MODULE 3: FLUID FLOWS

Boundary Layer:

The boundary layer is a thin region near the surface of a solid body where the fluid flow is significantly influenced by the presence of the boundary (solid surface). In this region, the velocity of the fluid changes from zero at the surface (due to the no-slip condition) to the free stream velocity away from the surface.

Thicknesses of Boundary Layer:

1. Laminar Boundary Layer Thickness (δ): It is the distance from the solid surface to the point where the flow velocity reaches approximately 99% of the free stream velocity. The laminar boundary layer thickness increases with the distance along the plate in the direction of flow.
2. Transition Point ($x_{transition}$): This is the point along the plate where the flow transitions from laminar to turbulent boundary layer. The transition point can vary based on the flow conditions and surface roughness.
3. Turbulent Boundary Layer Thickness (δ_t): It is the distance from the solid surface to the point where the flow velocity reaches approximately 99% of the free stream velocity in a turbulent boundary layer. The turbulent boundary layer thickness is typically larger than the laminar boundary layer thickness.

Characteristics along a Thin Plate:

4. Laminar Boundary Layer: Close to the leading edge of the plate, the boundary layer is usually laminar, characterized by smooth, orderly flow with low levels of turbulence. The boundary layer thickness increases gradually along the plate, and the velocity profile remains relatively unchanged.
5. Transition Zone: As the flow progresses along the plate, the laminar boundary layer may undergo transition to a turbulent boundary layer. This transition zone is characterized by fluctuations in flow properties and the onset of turbulent eddies.
6. Turbulent Boundary Layer: In the turbulent boundary layer, the flow is characterized by chaotic, high-velocity fluctuations and increased mixing. The boundary layer thickness is larger compared to the laminar boundary layer, and the velocity profile is flatter with a steeper gradient near the surface.
7. Separation: At some point along the plate, the boundary layer may separate from the surface due to adverse pressure gradients or flow separation. This results in recirculation zones and flow reversal, leading to increased drag and pressure losses.

Laminar Boundary Layer:

- Occurs at the beginning of the flow over a surface.
- Fluid particles move in smooth, parallel layers.
- The velocity of the fluid increases smoothly from zero at the surface to a maximum at the edge of the boundary layer.
- The flow is predictable and stable.

- Low levels of turbulence.

Turbulent Boundary Layer:

- Develops downstream of the laminar boundary layer.
- Fluid particles move in an irregular, chaotic manner, with eddies and swirls.
- Velocity fluctuations are significant.
- Higher levels of energy loss compared to laminar flow.
- Higher drag force due to increased friction.

Boundary Layer in Transition:

- Transition occurs when the laminar boundary layer becomes unstable and starts to break down into turbulence.
- The flow characteristics are mixed, with some regions exhibiting laminar-like behavior and others showing turbulent characteristics.
- Transition is influenced by factors such as Reynolds number, surface roughness, and disturbances in the flow.
- It is an area of active research to understand the mechanisms and control transition for various applications.

Boundary Layer Separation:

Boundary layer separation occurs when the flow separates from the surface of an object, creating a recirculation region or eddy behind the object. This separation is caused by adverse pressure gradients, flow separation points, or sudden changes in surface curvature that disrupt the smooth flow of the boundary layer.

Submerged Objects - Drag and Lift:

1. **Drag:** Drag on a submerged object is caused by the frictional resistance of the fluid as it flows past the object's surface. There are two main types of drag:
    - **Skin Friction Drag:** This is the drag caused by the shear stress between the fluid and the surface of the object. It is directly related to the roughness of the surface and the viscosity of the fluid.
    - **Form Drag:** Form drag is caused by the pressure difference between the front and rear of the object. It is influenced by the shape of the object and can be reduced by streamlining the object's shape.
2. **Lift:** Lift is the upward force generated on an object when there is a pressure difference between the upper and lower surfaces. Lift is typically associated with aerodynamic or hydrodynamic lift, such as that generated by airfoils or hydrofoils. Lift is influenced by the shape of the object, the angle of attack, and the speed of the fluid flow.

In the case of a submerged object, the presence of a boundary layer is crucial. The boundary layer affects both drag and lift:

- A thicker boundary layer can lead to earlier boundary layer separation, increasing drag.

