Fluid Mechanics (CT-213)

- ***Course Instructor***

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Steady Incompressible Flow in Pressure Conduits

Lecture - 10

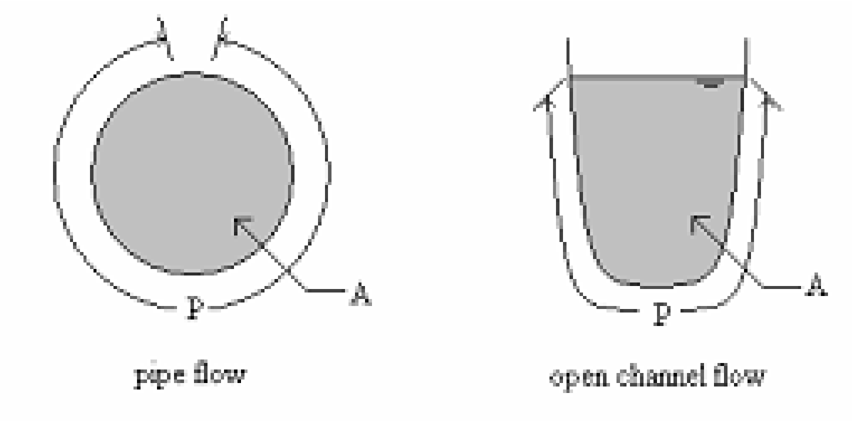
Significance of Conduits

- In considering the convenience and necessities in every day life, it is truly amazing to note the role played by conduits in transporting fluid.
- For example, the water in our homes is normally conveyed through pressure pipelines, from the distribution system, so that it will be available when and where we want it.
- Moreover, virtually all of this water leaves our homes as dilute wastes through sewers, another type of conduits. Oil is often transferred from their source by pressure pipelines to refineries while gas is conveyed by pipelines into a distribution network for supply.
- Thus, it can be seen that the fluid flow in conduits is of immense practical significance in civil/environmental engineering.

Pipe Flow System

- **A pipe is a closed conduit, generally of circular cross-section, used to carry water or any other fluid.**
- When the pipe is running full, the flow is under pressure. But if the pipe is not running full (as in case of sewer pipes, culverts etc), the flow is not under pressure.
- In such case the atmospheric pressure exists inside the pipe. We will discuss the flow of pipes under pressure only.

Hydraulic Radius

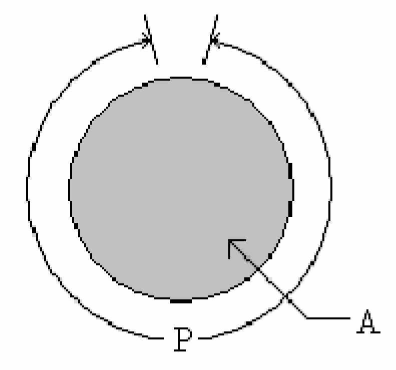


- Hydraulic Radius = R_h = A/P (8.3)

  Where,
  - A is cross-sectional Area
  - P is the Wetted Perimeter (length of boundary in contact with water)

Hydraulic Radius

- **For Pipe Flow:**



pipe flow

$$A = \pi R^2 \qquad \& \qquad P = 2\pi R$$

$$R_h = \frac{\pi R^2}{2\pi R} = \frac{R}{2} = \frac{D}{4} \qquad (8.4)$$

HEAD

(REF: Lecture 7)

$$\left(\frac{p_1}{\gamma}+z_1+\frac{V_1^2}{2g}\right)-h_L=\left(\frac{p_2}{\gamma}+z_2+\frac{V_2^2}{2g}\right) \qquad (5.28)$$

