CHAPTER 1: INSTRUMENTATION EQUIPMENT

MODULE 5: Flow Instrumentation

MODULE OBJECTIVES:

At the end of this module, you will be able to:

1. **State the relationship between flow and differential pressure developed across a flow restriction**
2. **Name the four most commonly used primary devices in flow measurement.**
3. **Sketch a flow measurement installation including an orifice plate, three-valve manifold and flow transmitter.**
4. **State the advantages and disadvantages of using the orifice plate as a primary device and compare with the venturi.**
5. **State an application for each of a venturi tube, flow nozzle and elbow taps in an industrial process plant.**

Energy and Flow Equation of Fluids

The total energy of fluid in a flow system is comprised of three components: potential energy, kinetic energy and pressure energy. When described in terms of metros head of the flowing fluid, we have, mathematically:

Total Energy = Potential + Kinetic + Pressure

$$= Z + \frac{V^2}{2g} + \frac{p}{\rho}$$

where

Z = Elevation of the center line of the pipe (m)

V = Velocity of the fluid (m/sec)

g = Acceleration due to gravity (9.8 m/sec^2)

P = Static Pressure (N/M^2)

ρ = Weight density of fluid (N/M^3)

Flow quantity inside a pipe is given as the product of the velocity of the fluid and the cross-sectional area of the pipe, that is:

$$Q = V \cdot A$$

where

Q = Flow rate (m^3/sec)

V = Velocity (m/sec)

A = Cross-sectional area (m^2)

Flow in a pipe with a restriction:

If the flow is steady, then the same quantity of fluid must pass through the two different sections of the pipework in a given time.

$$Q = A_1V_1 = A_2V_2$$

when $A_1 > A_2$, then $V_1 < V_2$

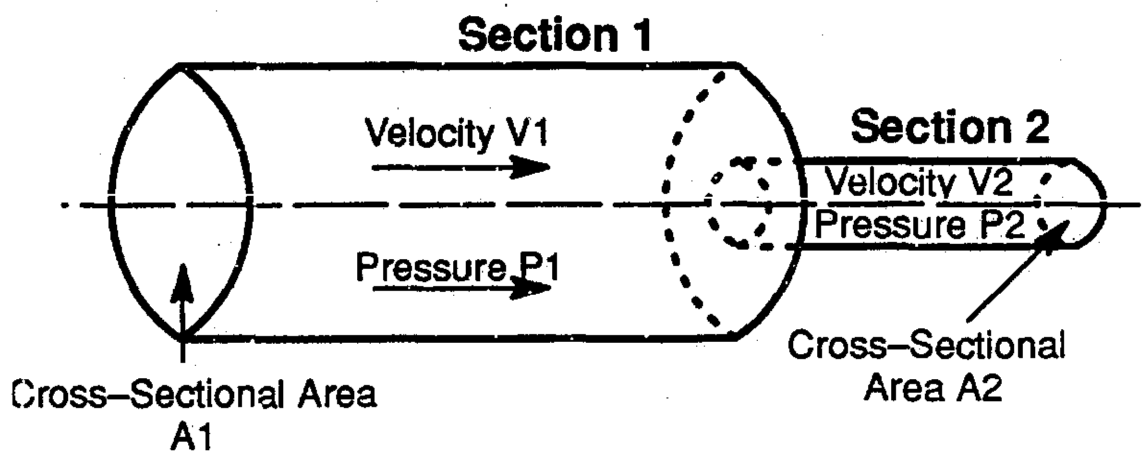

Figure 1: Pipework with Restriction.

Because of Conservation of Energy an increase in kinetic energy in Section 2, must be compensated for by a decrease in another form of energy.

The pipe is considered to be level, therefore, the potential energy (Z) in the two sections will be the same.

We now have:

$$\text{Total Energy} = \frac{P_1}{p} + \frac{V_1^2}{2g} = \frac{P_2}{p} + \frac{V_2^2}{2g}$$

where

P_1, P_2 = Pressure in Section 1 and 2 respectively.
V_1, V_2 = Velocity in Section 1 and 2 respectively.

Pressure and velocity being the only two variables, as V_2 increases, P_2 must decrease. Therefore, the increase in kinetic energy in Section 2 will be at the expense of a reduction in pressure energy in the same section.

