AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY (AUST)

ME-3105: FLUID MECHANICS

(LEC-10: Bernoulli's Equation and Frictional Head loss)

BY

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REAL AND IDEAL FLUID

IDEAL FLUID:

An ideal fluid has no viscous effect or no viscosity. Velocity distribution is uniform over the boundary. No frictional loss in the flow. Velocity at the boundary is not zero.

REAL FLUID:

- Real fluid has viscosity and due to viscous effect of the real fluid, the fluid particle has zero velocity at the boundary. There is frictional loss in the flow.
- Fluid particles away from the boundary attain higher velocity and the change of velocity across the flow resulting in velocity gradient and viscous shear resistance.

PIPE, DUCT AND TUBE

Duct, Pipe and Tube:

The terms pipe, duct, and conduit are usually used interchangeably for flow sections. *In general, flow sections of circular cross section are referred to as pipes (especially when the fluid is a liquid)*, and flow sections of noncircular cross section as ducts (especially when the fluid is a gas). Small diameter pipes are usually referred to as tubes.

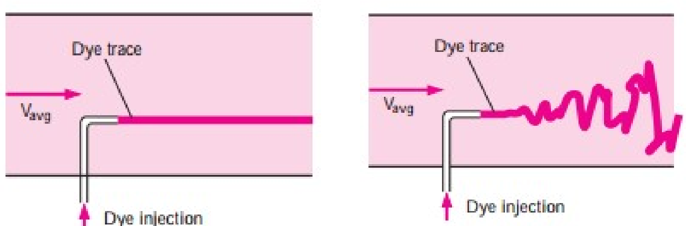
Use of Pipe and Duct:

Liquids are transported in circular pipes. This is because pipes with a circular cross section can withstand large pressure differences between the inside and the outside without undergoing significant distortion. *Noncircular pipes are usually used in applications such as the heating and cooling systems of buildings where the pressure difference is relatively small.*

Laminar, Transition and Turbulent Flow Visualization

Laminar Flow:

A careful inspection of flow in a pipe reveals that the fluid flow is streamlined at low velocities but turns chaotic as the velocity is increased above a critical value. The flow regime in the first case is said to be laminar, characterized by smooth streamlines and highly ordered motion.



(a) Laminar flow (b) Turbulent flow

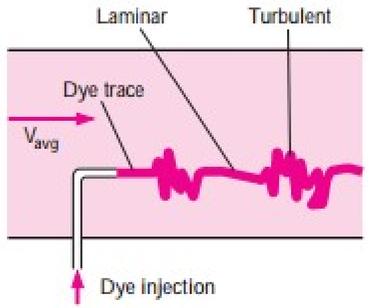
Turbulent Flow:

Turbulent in the second case, where it is characterized by velocity fluctuations and highly disordered motion.

Laminar, Transition and Turbulent Flow Visualization

Transition Flow:

The transition from laminar to turbulent flow does not occur suddenly; rather, it occurs over some region in which the flow fluctuates between laminar and turbulent flows before it becomes fully turbulent.



In the transitional flow region of $2300 \leq Re \leq 4000$, the flow switches between laminar and turbulent randomly.

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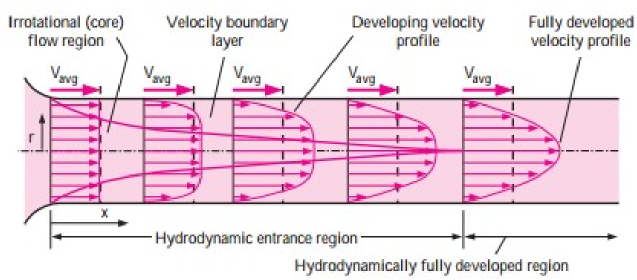
Development of Boundary Layer in Pipe Flow

Boundary Layer in Pipe Flow:

- Consider a fluid entering a circular pipe at a uniform velocity.
- Because of no-slip condition, the fluid particles in the layer in contact with the surface of the pipe come to a complete stop.
- This layer also causes the fluid particles in the adjacent layers to slow down gradually as a result of friction; and developed velocity gradient along the pipe.



