Module-2

FLUID KINEMATICS

2.1 Introduction.

Fluid Kinematics deals with the motion of Fluid without considering the cause of motion.

2.1.1 Lagrangian approach Lagrangian approach is for single Fluid particles. (Closed system analysis) In Lagrangian approach fluid motion is defined by analyzing the kinematic behavior of each individual fluid particle consisting of the flow.

2.1.2 Eulerian approach Eulerian approach for section (or) point. In Eulerian approach fluid motion is defined by analyzing the kinematic behavior of various fluid particles passing through the various fixed points in a control volume.

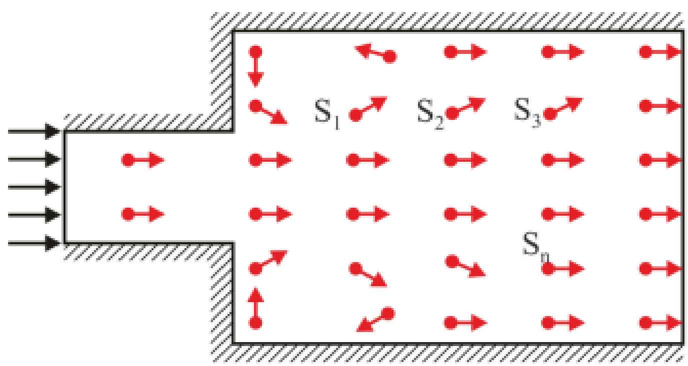


Fig.5.2 Eulerian Approach
(Study of particular section with time)

2.2 Various Types of Fluid Flow.

(I) Steady and Unsteady flow

(ii) Uniform and non-uniform flow

(iii) Compressible and Incompressible flow

(iv) Laminar and Turbulent flow

(v) Rotational and Irrotational flow

(vi) 1-D, 2-D & 3-D flow.

2.2.1 Steady and Unsteady Flow

A flow is said to be steady flow if fluid properties & flow velocity does not change with time at given location. The flow which is not steady flow is called unsteady flow. Steady Flow in Eulerian Approach For a steady flow, acceleration in each direction is equal to the convective acceleration in that direction, as local acceleration is zero.

2.2.2 Uniform and Non-Uniform Flow

A flow is said to be a uniform flow if fluid properties & flow velocity does not change with space at any given instant of time The flow which is not uniform flow is called non-uniform flow**.**

Uniform Flow in Eulerian Approach For a uniform flow, acceleration in a given direction is equal to the local acceleration in that particular direction as convective acceleration is zero.

Type of fluid flow	Convective Acceleration	Temporal Acceleration	Total Acceleration
Unsteady & Non-uniform	Exists	Exists	Exists
Unsteady & Uniform	Zero	Exists	Exists
Steady & Non-Uniform	Exists	Zero	Exists
Steady & Uniform	Zero	Zero	Zero

2.2.3 Compressible and Incompressible Flow

A flow is said to be incompressible flow if mathematically total derivative/material derivative of density is zero during the flow.

The flow which is not incompressible flow is compressible flow of compressible fluid can be incompressible flow, if Mach number must be less than equal to 0.3

2.2.4 Laminar & Turbulent Flow

1. Laminar flow is defined as the type of flow in which fluid particle move along well defined path or streamline.

2. Turbulent Flow It is defined as the type of flow in which fluid particles move in a Zig-zag way or random order.

2.2.5 Rotational and Irrotational Flow

A flow is said to be rotational if the fluid particles rotate about its own Centre of mass during the motion otherwise flow is irrotational.

A flow will be Irrotational under the following two conditions:

(i) Ideal fluid flow (inviscid fluid flow)
(ii) (ii) Real fluid flow having negligible velocity gradient.

2.2.6 1-D, 2-D & 3-D Flow

A flow is classified as 1-D, 2-D or 3-D flow depending on the number of space coordinates required to specify the velocity field.