By solving the energy and flow equation simultaneously, we can arrive at the relationship:

$$Q = K\sqrt{p_1 - p_2}$$

or

$$Q = K\sqrt{\Delta p}$$

where

Q = Flowrate (m^3/sec)

K = Constant, depends on pipe areas and ρ

$\Delta p = P_1 - P_2$ = Differential pressure between Section 1 and 2.

That is the <u>flow rate is proportional to the square root of the differential pressure</u> ($Q \propto P^{1/2}$). This is the principle behind pressure head flow metering in which a constriction is used to develop a differential pressure. By measuring the differential pressure between two different sections, flow rate can be calculated.

Primary Devices

To measure flow rate by means of differential pressure requires the use of a device that creates a constriction.

Orifice Plate

An orifice plate is basically a thin metal plate (1.5 to 6 mm in thickness) with a hole bored in the center.

The orifice has a diameter that is between 30% to 75% of the inside diameter of the pipe work in which it is installed. The ratio of orifice bore diameter (d) to the pipe inside diameter (D) is called the Beta Ratio (β).

$$\beta = d/D$$

For example, a β ratio of 0.5 indicates that the bore diameter is 50% of the pipe inside diameter.

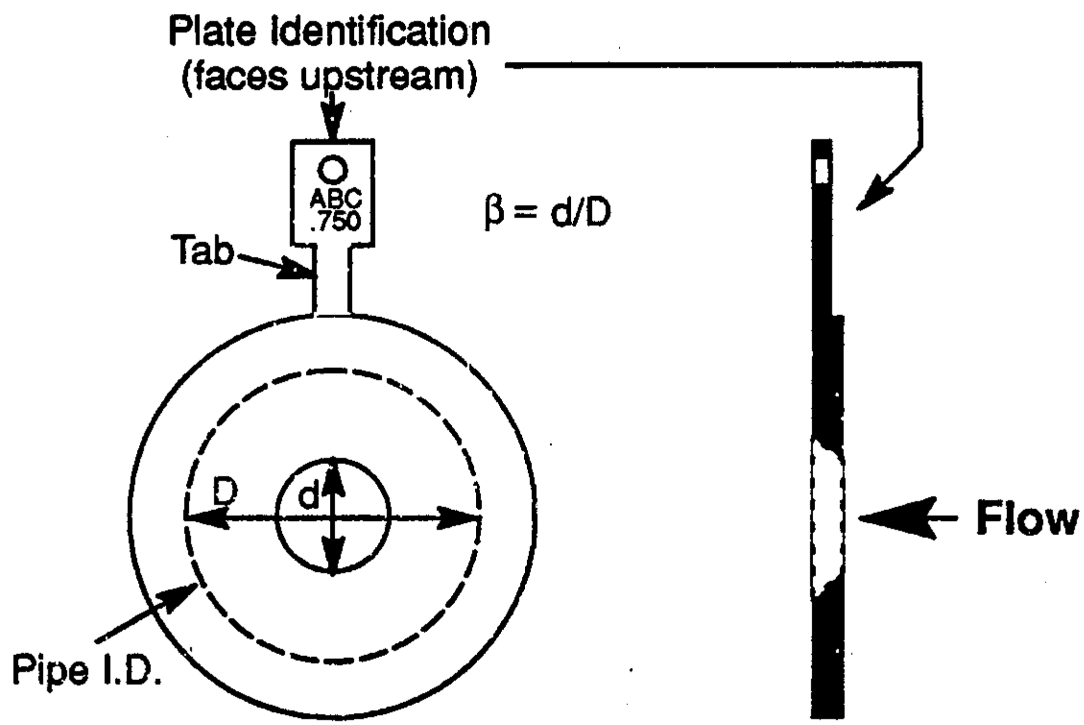

Figure 2: A Typical Orifice Plate.

The increase of fluid flow velocity through the reduced area at the orifice develops a differential pressure across the orifice.

The pressure drop is a function of flow rate.
The smaller the β ratio, the higher the differential pressure.