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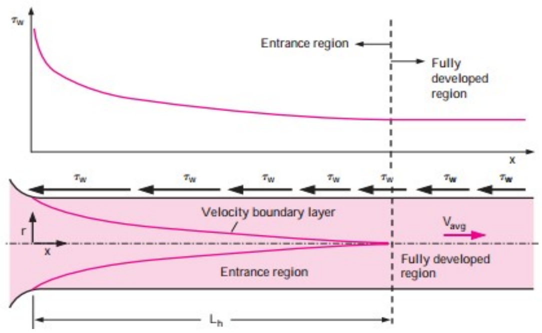
Development of Boundary Layer in Pipe Flow

Hydrodynamic Entry Length, L_h

The **length** of pipe/duct is required to achieve a maximum velocity of 99% of fully developed flow when the entering fluid velocity profile is uniform.



For laminar flow, $L_h = 0.05 R_e D$ and For turbulent flow, $L_h = 1.359 D R_e^{\frac{1}{4}} = 10D\,(\text{approx})$

Where D is the diameter of the pipe, and R_e is the Reynolds number.

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IMPULSE MOMENTUM EQUATION

The impulse-momentum equation is derived from the Impulse-Momentum principle, which states that the impulse applied to a body is equal to the resulting change of momentum of the body.

In other words, as per Newton's second law of motion, the resulting force acting on any body in any direction is equal to the rate of change of momentum of the body in that direction.

Impulse: Force working for a short period of time on a object or fluid body i.e.
' Force * Δt = Impulse ' and ' Impulse = Change of momentum (Δmv) '.

$$F = m \cdot a = m \cdot \left(\frac{\Delta V}{\Delta t}\right) = m \cdot \left(\frac{V_2 - V_1}{\Delta t}\right) = \frac{m \cdot V_2 - m \cdot V_1}{\Delta t}$$

$$\text{Rate of change of momentum} = \frac{m \cdot V_2 - m \cdot V_1}{\Delta t} = F$$

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IMPULSE MOMENTUM EQUATION

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$$\text{Rate of change of momentum} = \frac{m \cdot V_2 - m \cdot V_1}{\Delta t} = F$$

Impulse, $I = F \cdot \Delta t = m \cdot \Delta V$ where, m = mass

$$F = \left(\frac{m}{\Delta t}\right) \cdot \Delta V = m_{dot} \cdot (V_2 - V_1)$$

where m_{dot} = mass flow rate = $\rho * A * V = \rho * Q$

$$F = \rho \cdot Q \cdot (V_2 - V_1)$$

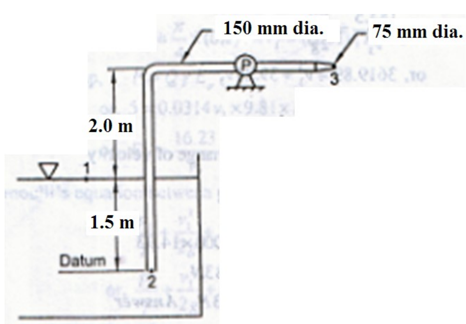
If momentum equation is applied to a control volume, then

$$F = \rho_2 \cdot Q_2 \cdot V_2 - \rho_1 \cdot Q_1 \cdot V_1$$

If force on fluid, F = 0, then $\rho_2 \cdot Q_2 \cdot V_2 = \rho_1 \cdot Q_1 \cdot V_1$

Impulse Momentum Equation~ PROBLEM

Problem-1: Water is flowing from a reservoir by a pump, which develops 8.0 kW on the flow. Find **thrust** on the pump's support structure.



$$F = \rho \cdot Q \cdot (V_2 - V_1)$$

$$P_{pump} = \rho \cdot g \cdot Q \cdot h_{pump}$$

$$Q = A * V$$

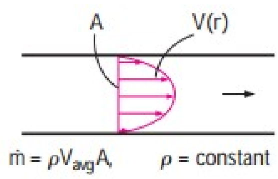
$$P_{pump} = 8.0 \cdot kw$$

Thrust means Force on the pump's support???