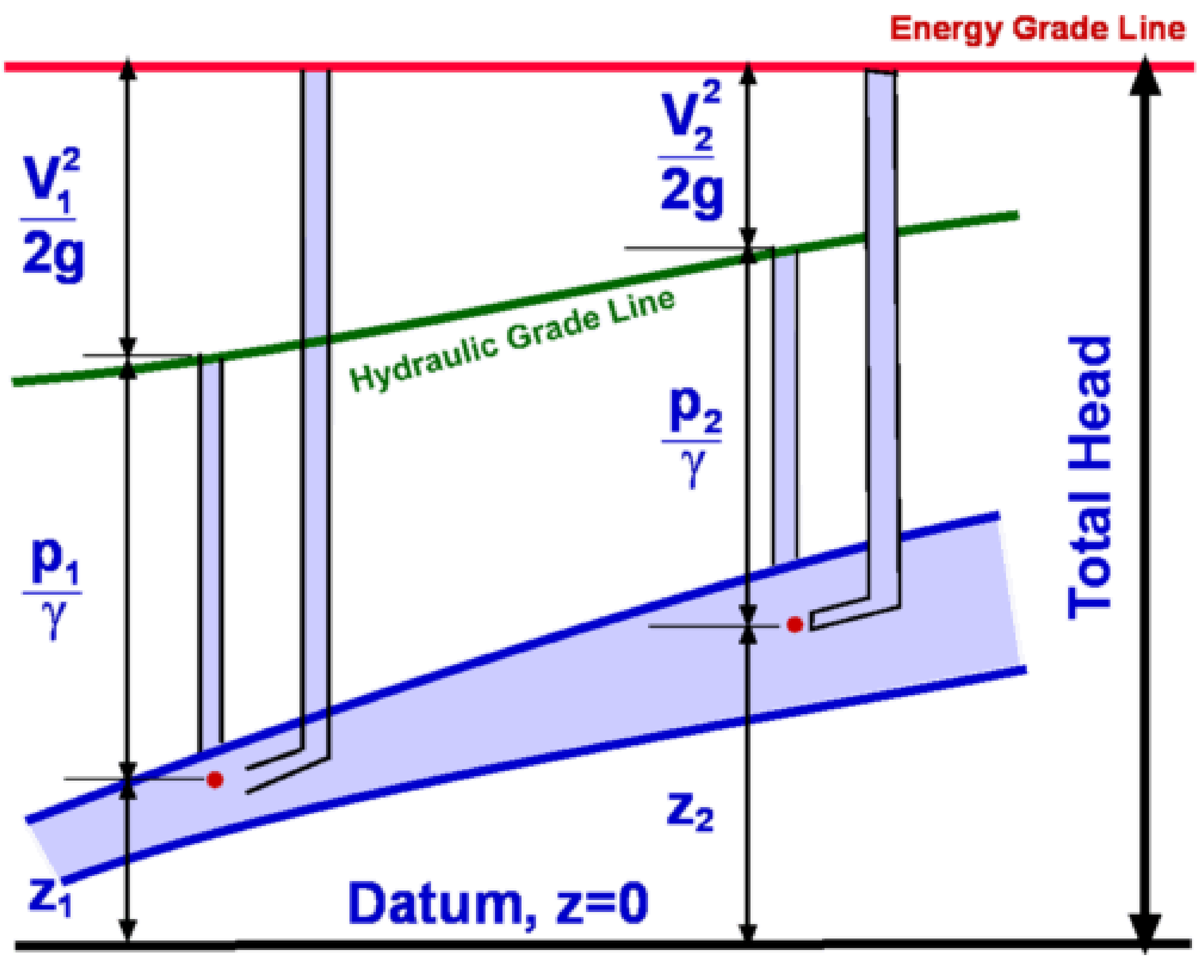
- In above equation each term has the dimensions of length. Thus p/γ, called the pressure head, represents the energy per unit weight stored in the fluid by virtue of the pressure under which the fluid exists.
- Z called the elevation head or potential head, represents the potential energy per pound of fluid;
- $V^2/2g$, called the velocity head, represents the kinetic energy per pound of fluid.
- We call the sum of these three terms the total head, usually denoted by H, so that

$$H=\frac{p}{\gamma}+z+\frac{V^2}{2g} \qquad (5.35)$$

Graphical representation of Pressure Head and Velocity Head

- If **pressure head** of liquid flowing in a pipe be plotted as vertical ordinates on the centre line of the pipe, then the line joining the tops of such ordinates is known as **Hydraulic Grade Line (HGL).**
- If the **sum of pressure heads** and **velocity heads** of a liquid flowing in a pipe be plotted as vertical ordinates on the center line of the pipe then the line joining the tops of such ordinates is known as **Energy Grade Line (EGL) or Total Energy Line (TEL).**
- In other words **EGL** lies over the **HGL** by an amount equal to the velocity heads as shown the figure.

Graphical representation of Pressure Head and Velocity Head



Loss of Head in Pipes

- When the water is flowing in a pipe, it experiences some resistance to its motion, whose effect is to reduce the velocity and ultimately the available head of water.
- Though there are many type of losses, yet the major loss is due to **frictional resistance** of the pipe only.
- The frictional resistance depends upon the **roughness** of the inside surface of pipe. It has been experimentally found that **more the roughness** of inside surface of pipe, **greater** will be the resistance.
- This friction is known as fluid friction and the resistance is known as frictional resistance.

Losses

- Fluids have losses due to friction in the pipe and minor losses associated with tees, elbow, valves etc.
- Bernoulli's Equation becomes,

$$\left(\frac{p_1}{\gamma}+z_1+\frac{V_1^2}{2g}\right)=\left(\frac{p_2}{\gamma}+z_2+\frac{V_2^2}{2g}\right)+h_f+h_m$$

Where,

h_f friction head loss.

h_m minor head loss.