Vena contracta

- With an orifice plate in the pipe work, static pressure increases slightly upstream of the orifice (due to back pressure effect) and then decreases sharply as the flow passes through the orifice, reaching a minimum at a point called the where the velocity of the flow is at a maximum.
- Beyond this point, static pressure starts to recover as the flow slows down. However, with an orifice plate, static pressure downstream is always considerably lower than the upstream pressure. In addition some pressure energy is converted to sound and heat at the orifice plate..
- Note that the measured differential pressure developed by an orifice plate also depends on the location of the pressure sensing points or pressure taps.

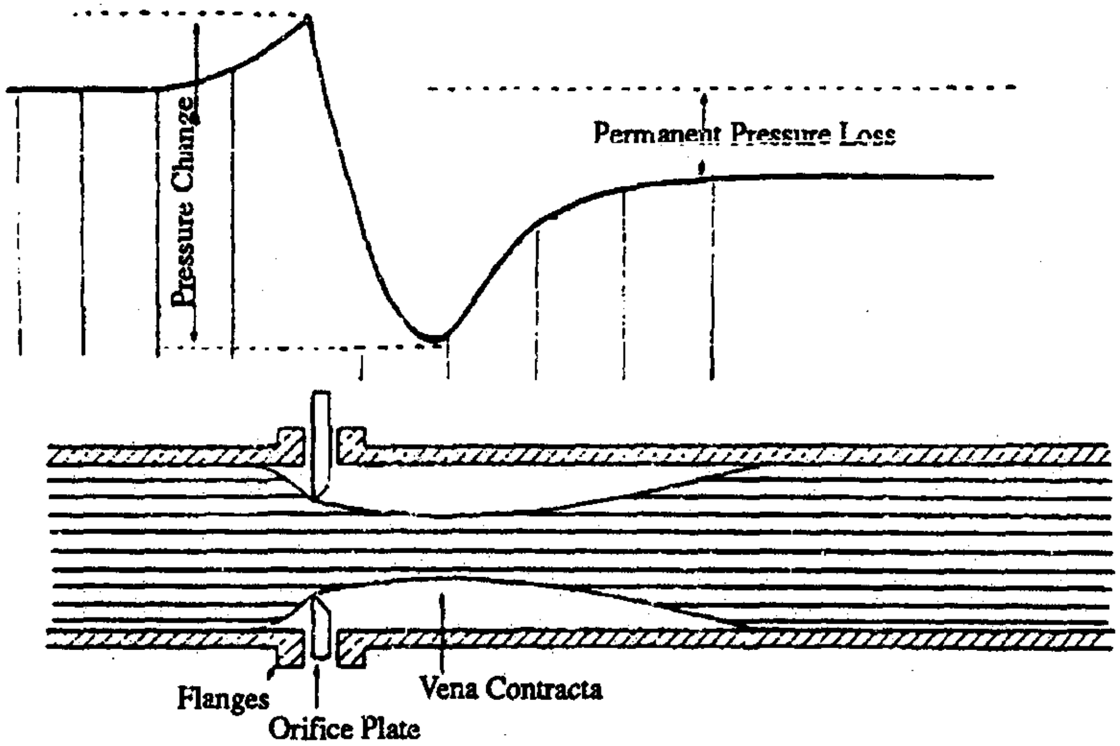

Figure 3: Orifice Plate Installation With Pressure Profile.

Pressure Tap Location

- Flange taps are the most widely used pressure tapping location.
- They are holes bored through the flanges, located one inch upstream and one inch downstream from the respective faces of the orifice plate.
- The upstream and downstream sides of the orifice plate are connected to the high pressure and low pressure sides of a DP transmitter.
- Usually a three-valve manifold has to be used to protect the DP capsule from being over-ranged.
- The same procedure for valving in and out the three valve manifold in a level installation is applied to flow installation.