Correction in Bernoulli's Equation

Kinetic Energy Correction Factor:

- Kinetic energy of a fluid stream obtained from $V^2/2$ is not the same as the actual kinetic energy, since velocity 'V' is derived from the equation of average velocity (V = Q / A).
- In reality velocities of all fluid particles are not same across the cross-section of a pipe or conduit. This error can be corrected by multiplying the kinetic energy terms " $V^2/2$ " by a correction factor ' α ', which is known as kinetic energy correction factor.



$$\alpha = \frac{\dot{KE}_{act}}{\dot{KE}_{avg}}$$

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Correction in Bernoulli's Equation

Kinetic Energy Correction Factor (Cont'd):

- α = 2.0 for laminar flow and α = 1.05 for turbulent flow.
- *Kinetic energy correction factors are often ignored (i.e. α = 1) in an elementary analysis since practically most of the flows are turbulent.*

Corrected Bernoulli's or Energy equation,

$$\frac{P_1}{\gamma} + \alpha_1 \cdot \left(\frac{V_1^2}{2 \cdot g}\right) + Z_1 = \frac{P_2}{\gamma} + \alpha_2 \cdot \left(\frac{V_2^2}{2g}\right) + Z_2 + h_{lf}$$

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Total Energy Loss in Pipe Flow

- When a fluid flows through pipe, fluid experience some resistances or losses of energy due to the friction, change in direction and also for fittings in the pipe.
- The energy losses in the pipe flow are classified as **major loss** and **minor losses.**

Major Losses:

It is caused by the friction in the pipe known as frictional head loss, h_{lf} . It is calculated by Darcy-Weisbach equation,

$$h_{lf} = \frac{f \cdot L \cdot V_{avg}{}^2}{2g \cdot D} = \left(\frac{f \cdot L}{D}\right) \cdot \frac{V_{avg}{}^2}{2g}$$

Minor Losses:

The fluid passes through various pipe fittings, valves, bends, elbows, tees, inlets, exits, enlargements, and contractions in the piping system. As a result, fluid experience resistances or loss of energy in the pipe flow other than major loss. Minor loss of energy due to pipe fittings,

$$h_L = K_L \cdot \left(\frac{v^2}{2 \cdot g}\right)$$

K_L is called minor loss coefficient

Total Energy Loss in Pipe Flow

Total head loss in the pipe flow,

$$h_{L\_tota} = h_{L\_major} + h_{L\_minor} = \sum_i h_{L\_major} + \sum_i h_{L\_minor}$$

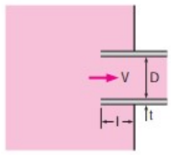
Total head loss (general): $h_{L,\,total} = h_{L,\,major} + h_{L,\,minor} = \sum_i f_i \frac{L_i}{D_i}\frac{V_i^2}{2g} + \sum_j K_{L,j}\frac{V_j^2}{2g}$

How Find Value of K_L for Minor Loss

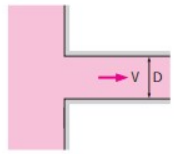
Loss coefficients K_L of various pipe components for turbulent flow (for use in the relation $h_L = K_L V^2/(2g)$, where V is the average velocity in the pipe that contains the component)*

Pipe Inlet

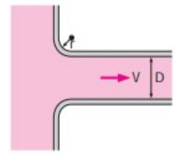
Reentrant: $K_L = 0.80$
($t \ll D$ and $l \approx 0.1D$)



Sharp-edged: $K_L = 0.50$

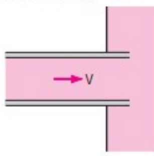


Well-rounded ($r/D > 0.2$): $K_L = 0.03$
Slightly rounded ($r/D = 0.1$): $K_L = 0.12$
(see Fig. 8–36)

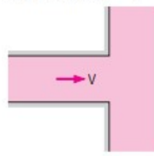


Pipe Exit

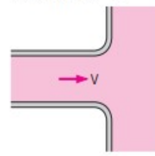
Reentrant: $K_L = \alpha$



Sharp-edged: $K_L = \alpha$



Rounded: $K_L = \alpha$



Note: The kinetic energy correction factor is $\alpha = 2$ for fully developed laminar flow, and $\alpha \approx 1$ for fully developed turbulent flow.

