Program : **B.Tech**

Subject Name: **Fluid Mechanics I**

Subject Code: **CE-501**

Semester: **5th**

UNIT-2

Kinematics of Flow : Types of flow-ideal & real , steady & unsteady, uniform & non uniform, one, two and three dimensional flow, path lines, streak lines, streamlines and stream tubes; continuity equation for one and three dimensional flow, rotational & irrotational flow, circulation, stagnation point, separation of flow, sources & sinks, velocity potential, stream function, flow nets- their utility & method of drawing flow nets

1. Classification of Fluid

a) Ideal fluid:

It is hypothetical which represents frictionless flow i.e. fluid without any viscosity. It is also called in viscid fluid. In ideal fluid the internal forces at any internal section are always normal to the section, even during motion. Hence the forces are purely pressure forces.

b) Real fluid:

In a real fluid tangential or shearing force always come into being whenever the motion takes place, thus giving the rise to fluid friction, also known as viscosity.

2.

a) Compressible fluid:

Fluids which will change in volume with the application of force are known as compressible fluid. Gases are compressible.

b) Incompressible fluid:

It implies fluids with constant density i.e. it will not change in volume with the application of force. Though liquids are slightly compressible they are usually assumed to be incompressible.

3.

a) Newtonian fluid: A Newtonian fluid is a fluid whose stress versus strain rate curve is linear and passes through the origin. The constant of proportionality is known as the viscosity.

A simple equation to describe Newtonian fluid behavior is

$$\tau = \mu \frac{du}{dy}$$

Where

t is the shear stress exerted by the fluid [Pa]

μ is the fluid viscosity - a constant of proportionality [Pa·s]

$\frac{du}{dy}$ is the velocity gradient perpendicular to the direction of shear [s-1]

For a Newtonian fluid, the viscosity, by definition, depends only on temperature and pressure (and also the chemical composition of the fluid if the fluid is not a pure substance), not on the forces acting upon it.

b) Non-Newtonian fluid: A non-Newtonian fluid is a fluid whose flow properties are not described by a single constant value of viscosity. Many polymer solutions and molten polymers are non-Newtonian fluids. In a non-Newtonian fluid, the relation between the shear stress and the strain rate is nonlinear, and can even be time-dependent.

Viscosity:

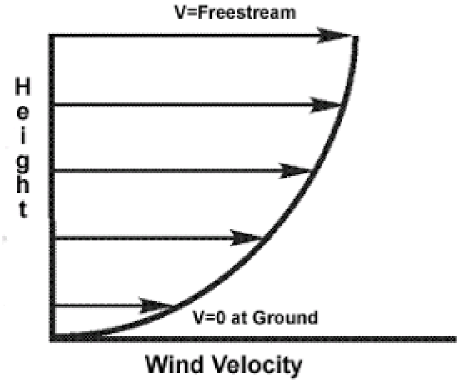
The viscosity of a fluid is a measure of its resistance to shear or angular deformation. The friction forces in fluid flow result from the cohesion &momentum interchange between molecules in fluid.

Viscosity depends on temperature. But this property is different for liquid & gas. As temperature increases, the viscosities of all liquids decrease, while the viscosities of all gases increase.

Classification of flow

Laminar /streamline/ viscous flow:

It occurs when a fluid flows in parallel layers, with no disruption between the layers. The fluid appears to move by the sliding of laminations of infinitesimal thickness relative to the adjacent layer.



Laminar Flow along a flat surface. The windspeed at the ground must be zero, as a boundary condition. At some height it becomes steady. This change with height creates windshear, and this shear is what picks up snow from the surface.

b) Turbulent flow:

The main characteristics of turbulent flow is its irregularity, there being no definite frequency, as in wave action, and no observable pattern.

Steady flow:

A steady flow is one in which all conditions at any point in a stream remain constant with respect to time, but the conditions may be different at different points. True steady flow is found only in laminar flow.

Unsteady flow:

An unsteady flow is one in which all conditions at any point in a stream do not remain constant with respect to time.