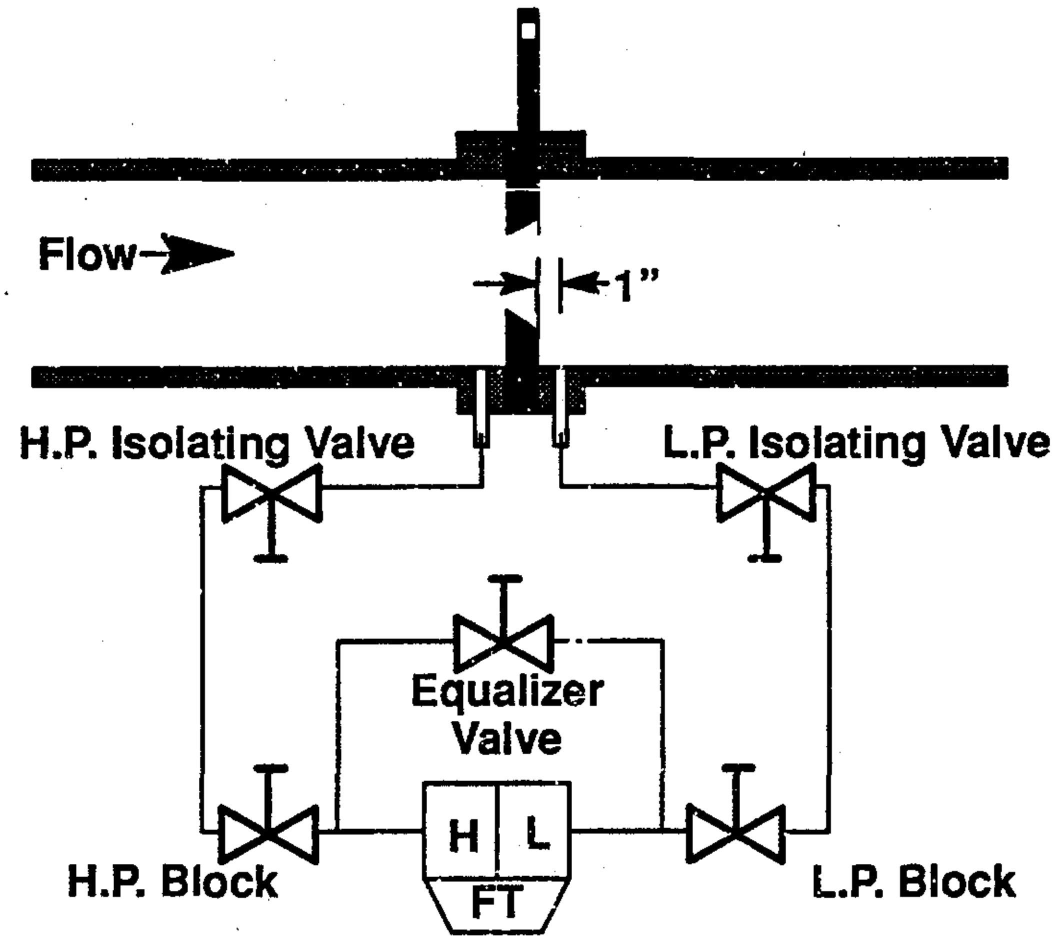

Figure 4: Orifice Plate with Flange Taps and 3 Valve Manifold.

Operation Sequences of Three-Valve Manifold

Valving Transmitter Into Service

1. Check all valves closed.
2. Open the equalizing valve.
3. Open the high pressure block valve.
4. Close the equalizing valve.
5. Open the low pressure block valve.

Transmitter is now in service.

Removing Transmitter From Service

1. Close the low pressure block valve.
2. Open the equalizing valve.
3. Close the high pressure block valve.

Transmitter is now out of service.

