10,000 or more
- Errors can result from pipe vibration due to external machinery or other causes, or when the velocity is too low; however, some sophisticated devices have been developed and tested to correct for such errors

VII. Ultrasonic Meters

1. Doppler

    - An emitted pressure wave reflects off a deflector plate
    - Difference between transmitted and reflected frequencies correlates to flow velocity
    - Liquid does not have to be clean – in fact, it may not work well if the liquid is “too clean” because it needs particles to reflect the signal

2. Transit-time

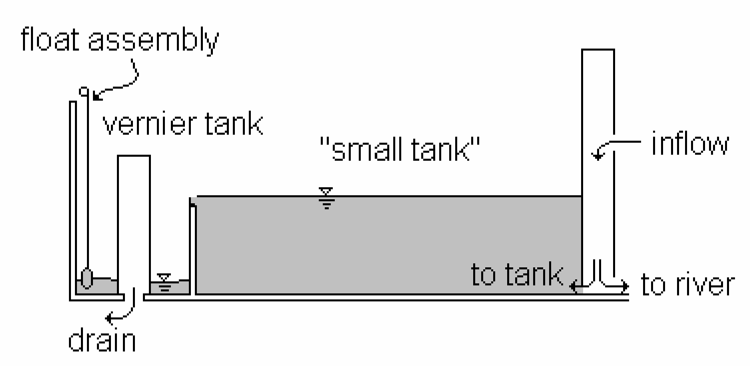
    - Also called “time-of-flight”
    - The liquid should be fairly clean with this method
    - Devices generates high-frequency (≈1 MHz) pressure wave(s)
    - Time to reach an opposing wall (inside the pipe) depends on:

        a) Flow velocity
        b) Beam orientation (angle)
        c) Speed of sound through the liquid medium

    - Upstream straightening vanes may be needed to avoid swirling flow
    - May have a single or multiple transmitted sound beams

VIII. Other Measurement Devices

- Collins meters
- Commercial propeller flow meters
- Electromagnetic flow meters
- Volumetric tank



- Weight tank

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