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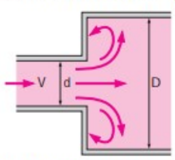
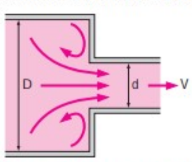
How Find Value of K_L for Minor Loss

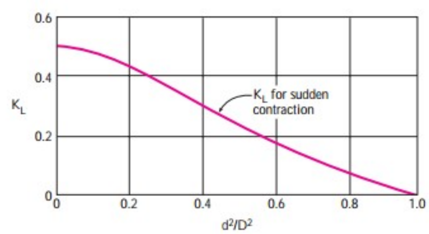
Sudden Expansion and Contraction (based on the velocity in the smaller-diameter pipe)

Sudden expansion: $K_L = \left(1 - \frac{d^2}{D^2}\right)^2$



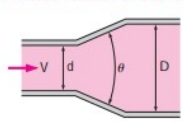
Sudden contraction: See chart.



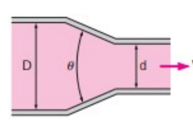


Gradual Expansion and Contraction (based on the velocity in the smaller-diameter pipe)

Expansion:
$K_L = 0.02$ for $\theta = 20°$
$K_L = 0.04$ for $\theta = 45°$
$K_L = 0.07$ for $\theta = 60°$



Contraction (for $\theta = 20°$):
$K_L = 0.30$ for $d/D = 0.2$
$K_L = 0.25$ for $d/D = 0.4$
$K_L = 0.15$ for $d/D = 0.6$
$K_L = 0.10$ for $d/D = 0.8$



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How to Find the Value of Friction Factor ' f ' for Major Loss

Darcy-Weisbach , $h_{lf} = \dfrac{f \cdot L \cdot V_{avg}^2}{2 \cdot g \cdot D}$

For Laminar flow, $f = \dfrac{64}{R_e}$ for laminar flow (not valid for turbulen flow)

For turbulent flow, value of friction factor ' f ' need to find from the following equation or Moody diagram.

$$\frac{1}{\sqrt{f}} = -2 \cdot \log_{10} \left(\frac{\frac{\varepsilon}{D}}{3.7} + \frac{2.51}{R_e \cdot \sqrt{f}} \right)$$

Where ε = Roughness factor, D = Diameter of pipe, R_e = Reynolds number

what is Reynolds number ' $\mathbf{R_e}$ ' (see next slide).

What is MOODY DIAGRAM ???

Reynolds's Number, R_e

- Reynolds Number: The ratio of inertial force to viscous force in the fluid flow is called the Reynolds number, and it is expressed for internal flow in a circular pipe as ' $\mathbf{R_e}$ '

$$R_e = \frac{\text{Inertia force}}{\text{Viscous force}} = \frac{m \cdot a}{\tau \cdot A} = \frac{\rho \cdot L^3 \cdot \frac{V}{t}}{\mu \cdot \frac{V}{L} \cdot L^2} = \frac{\rho \cdot L^2 \cdot V^2}{\mu \cdot V \cdot L} = \frac{\rho \cdot V \cdot L}{\mu} \qquad \tau = \mu \cdot \frac{dv}{dy}$$

For pipe flow, $R_e = \dfrac{\rho \cdot V \cdot D_h}{\mu}$ (general form for internal flow)