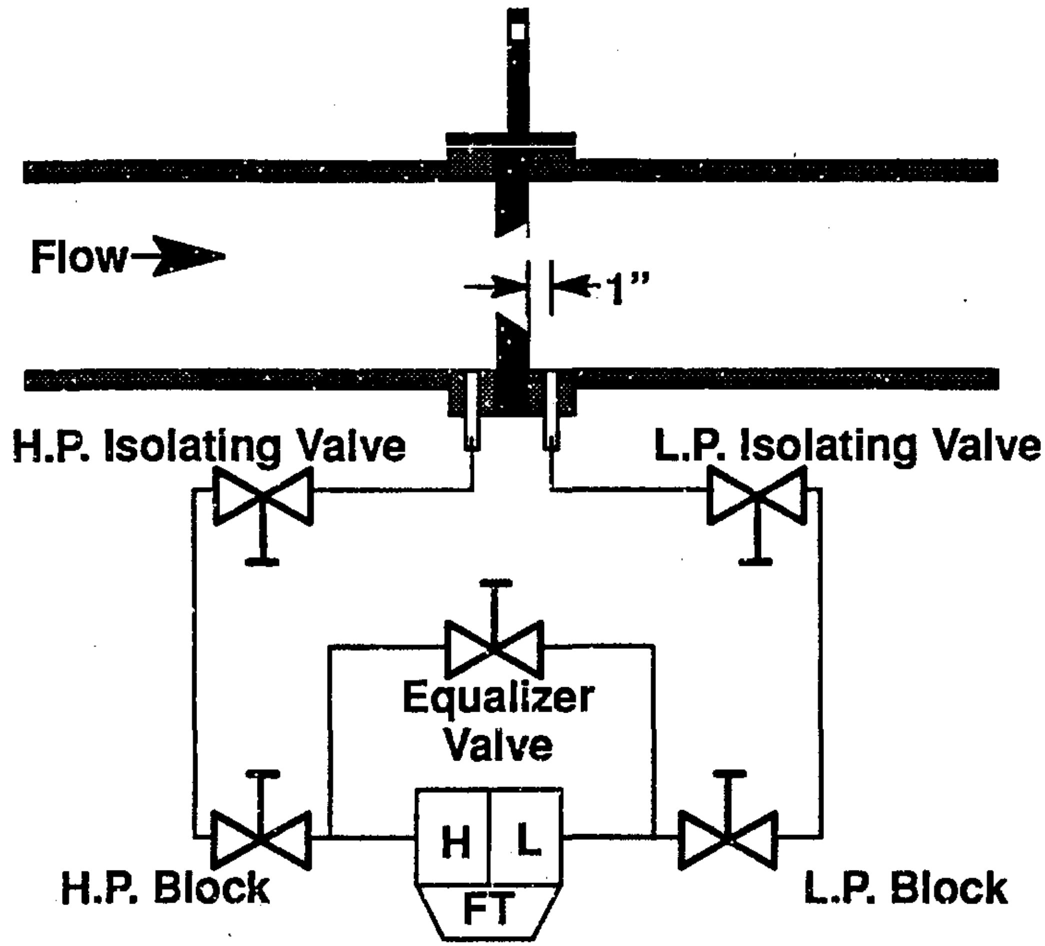

Figure 4: Orifice Plate with Flange Taps and 3 Valve Manifold.

Other Types of Pressure Taps

Other common types of pressure take off include:

Corner taps which are located right at upstream and downstream faces of the orifice plates. (Figure 5).

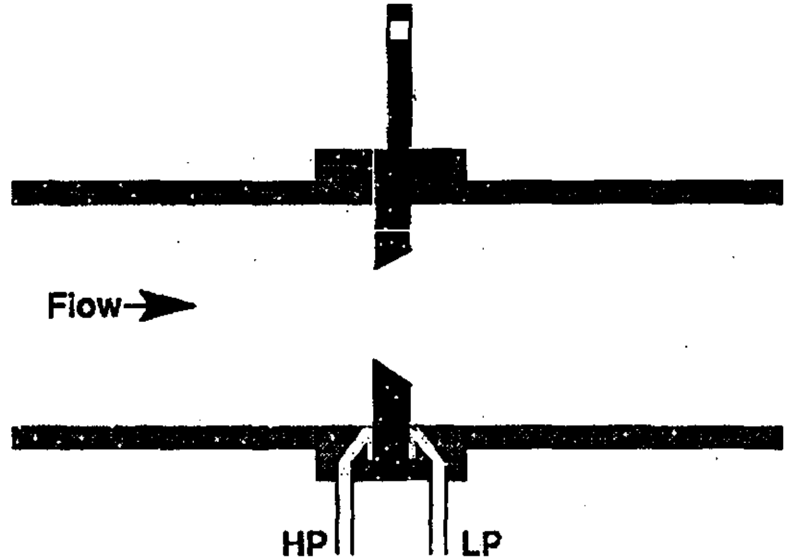

Figure 5: Orifice Plate with Corner Taps.

Pipe taps, which are located two and a half pipe inner diameters upstream and eight pipe inner diameters downstream.

Vena contracts taps, are located one pipe inner diameter upstream and at the point of minimum pressure, usually one half pipe inner diameter downstream (Figure 6).