1. Frictional Losses in Pipe Flow

- In fluid flow, the friction head loss can be calculated by considering the pressure losses along the pipelines.
- In a horizontal pipe of diameter (D) carrying a steady flow there will be a pressure drop in a length (L) of the pipe.
- Equating the frictional resistance to the difference in pressure forces, and manipulating resulted into the following expression:

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

- This equation is known as **Darcy-Weisbach (D-W)** equation, in which (*f*) is the friction factor. It should be noted that *f* is dimensionless, and the value is not constant.

- **Problem:** Compute the head loss due to pipe friction in a circular pipe of 40 *mm* diameter and 750 *m* laid horizontal when water flows at a rate: (a) 4 litres per minute; (b) 30 litres per minute. Take dynamic viscosity of water equal to 1.14 x 10-3 *N s m*-2. Assume that for the pipe absolute roughness, *k* is 0.00008 *m*.

Solution.

(a) Diameter of pipe, $D = 40\ mm = 40 \times 10^{-3}\ m$
Length of pipe, L = 750 m
Orientation of pipe: horizontal
Rate of flow, $Q = 4\ lpm = 4 \times 10^{-3}\ m^3 / 60\ s = 66.7 \times 10^{-6}\ m^3 s^{-1}$

Cross-sectional area of pipe, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4}(40x10^{-3})^2 = 1.26 \times 10^{-3}\ m^2$

Average velocity of flow in the pipe, $V = Q/A = \frac{66.7x10^{-6}}{1.26x10^{-3}} = 52.9 \times 10^{-3}\ m\ s^{-1}$

In order to determine the type of flow occurring in the pipe, let us determine the Reynolds number of flow.

$$Re = \frac{\rho VD}{\mu} = \frac{(1000)(52.9x10^{-3})(40x10^{-3})}{1.14x10^{-3}} = 1856$$

$$f = \frac{16}{\mathrm{Re}} = \frac{16}{1856} = 0.00862$$

Hence, $h_f = \frac{4x0.00862x750}{40x10^{-3}} x \frac{(52.9x10^{-3})^2}{(2x9.81)} = 92.4 \times 10^{-3}\ m$ of water.

For Q = 30 lit/min

Hence, $h_f = \frac{4fL}{D}\frac{V^2}{2g} = \frac{4x0.008x750}{40x10^{-3}} x \frac{(0.4)^2}{(2x9.81)} = 4.89\ m$ of water

2. Minor Losses

- In addition to head loss due to friction, there are always other head losses due to pipe expansions and contractions, bends, valves, and other pipe fittings. These losses are usually known as **minor losses (h_m)**.

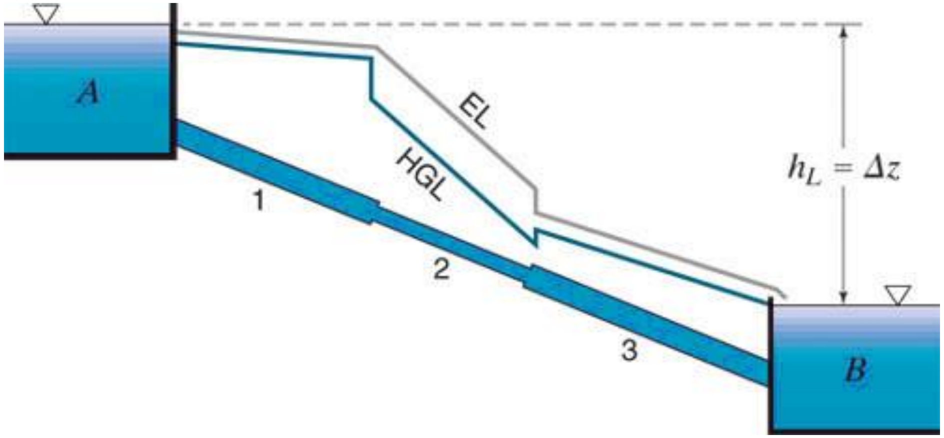
- In case of a long pipeline, the minor losses maybe negligible compared to the friction losses, however, in the case of short pipelines, their contribution may be significant. These are:

  - Losses due to pipe fittings
  - Sudden Enlargement
  - Sudden Contraction
  - Bends etc.