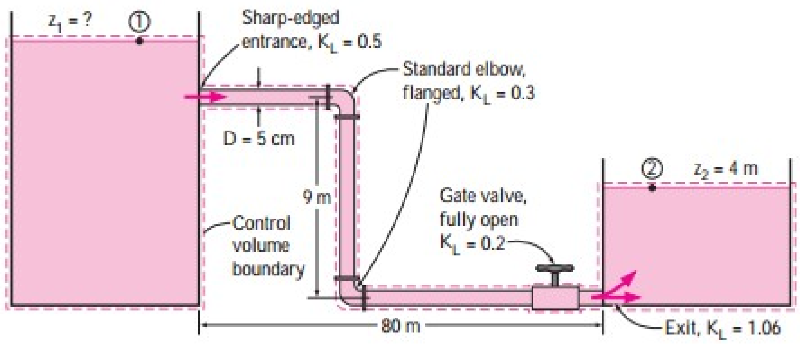
where D_h is known as hydraulic diameter and

$$D_h = \frac{4 \times \text{Cross Sectional Area}}{\text{Wetted Perimeter}} = \frac{4 \times A}{P}$$

$Re \lesssim 2300$	laminar flow
$2300 \lesssim Re \lesssim 4000$	transitional flow
$Re \gtrsim 4000$	turbulent flow

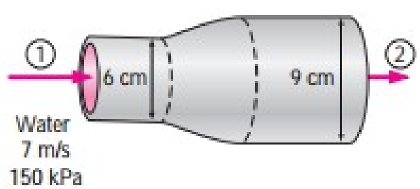
Problem-2

Water at 10°C flows from a large reservoir to a smaller one through a 5.0 cm diameter cast iron piping system, as shown in Figure. Determine the elevation z_1 for a flow rate of 6.0 L/s . Given surface roughness of cast iron ε = 0.26 mm and viscosity of water at 10°C, $\mu = 1.307 \times 10^{-3}$ N.S/m^2.



Problem-3

A 6-cm-diameter horizontal **water** pipe expands gradually to a 9-cm-diameter pipe (Fig. below). The walls of the expansion section are angled 30° from the horizontal. The average velocity and pressure of water before the expansion section are 7.0 m/s and 150 kPa respectively. Determine the head loss in the expansion section and the pressure in the larger-diameter pipe. Assume, $\mu = 1.02 \times 10^{-3}$ N-S/m^2 for water.



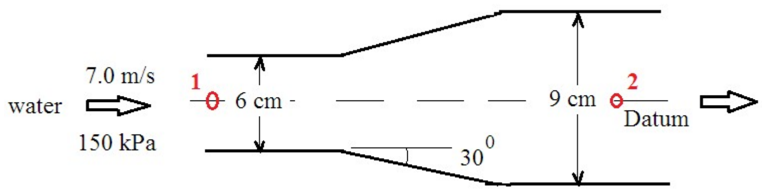
$Z_1 = Z_2$, V_1 = 7.0 m/s, P_1 = 150 * 1000 N/m^2; D_1 = 0.06 m; D_2 = 0.09 m

P = 1000 kg/m^3 ; $\mu = 1.307 * 10^{-3}$ N.s/m^2 ; h_L = ???? P_2 = ???

Bernoulli's equation; and also Continuity Equation: Q = A* V
Reynolds' number ? Flow turbulent or Laminar

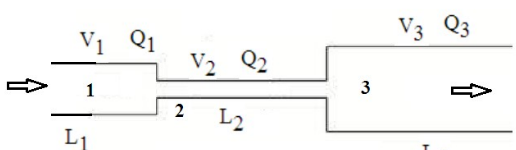
Problem-3

A 6-cm-diameter horizontal **water** pipe expands gradually to a 9-cm-diameter pipe (Fig. below). The walls of the expansion section are angled 30° from the horizontal. The average velocity and pressure of water before the expansion section are 7.0 m/s and 150 kPa respectively. Determine the head loss in the expansion section and the pressure in the larger-diameter pipe. Assume, $\mu = 1.307 \times 10^{-3}$ N-S/m^2 for water.