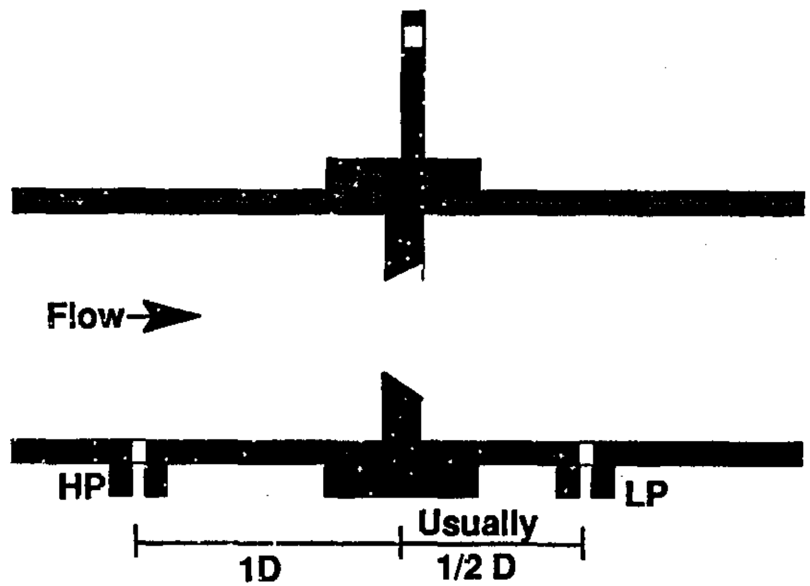

Figure 6: Orifice Plate with Vena Contracta Taps.

When an orifice plate is used with one of the standardized pressure tap locations, an on-location calibration of the flow transmitter is not necessary. Once the ratio and the kind of pressure tap to be used are decided, there are empirically derived charts and tables available to facilitate calibration.

Advantages And Disadvantages of Orifice Plate

Advantages of orifice plates include:

1. **High differential pressure generated.**
2. **Exhaustive data available.**
3. **Low purchase price and installation cost.**
4. **Easy replacement.**

On the other hand, disadvantages include:

1. **High permanent pressure loss implies higher pumping cost.**
2. **Cannot be used on dirty fluids, slurries or wet steam as erosion will alter the differential pressure generated by the orifice plate.**

Venturi Tubes

For applications where high permanent pressure loss is not tolerable, a venturi tube (Figure 7) can be used. Because of its gradually curved inlet and outlet cones, almost no permanent pressure drop occurs. This design also minimizes wear and plugging by allowing the flow to sweep suspended solids through without obstruction.

A venturi tube has the following disadvantages:

1. Calculated calibration figures are less accurate than for orifice plates. For greater accuracy, each individual venturi tube has to be flow calibrated.
2. The differential pressure generated by a venturi tube is lower than for an orifice plate. Hence a high sensitivity flow transmitter is needed.
3. It is expensive.