- The shape of the object and the flow conditions can also affect the boundary layer and the likelihood of separation.
- Lift on a submerged object can be affected by the boundary layer's behavior, particularly near the leading edge where the flow is critical for generating lift.

Understanding the boundary layer behavior is essential for designing submerged objects to minimize drag and optimize lift for various applications, such as ship and submarine design, underwater vehicles, and offshore structures.

FLUID FlOW-INTRODUCTION

Flow through pipes is an important topic in fluid mechanics. It is important to understand the different types of losses that occur during the flow through pipes.

In flow through pipes, losses that occur in the pipe flow are a very important parameter for the design. These losses include the major loss due to friction and some minor losses. Darcy Weisbach’s equations can calculate major losses in flow through pipes.

Minor Losses

	Type of Minor Losses In Pipe	Formula
1	Loss of Head At Entrance	$h_e = k_e \frac{v^2}{2g}$
2	Loss of Head At submerged Discharge (i) Discharge Into Still Water	$h_d = k_d \frac{v^2}{2g}$ $h_d = \frac{v^2}{2g}$ $when\ k_d = 1.0$
3	(ii) Discharge Into Moving Water	$h_d = \frac{v^2}{2g} - \frac{v_c^2}{2g}$
4	Loss Due to Contraction	$h_c = k_c \frac{v^2}{2g}$
5	Loss Due to Expansion	$h_x = \frac{(v_1 - v_2)^2}{2g}$ $h_x = k' \frac{(v_1 - v_2)^2}{2g}$
6	Loss In Pipe Fitting	$h_p = k \frac{v^2}{2g}$
7	Loss In Elbows and Bends	$h_b = k_b \frac{v^2}{2g}$

Major Losses

Loss of head due to friction

hf = 4fLv2/2gd

where,

- L = Length of pipe,
- v = Mean velocity of flow
- d = Diameter of pipe,

- f = Coefficient of friction

or $h_f = f'Lv^2/2gd$

$f' = 4f$

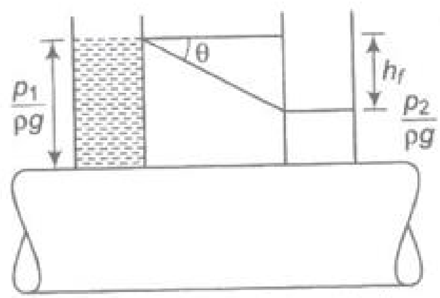
friction factor for laminar flow, $f = 64/ Re$

Coefficient of friction, $f = 16/ Re$

For turbulent flow, the coefficient of friction

$f = 0.079/(Re)^{0.25}$

Chezy's Formula: In fluid dynamics, Chezy's formula describes the mean flow velocity of steady, turbulent open channel flow.



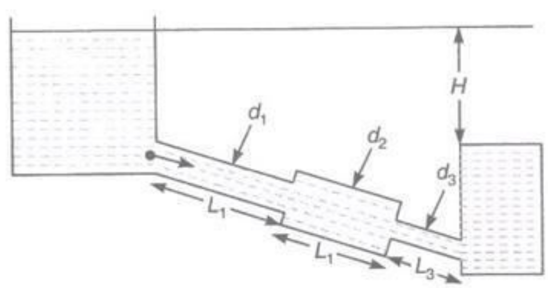
Chezy's formula of steady flow

$v = c\sqrt{mi}$, c= Chezy's Constant = $\sqrt{(8g/f)}$

PIPES IN SERIES

Pipes may be connected in series, parallel or in both. Let's see their combinations.

Pipe in Series: As pipes are in series, the discharge through each pipe will be the same.