Pipes in Series and Parallel

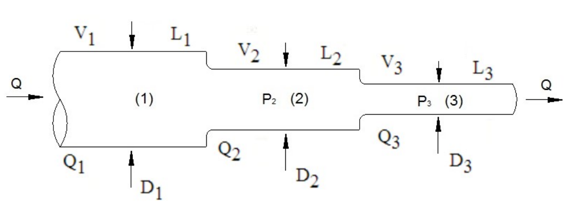
Pipe in Series



Pipes in Series

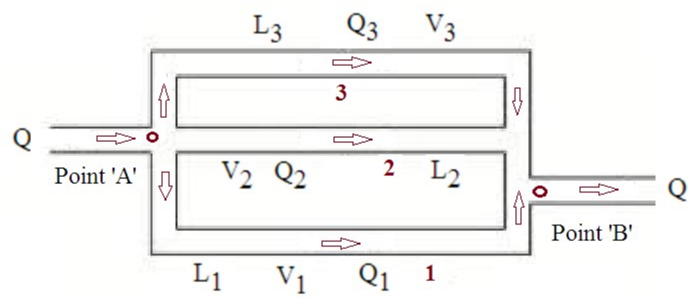
$$Q = Q_3 = Q_2 = Q_1$$

$$h_{Lf} = h_{Lf1} + h_{Lf2} + h_{Lf3}$$



Pipes in Series and Parallel

Pipe in Parallel



Pipes in parallel

$$Q = Q_1 + Q_2 + Q_3 = Q$$

$$h_{Lf\_AB} = h_{Lf1} = h_{Lf2} = h_{Lf3}$$

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Water Hammer, Effect and Solution

- **Water hammer** (also known as **fluid hammer**) is a pressure surge or wave caused when a fluid *(usually a liquid but sometimes also a gas)* in motion is forced to stop or change direction *(change momentum)* suddenly.
- A water hammer commonly occurs when a valve closes suddenly at an end of a pipeline or fluid system, and a pressure wave propagates in the pipe. It is also called hydraulic shock. This pressure wave can cause major problems, from noise and vibration to pipe collapse.
- It is possible to reduce the effects of the water hammer by incorporating the accumulators, expansion tanks, surge tanks, and other features in the pipe line or fluid systems.

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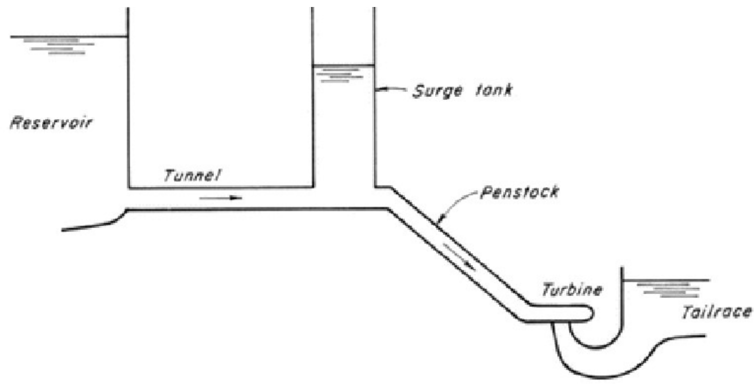
Water Hammer, Effect and Solution



Example of using Surge Tank in Fluid System.

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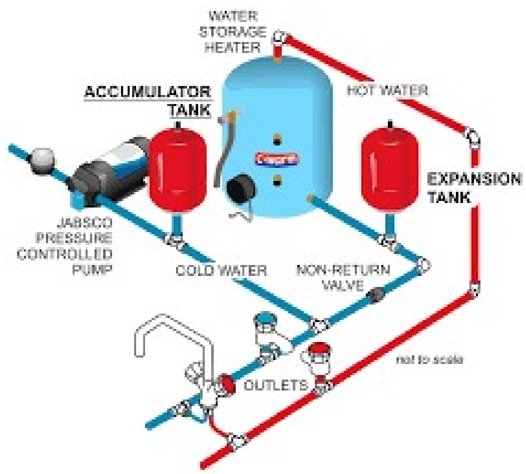
Water Hammer, Effect and Solution



Example of using Expansion Tank and Accumulator Tank.

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Different Type of Pipe Fittings

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Different Type of Pipe Fittings

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What is Valve?