2.3 Various Flow Lines

- Streamline
- Path line
- Streamline
- Timeline

2.3.1 Streamline.

Streamline is an imaginary line or curve in space such that tangent drawn to it at any point gives the direction of instantaneous velocity of fluid particle present at that point

Note:

• Component of velocity in normal direction to the streamline is zero, hence there is no flow across the streamline.

• Streamline is drawn for an instant of time.

• Streamlines are based on Eulerian approach.

• Two streamlines cannot intersect each other.

• A given streamline cannot intersect itself.

• Streamlines are defined everywhere except at stagnation point.

• A bundle of neighboring streamlines may be imagined forming a passage through which the fluid flows. This passage is known as stream tube.

2.3.2 Path Line

• Path line is the path traced by single fluid particle at different instants of time.

• Path line is based on Lagrangian approach.

• A path line can intersect itself.

Stream line	Path line
Direction of Instantaneous velocity	Position / Location
Number of fluid particles	Single fluid Particle
Particular instant of time	Over a period of time
Eulerian approach	Lagrangian approach
Can't intersect itself	Can intersect itself

2.3.3 streak line

• streak line is the locus of different fluid particles which pass through a given point.

• streak line is drawn for a particular instant of time.

2.3.4 Timeline

• A timeline is a set of adjacent fluid particles in a flow field that were marked at a given instant of time.

2.4 Continuity Equation

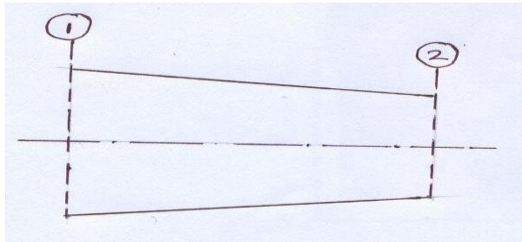
Rate of flow or discharge (Q) is the volume of fluid flowing per second. For incompressible fluids flowing across a section.

Volume flow rate, $Q = A \times V$ m^3/s where A=cross sectional area and V= average velocity.

For compressible fluids, the rate of flow is expressed as a mass of fluid flowing across a section per second.

Mass flow rate (m) = (ρAV) kg/s where ρ = density.

Continuity equation is based on Law of Conservation of Mass. For a fluid flowing through a pipe, in a steady flow, the quantity of fluid flowing per second at all cross-sections is a constant.



Let v_1=average velocity at section [1], ρ_1=density of fluid at [1], A_1=area of flow at [1]; Let v_2, ρ_2, A_2 be corresponding values at section [2]. Rate of flow at section [1]= $\rho_1 A_1 v_1$ Rate of flow at section [2] = $\rho_2 A_2 v_2$

$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$

This equation is applicable to steady compressible or incompressible fluid flows and is called Continuity Equation. If the fluid is incompressible, $\rho_1 = \rho_2$ and the continuity equation reduces to $A_1 v_1 = A_2 v_2$

For steady, one-dimensional flow with one inlet and one outlet,

$$\rho_1 A_1 v_1 - \rho_2 A_2 v_2 = 0$$

Outcome; - Apply the knowledge of fluid kinematics

Apply the principle of kinematics

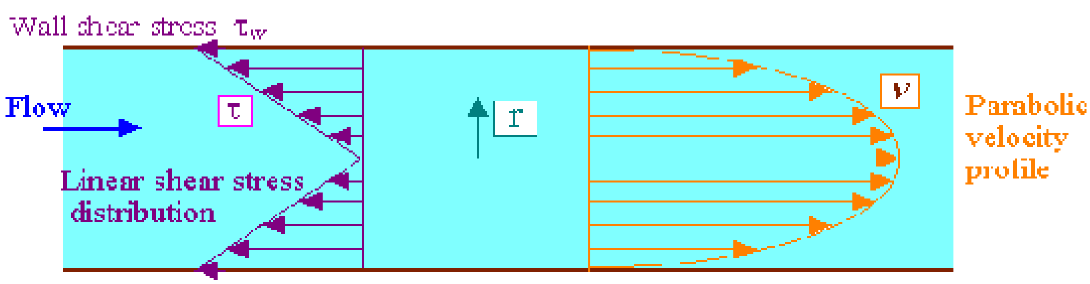
2.5 Laminar and turbulent flow

Laminar and turbulent flow are two fundamental types of fluid motion that exhibit distinct characteristics and behaviors. Laminar flow refers to a smooth and ordered flow pattern where fluid particles move in parallel layers without significant mixing or disruption. It is characterized by well-defined velocity profiles and predictable motion. In contrast, turbulent flow is characterized by chaotic and irregular fluid motion with high levels of mixing and fluctuation.