PIPE FLOW ANALYSIS

Pipes in Series

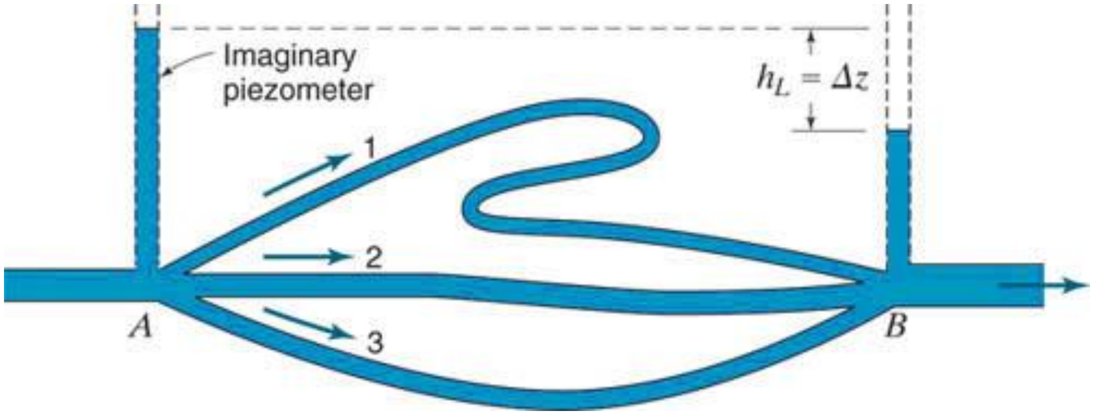
- When two or more pipes of different diameters or roughness are connected in such a way that the fluid follows a single flow path throughout the system, the system represents a series pipeline.
- In a series pipeline the total energy loss is the sum of the individual minor losses and all pipe friction losses.



- Discharge = Q = Q_1 = Q_2 = Q_3 = ---
- Head losses = $h_L = h_{L1} + h_{L2} + h_{L3} + ---$

Pipes in Parallel

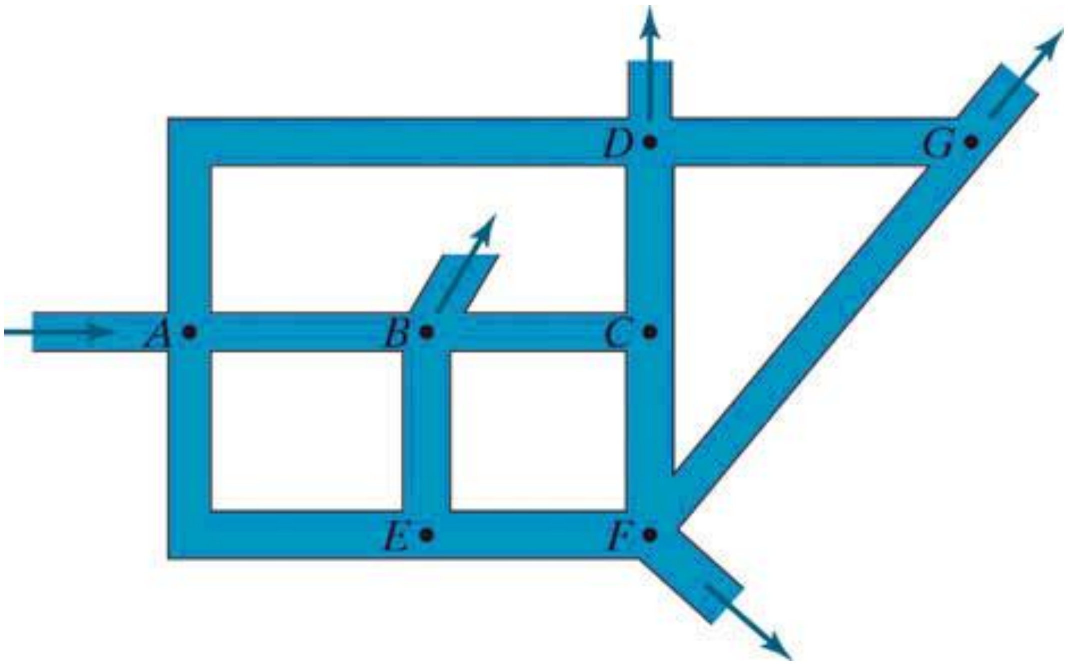
- A combination of two or more pipes connected between two points so that the discharge divides at the first junction and re-joins at the next is known as pipes in parallel.
- Here the head loss between the two junctions is the same for all pipes.



- Discharge = Q = $Q_1 + Q_2 + Q_3 +$ ---
- Head losses = $h_L = h_{L1} = h_{L2} = h_{L3}$ = ---

Pipe Networks

- In municipal distribution systems, pipes are frequently interconnected so that the flow to a given outlet may come by several different paths, as in Fig.



Pipe Networks

- As a result, we often cannot tell by inspection which way the flow travels, as in pipe *BE*. Nevertheless, the flow in any network, however complicated, must satisfy the basic relations of continuity and energy as follows:

1. The flow into any junction must equal the flow out of it.

2. The flow in each pipe must satisfy the pipe-friction laws for flow in a single pipe.

3. The algebraic sum of the head losses around any closed loop must be zero.