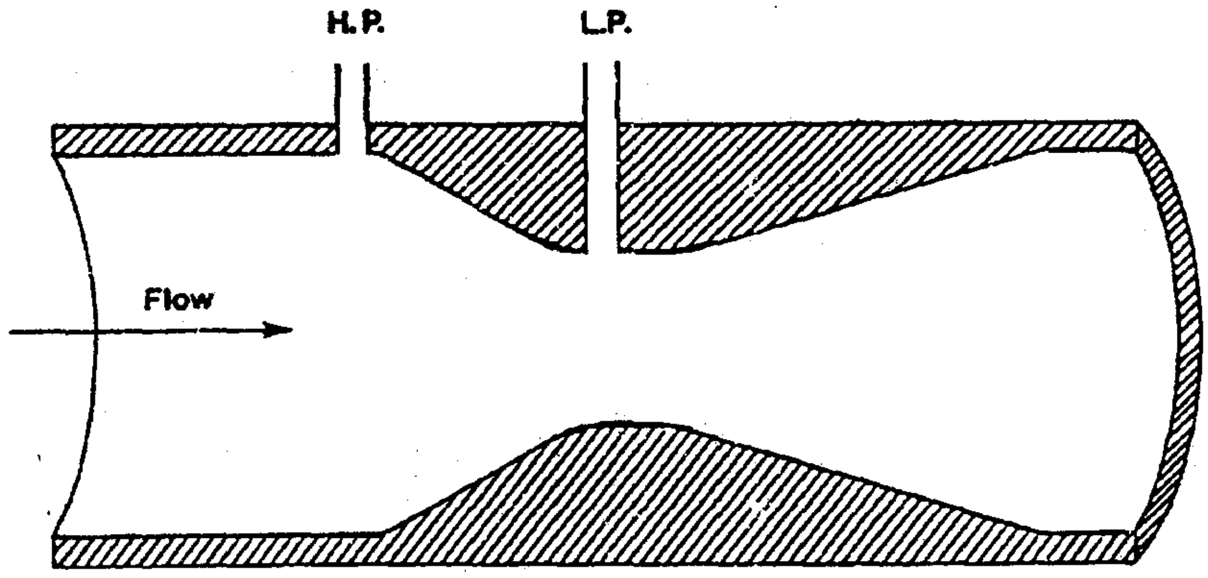

Figure 7: A Venturi Tube.

Flow Nozzle

A flow nozzle is also called a half venturi.

The flow nozzle has properties between an orifice plate and a venturi. Because of its streamlined contour, the flow nozzle has a lower permanent pressure loss than an orifice plate (but higher than a venturi). The differential it generates is also lower than an orifice plate (but again higher than the venturi tube).

Flow nozzles are widely used for flow measurements at high velocities. They are more rugged and more resistant to erosion than the sharp-edged orifice plate, and therefore are typically used in cases where the flow rate is high and the flow has a high gas content. They are also less expensive than the venturi tube.