Uniform flow:

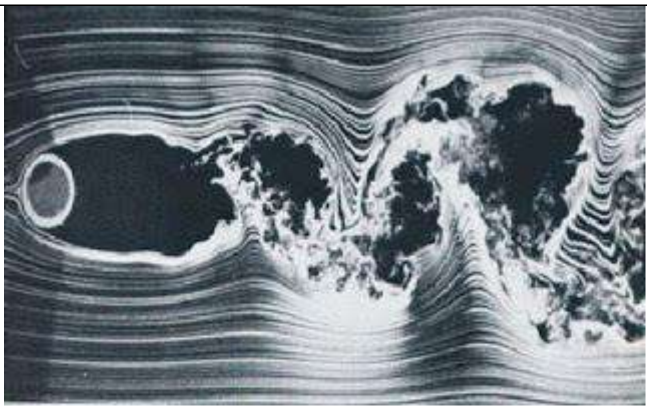
A truly uniform flow is one in which the velocity is the same in both magnitude direction at a given instant at every point in the fluid.

Non uniform flow:

A non-uniform flow is one in which the velocity is not same in magnitude or direction at a given instant at every point in the fluid.

a) Rotational flow:

It implies the flow where the fluid particles rotate about their own axis.



b) Irrigational flow:

It implies the flow where the fluid particles do not rotate about their axis, they only retain their orientation.

OTHER DEFINITIONS

Path lines:

It is the trace made by a single particle over a period of time.

Stream lines:

Streamlines show the mean directions of a number of particles at the same instant of time. Streamlines are a family of curves that are instantaneously tangent to the velocity vector of the flow.

Streak lines:

Streak lines are the locus of points of all the fluid particles that have passed continuously through a particular spatial point in the past. Dye steadily injected into the fluid at a fixed point extends along a streak line. These can be thought of as a "recording" of the path a fluid element in the flow takes over a certain period. The direction the path takes will be determined by the streamlines of the fluid at each moment in time.

Elementary flow patterns

Recall the discussion of flow patterns in Chapter 1. The equations for particle paths in a three-dimensional, steady fluid flow are

$$\frac{dx}{dt} = U(\bar{x}) \qquad \frac{dy}{dt} = V(\bar{x}) \qquad \frac{dz}{dt} = W(\bar{x}).$$

Although the position of a particle depends on time as it moves with the flow, the flow pattern itself does not depend on time and the system (4.1) is said to be autonomous. Autonomous systems of deferential equations arise in a vast variety of applications in mechanics, from the motions of the planets to the dynamics of pendulums to velocity vector fields in steady fluid flow. A great deal about the flow can be learned by plotting the velocity vector field Ui (¯x). When the flow pattern is plotted one notices that among the most prominent features are stagnation points also known as critical points that occur where

Ui (¯xc) = 0.

Quite often the qualitative features of the flow can be almost completely described once the critical points of the flow field have been identified and classified.

Stagnation point

In fluid dynamics, a stagnation point is a point in a flow field where the local velocity of the fluid is zero. Stagnation points exist at the surface of objects in the flow field, where the fluid is brought to rest by the object. The Bernoulli equation shows that the static pressure is highest when the velocity is zero and hence static pressure is at its maximum value at stagnation points. This static pressure is called the stagnation pressure.

The Bernoulli equation applicable to incompressible flow shows that the stagnation pressure is equal to the dynamic pressure plus static pressure. Total pressure is also equal to dynamic pressure plus static pressure so, in incompressible flows, stagnation pressure is equal to total pressure. (In compressible flows, stagnation pressure is also equal to total pressure providing the fluid entering the stagnation point is brought to rest isentropic ally.)

Separation of Flow

Pressure gradient is one of the factors that influences a flow immensely. It is easy to see that the shear stress caused by viscosity has a retarding effect upon the flow. This effect can however be overcome if there is a negative pressure gradient offered to the flow. A negative pressure gradient is termed a Favorable pressure gradient. Such a gradient enables the flow. A positive pressure gradient has the opposite effect and is termed the Adverse Pressure Gradient. Fluid might find it difficult to negotiate an adverse pressure gradient. Sometimes, we say the fluid has to climb the pressure hill.