Pipe in series

Q = A1v1 = A2v2 = A3v3

Total loss of head = Major loss + Minor loss

H = hL1 + hL2

Major loss = Head loss

due to friction in each pipe

hL1 = hf1 + hf2 + hf3

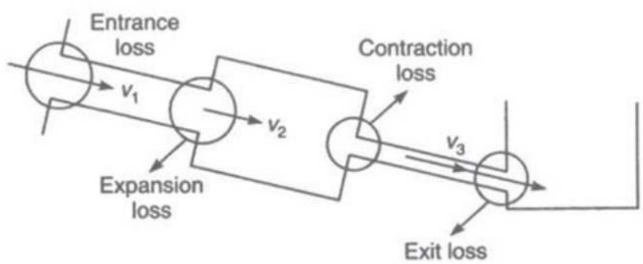
While, minor loss = Entrance loss + Expansion loss + Contraction loss + Exit loss

$$h_{L_2} = \frac{0.5v_1^2}{2g} + \frac{(v_2 + v_1)^2}{2g} + \frac{0.5v_3^2}{2g} + \frac{v_3^2}{2g}$$

If minor losses are neglected, then,

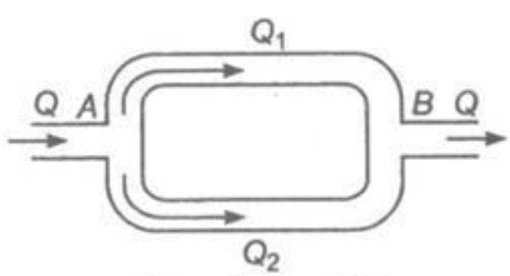
$$H = \frac{f_1 L_1 v_1^2}{d_1 . 2g} + \frac{f_2 L_2 v_2^2}{d_2 . 2g} + \frac{f_3 L_3 v_3^2}{d_3 . 2g}$$

$$H = \frac{f_1 L_1 Q^2}{12 \cdot 1 d_1^5} + \frac{f_2 L_2 Q^2}{12 \cdot 1 d_2^5} + \frac{f_3 L_3 Q^2}{12 \cdot 1 d_3^5}$$



Head loss when minor loss are neglected

Pipes in Parallel: In this, discharge in the main pipe is equal to the sum of discharge in each parallel pipe.



Pipes in parallel

Hence, Q = Q1 + Q2

The head loss in each parallel pipe is the same,

hf1 = hf2

where hf1 and hf2 are head loss at 1 and 2, respectively.

Equivalent Pipe: A compound pipe with several pipes of different lengths and diameters to be replaced by a pipe with a uniform diameter and the same length as a compound pipe is called an equivalent pipe.

$$h_{Le} = h_{f_1} + h_{f_2} + h_{f3}$$

$$\frac{fLQ^2}{12.1d^5} = \frac{f_1L_1Q^2}{12.1d_1^5} + \frac{f_2L_2Q^2}{12.1d_2^5} + \frac{f_3L_3Q^2}{12.1d_3^5}$$

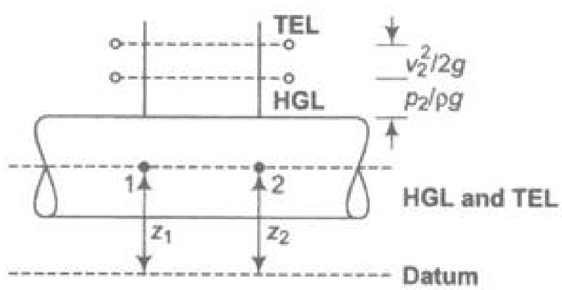
(where, L = L1 + L2 + L3)

If f = f1 = f2 = f3

Then,

$$\frac{L}{d^5} = \frac{L_1}{d_1^5} + \frac{L_2}{d_2^5} + \frac{L_3}{d_3^5} \Rightarrow \frac{L}{d^5} = \frac{L_1}{d_1^5} + \frac{L_2}{d_2^5} + \frac{L_3}{d_3^5}$$

Hydraulic Gradient Line (HGL) and Total Energy Line (TEL)



Equivalent pipe diagram

HGL → It joins the piezometric head ((p/ρg) + z) at various points.

TEL → It joins the total energy head at various points:

{((p/ρg) + z) + (v2/2g)}

Dimensionless numbers.

Dimensionless numbers are the numbers obtained by dividing inertia force or gravity force or pressure force or elastic force or surface tension. They are called as non-dimensional parameters.

The types of dimensionless numbers are:

1. Reynold’s number
2. Froude’s number
3. Euler’s number
4. Weber’s number
5. Mach’s number