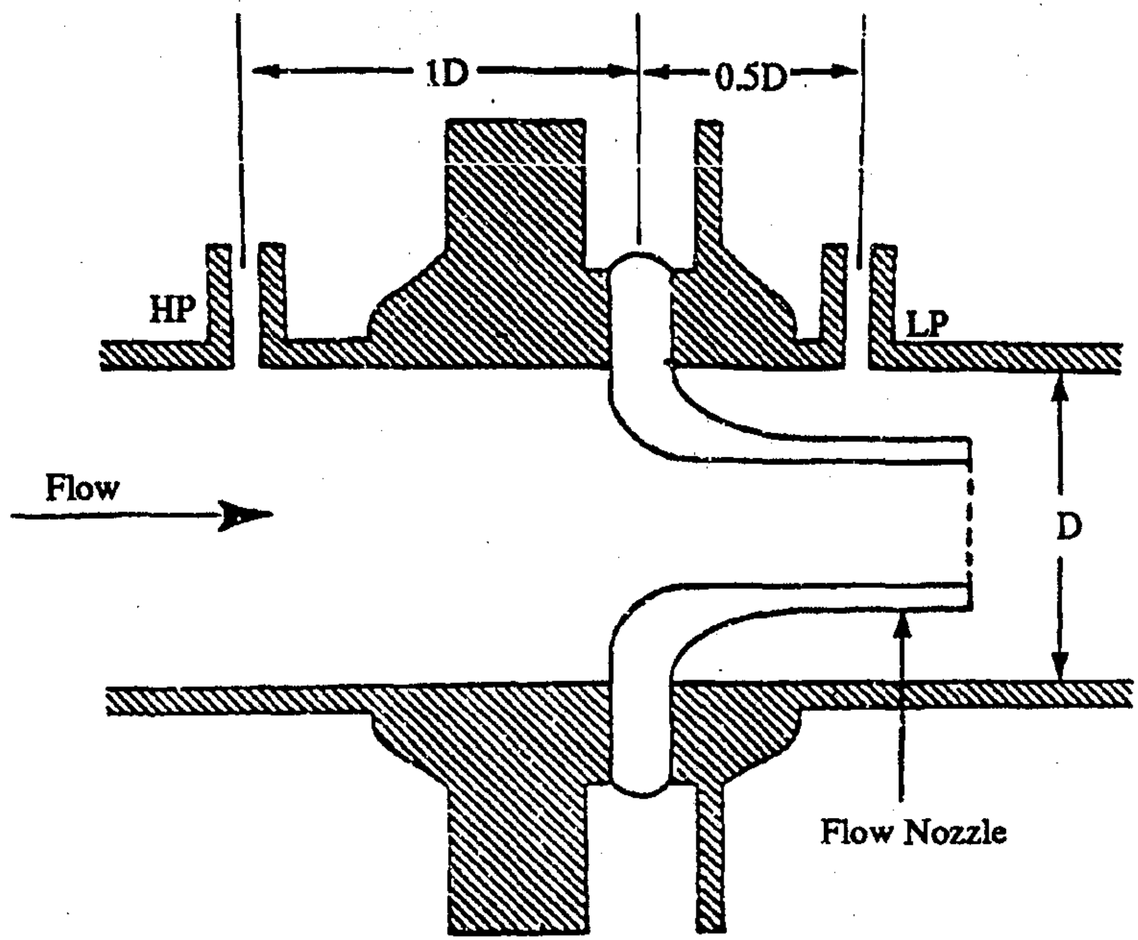

Figure 8: Representative Flow Nozzle Installation.

Elbow Taps

- Centrifugal force generated by a fluid flowing through an elbow can be used to measure fluid flow.
- As fluid goes around an elbow, a high pressure area appears on the outer face of the elbow. If a flow transmitter is used to sense this high pressure and the lower pressure at the inner face of the elbow, flow rate can be measured.
- Elbow taps are typically used to measure steam flow from the boilers, where the large volume of saturated steam at high pressure and temperature could cause an erosion problem for other primary devices.
- Another advantage is that the elbows are often already in the regular piping configuration so no additional pressure loss is introduced.

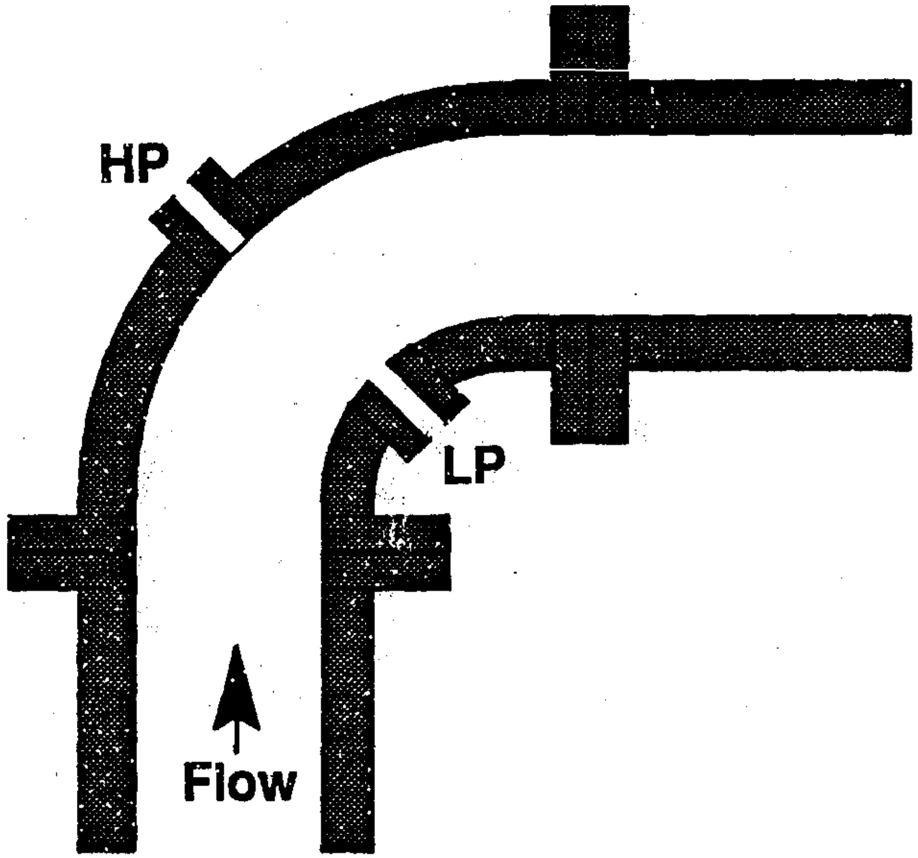

Figure 9: A Representative Elbow Tap Installation.