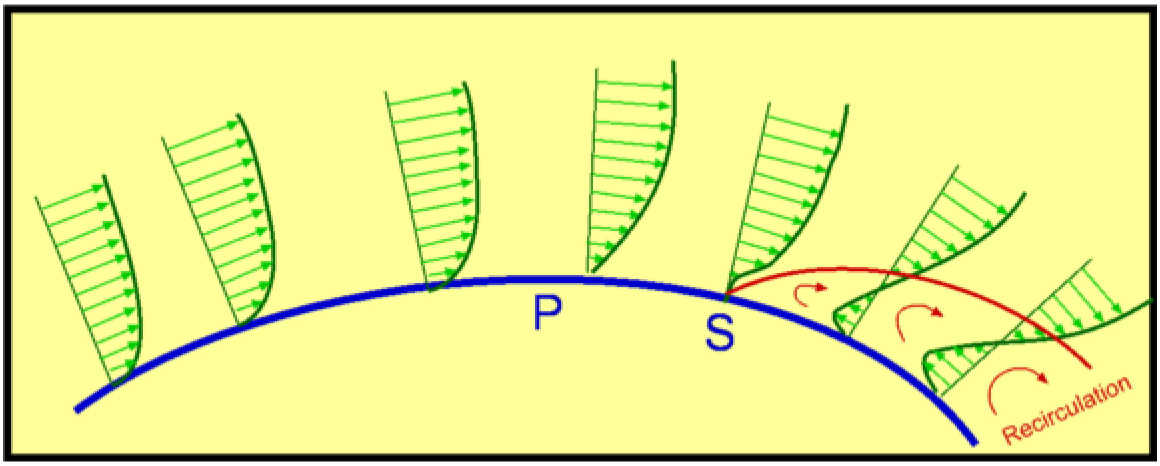


Figure : Separation of flow over a curved surface

One of the severe effects of an adverse pressure gradient is to separate the flow. Consider flow past a curved surface as shown in Fig.6.4. The geometry of the surface is such that we have a favorable gradient in pressure to start with and up to a point P. The negative pressure gradient will counteract the retarding effect of the shear stress (which is due to viscosity) in the boundary layer. For the geometry considered we have an adverse pressure gradient downstream of P.

Now the adverse pressure gradient begins to retard. This effect is felt more strongly in the regions close to the wall where the momentum is lower than in the regions near the free stream. As indicated in the figure, the velocity near the wall reduces and the boundary layer thickens. A continuous retardation of flow brings the wall shear stress at the point S on the wall to zero. From this point Onwards the shear stress becomes negative and the flow reverses and a region of recirculating flow develops. We see that the flow no longer follows the contour of the body. We say that the flow has separated. The point S where the shear stress is zero is called the Point of Separation.

Depending on the flow conditions the recirculating flow terminate and the flow may become reattached to the body. A separation bubble is formed. There are a variety of factors that could influence this reattachment. The pressure gradient may be now favorable due to body geometry and

other reasons. The other factor is that the flow initially laminar may undergo transition within the bubble and may become turbulent. A turbulent flow has more energy and momentum than a laminar flow. This can kill separation and the flow may reattach. A short bubble may not be of much consequence.

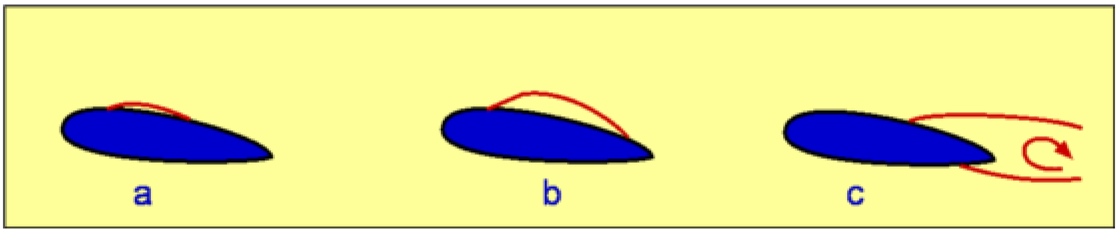


Figure: Separation bubble over an aero foil

On aero foils sometimes the separation occurs near the leading edge and gives rise to a short bubble. What can be dangerous is the separation occurring more towards the trailing edge and the flow not reattaching. In this situation the separated region merges with the wake and may result in stall of the aero foil (loss of lift).

