ATME College of Engineering

FLUID MECHANICS BME403

Module-2

Fluid Kinematics

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Fluid Kinematics

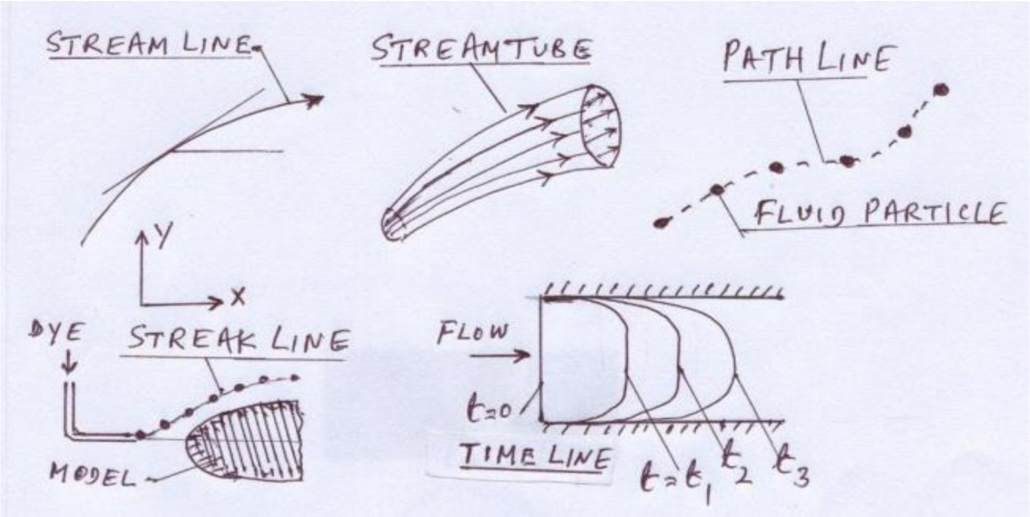
- **Fluid Kinematic Concepts**
- **Velocity field**
- **Types of fluid flow**
- **Continuity equation**
- **FLUID KINEMATICS**
  - Fluid Kinematics gives the geometry of fluid motion. It is a branch of fluid mechanics, which describes the fluid motion, and its consequences without consideration of the nature of forces causing the motion. Fluid kinematics is the study of velocity as a function of space and time in the flow field. From velocity, pressure variations and hence, forces acting on the fluid can be determined.

VELOCITY FIELD&FLOW PATTERNS

Velocity field

- Velocity at a given point is defined as the instantaneous velocity of the fluid particle, which at a given instant is passing through the point. It is represented by V=V(x,y,z,t). Vectorially, V=ui+vj+wk where u,v,w are three scalar components of velocity in x,y and z directions and (t) is the time. Velocity is a vector quantity and velocity field is a vector field.

- **FLOW PATTERNS**



Fluid Mechanics is a visual subject. Patterns of flow can be visualized in several ways. Basic types of line patterns used to visualize flow are streamline, path line, streak line and timeline.

(a) Streamline is a line, which is everywhere tangent to the velocity vector at a given instant.

(b) Path line is the actual path traversed by a given particle.

TYPES OF FLUID FLOW

1. **Uniform and non-uniform flows**
2. **Laminar and Turbulent flows**
3. **Compressible and Incompressible flows**
4. **Rotational and Irrotational flows**
5. **One-, Two- and Three-dimensional flows.**

Steady and Unsteady Flow

Steady flow is the type of flow in which the various flow parameters and fluid properties at any point do not change with time. In a steady flow, any property may vary from point to point in the field, but all properties remain constant with time at every point. $[\partial V/\partial t]_{x,y,z} = 0$; $[\partial p/\partial t]_{x,y,z} = 0$. Ex.: V=V(x, y,z); p=p(x,y,z) . Time is a criterion.

Unsteady flow is the type of flow in which the various flow parameters and fluid properties at any point change with time. $[\partial V/\partial t]_{x,y,z} \neq 0$; $[\partial p/\partial t]_{x,y,z} \neq 0$, E.g..:V=V(x,y,z,t), p=p(x,y,z,t) or V=V(t), p=p(t) . Time is a criterion

Uniform Flow is the type of flow in which velocity and other flow parameters at any instant of time do not change with respect to space. E.g., V=V(x) indicates that the flow is uniform in ‘y’ and ‘z’ axis. V=V (t) indicates that the flow is uniform in ‘x’, y’ and ‘z’ directions. Space is a criterion.

Uniform flow field is used to describe a flow, in which the magnitude and direction of the velocity vector are constant, i.e., independent of all space coordinates throughout the entire flow field (as opposed to uniform flow at a cross section). That is, $[\partial V/ \partial s]_{t=constant} = 0$, that is ‘V’ has unique value in entire flow field

Fig.1

Laminar and Turbulent Flows

- **Laminar Flow** is a type of flow in which the fluid particles move along well-defined paths or streamlines. The fluid particles move in laminas or layers gliding smoothly over one another. The behavior of fluid particles in motion is a criterion.

- **Turbulent Flow** is a type of flow in which the fluid particles move in a zigzag way in the flow field. Fluid particles move randomly from one layer to another. Reynolds number is a criterion. We can assume that for a flow in pipe, for Reynolds No. less than 2000, the flow is laminar; between 2000-4000, the flow is transitional; and greater than 4000, the flow is turbulent.

Compressible and Incompressible Flows

- **Incompressible Flow** is a type of flow in which the density (ρ) is constant in the flow field. This assumption is valid for flow Mach numbers with in 0.25. Mach numbers are used as a criterion. Mach number is the ratio of flow velocity to velocity of sound waves in the fluid medium

- **Compressible Flow** is the type of flow in which the density of the fluid changes in the flow field. Density is not constant in the flow field. Classification of flow based on Mach number is given below:

  - $M < 0.25$ – Low speed
  - $M <$ unity – Subsonic
  - M around unity – Transonic
  - $M >$ unity – Supersonic
  - $M >>$ unity, (say 7) – Hypersonic

Rotational and Irrotational Flows

Rotational flow is the type of flow in which the fluid particles while flowing along streamlines also rotate about their own axis. **Irrotational flow** is the type of flow in which the fluid particles while flowing along streamlines do not rotate about their own axis.

One-, Two- and Three-Dimensional Flows

One-dimensional flow is the type of flow in which flow parameters such as velocity is a function of time and one space coordinate only. Ex., V=V(x,t) – 1-D, unsteady ; V=V(x) – 1-D, steady

Two-dimensional flow is the type of flow in which flow parameters describing the flow vary in two space coordinates and time. For Ex., V=V(x,y,t) – 2-D, unsteady; V=V(x,y) – 2-D, steady

Three-dimensional flow is the type of flow in which the flow parameters describing the flow vary in three space coordinates and time.

Ex., V=V(x,y,z,t) – 3-D, unsteady ; V=V(x,y,z) – 3D, steady.

Continuity Equation

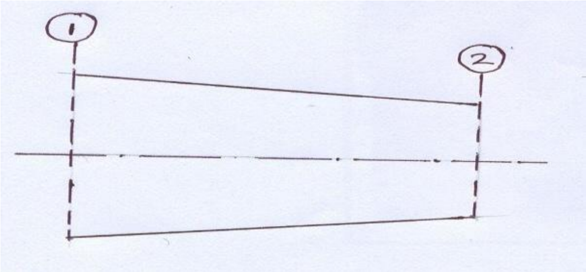
Rate of flow or discharge (Q) is the volume of fluid flowing per second. For incompressible fluids flowing across a section.

Volume flow rate, Q= A×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.



Continuity Equation

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.