What is the Definition of Laminar Flow?

- Laminar flow refers to a smooth, orderly flow pattern of a fluid without significant mixing or turbulence.
- It occurs when the fluid moves in parallel layers or streamlines, with minimal disruption between adjacent layers.
- The velocity of the fluid remains constant along any given streamline in laminar flow.
- Laminar flow is characterized by predictable and well-defined flow paths, with fluid particles moving in an organized manner.

- It typically occurs at lower flow velocities or in situations where the fluid has high viscosity.
- Laminar flow is often observed in small-diameter pipes, low Reynolds number flows, and viscous fluids.
- The flow profile in laminar flow is parabolic, with the highest velocity at the center and decreasing velocities towards the walls.
- Mixing of different fluid layers is limited in laminar flow, resulting in less energy dissipation and lower fluid pressure drop compared to turbulent flow.
- Laminar flow is more easily controlled and analyzed compared to turbulent flow, making it suitable for precise applications such as microfluidics and chemical reactions.
- Transition from laminar to turbulent flow can occur based on factors like flow velocity, pipe diameter, and fluid properties.



What is the Definition of Turbulent Flow?

- Turbulent flow is a chaotic and irregular flow pattern of a fluid, characterized by fluctuations and mixing of fluid particles.
- It occurs when the fluid moves in a disordered manner with eddies, swirls, and vortices, resulting in high levels of turbulence and mixing.
- Turbulent flow is typically observed at higher flow velocities or in situations where the fluid has low viscosity.
- The velocity of the fluid varies randomly in both magnitude and direction within a turbulent flow.

- Turbulent flow is associated with higher levels of energy dissipation, pressure drop, and fluid mixing compared to laminar flow.
- The flow profile in turbulent flow is less predictable and may exhibit a flat velocity distribution across the pipe, with variations throughout the cross-section.
- Turbulent flow can enhance heat and mass transfer rates due to increased fluid mixing and enhanced boundary layer thinning.
- It is commonly observed in large-diameter pipes, high Reynolds number flows, and situations where flow disturbances or obstacles are present.
- The transition from laminar to turbulent flow depends on factors like flow velocity, pipe diameter, fluid properties, and roughness surface.
- Turbulent flow is more challenging to control and analyze compared to laminar flow, but it is essential for applications that require efficient mixing, heat transfer, and momentum exchang

Difference between Laminar and Turbulent Flow

The following table shows the difference between laminar and turbulent flow.

Property	**Laminar Flow**	**Turbulent Flow**
Flow Pattern	Smooth, orderly, and parallel layers (streamlines)	Chaotic, irregular, and mixing of fluid particles
Velocity Profile	Parabolic profile with constant velocity along streamlines	Fluctuating and random velocity variations in magnitude and direction
Energy Dissipation	Lower energy dissipation	Higher energy dissipation
Mixing Efficiency	Limited mixing between fluid layers	Enhanced mixing and mixing efficiency
Pressure Drop	Lower pressure drops	Higher pressure drops
Flow Stability	Stable flow with well-defined flow paths	Unstable and sensitive to disturbances

Occurrence	Lower flow velocities, small-diameter pipes, high viscosity	Higher flow velocities, large-diameter pipes, low viscosity
Heat Transfer and Mass Transfer	Lower heat and mass transfer rates	Higher heat and mass transfer rates
Control and Analysis	Easier to control and analyze	More challenging to control and analyze
Applications	Precise applications, microfluidics, laminar reactors	Mixing, heat transfer, and turbulence-dependent processes