- Valve is a device that regulates, controls or directs the flow of a fluid by opening, closing, or partially obstructing fluid flow.
- It is a mechanical device that controls the flow and pressure of fluid within a fluid system or Process.
- Types of valves are used in the fluid system depends on the requirements.
- Cost of the valve in the piping system is about 20% to 30% of the overall cost of the piping.

Types of Valve

- Gate Valve
- Globe Valve
- Check Valve
- Plug valve
- Ball Valve
- Butterfly Valve
- Needle Valve
- Pinch Valve
- Pressure Relief Valve

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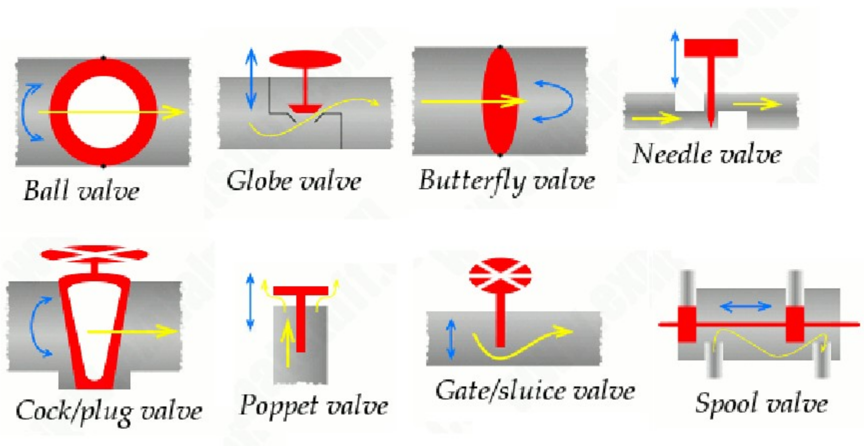
Different Types of Valve



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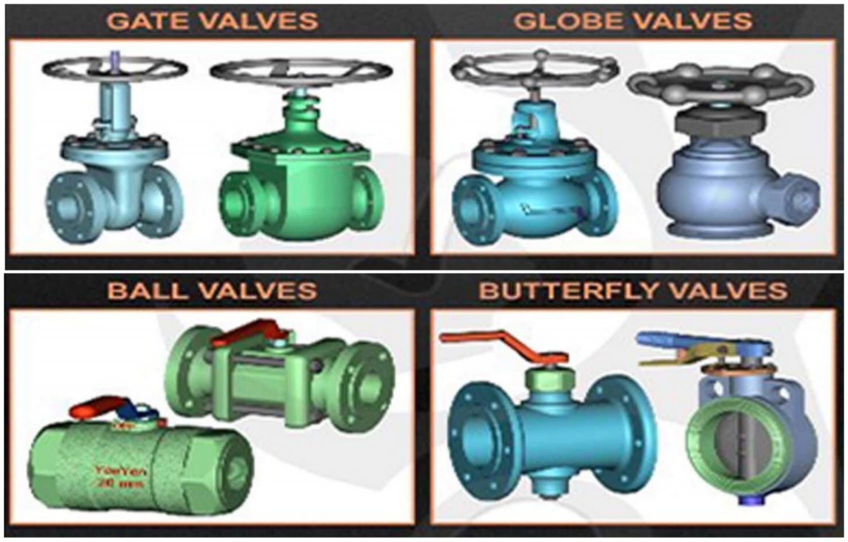
Different Types of Valve



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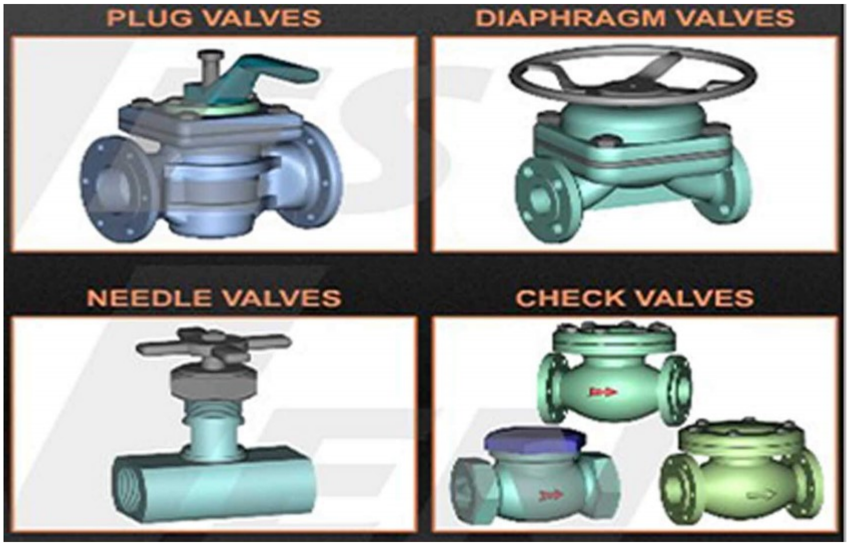
Different Types of Valve



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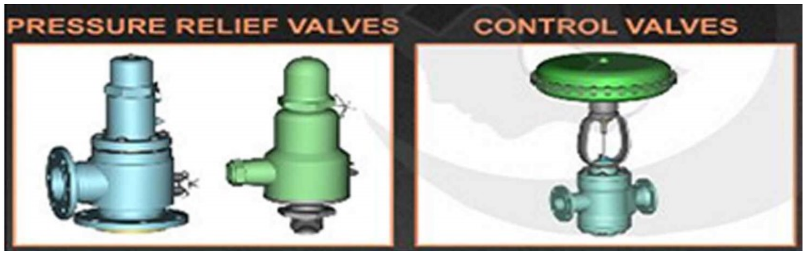
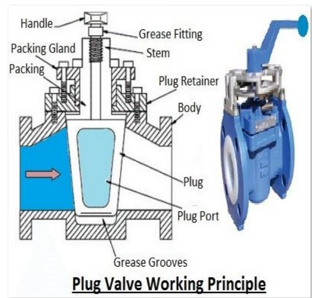
Different Types of Valve





Study List of this Lecture !!!

1) Define ideal and real fluid. What are differences between ideal and real fluid? Discuss briefly.
2) Define pipe, tube and duct. Discuss briefly their application.
3) How do you indentify a fluid flow is laminar or turbulent. Explain briefly.
4) What is the hydrodynamic entry length (L_h) ? How do you find the hydrodynamic entry length of a pipe for a laminar and turbulent flow?
5) Define impulse momentum equation? Derive impulse momentum equation for fluid system. What is the application of impulse momentum equation.
6) What is the major and minor loss in the fluid system? How do you find it for a fluid system. Explain briefly.
7) Why do we need to add kinetic energy correction factor in the Bernoulli's equation? How do you determine the kinetic energy correction factor of a fluid flow.
8) Write the equations of major and minor head loss in the pipe flow. Explain each term of the equation.

Study List of this Lecture !!!

9) Define Reynolds number and hydraulic diameter. What is the application of Reynolds number. Explain briefly.
10) Define laminar, transition and turbulent flow with respect to Reynolds number. What is critical Reynolds number.
11) How do you indentify flow is laminar or turbulent. Explain briefly.
12) What is hydrodynamic entry length (L_h) ? How do you find the hydrodynamic entry length of a pipe for a laminar and turbulent flow?
13) Define impulse momentum equation? Derive impulse momentum equation for fluid system. What is the application of impulse momentum equation.
14) What is Moody diagram? What is the application of it? What are the variables of the moody diagram.
15) Explain the pipes in series and parallel with neat sketches.
16) Define the term 'valve' of fluid system. Write the name of different types of valve are used in the fluid system. What is the average cost of the valves in a pipe line or fluid system.

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Study List of this Lecture !!!

17) Define the term 'Water hammer'. Describe briefly the causes, effect, and remedy of water hammer.
18) State the five name of pipe fittings with neat sketches.

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