Sources and Sinks

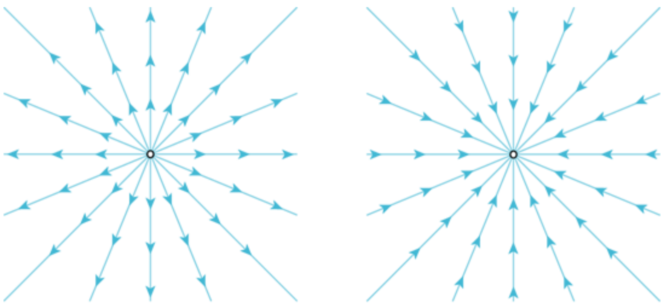
If the two-dimensional motion of an ideal fluid consists of an outward radial flow from a point and is symmetrical in all directions, then the point is called a simple source. A source at the origin can be considered as a line perpendicular to the z plane along which fluid is being emitted. If the rate of emission of volume of fluid per unit length $2\pi m$, then the origin is said to be a source of strength m, the complex potential for the flow is

$$F(z) = m \log(z),$$

and the velocity $\mathbf{V}$ at the point (x, y) is given by

$$\mathbf{V}(x, y) = \overline{F'(z)} = \frac{m}{\overline{z}}.$$

For fluid flows, a sink is a negative source and is a point of inward radial flow at which the fluid is considered to be absorbed or annihilated. Sources and sinks for flows are illustrated in Figure.



(a) A source at the origin. (b) A sink at the origin.

Fig. : Sources and sinks for an ideal fluid.

Stream Function

The idea of introducing stream function works only if the continuity equation is reduced to two terms. There are 4-terms in the continuity equation that one can get by expanding the vector equation (3.3.1) i.e.

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$$

For a steady, incompressible, plane, two-dimensional flow, this equation reduces to,

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0$$

Here, the striking idea of stream function works that will eliminate two velocity components *u and v*into a single variable (Fig. 3.3.1-a). So, the *stream function* $\{\psi(x,y)\}$ relates to the velocity components in such a way that continuity equation is satisfied.

$$u=\frac{\partial \psi}{\partial y};\ v=-\frac{\partial \psi}{\partial x}$$

$$\text{or},\vec{V}=\frac{\partial \psi}{\partial y}\hat{i}-\frac{\partial \psi}{\partial x}\hat{j}$$

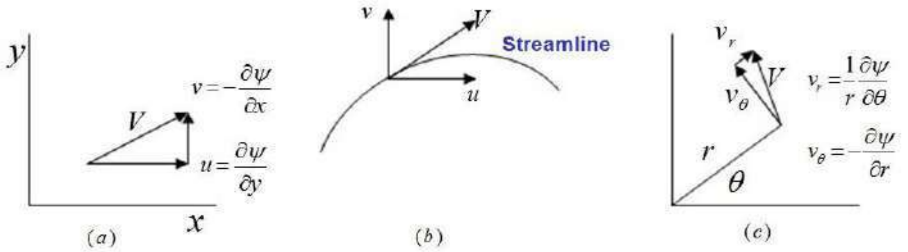


Fig.: Velocity components along a streamline.

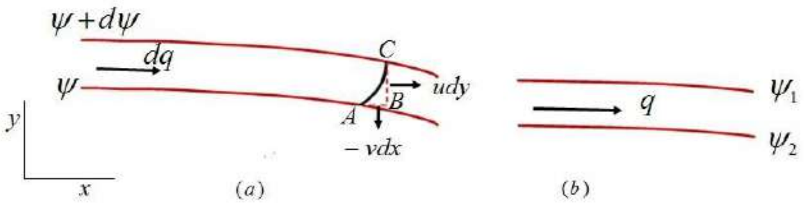
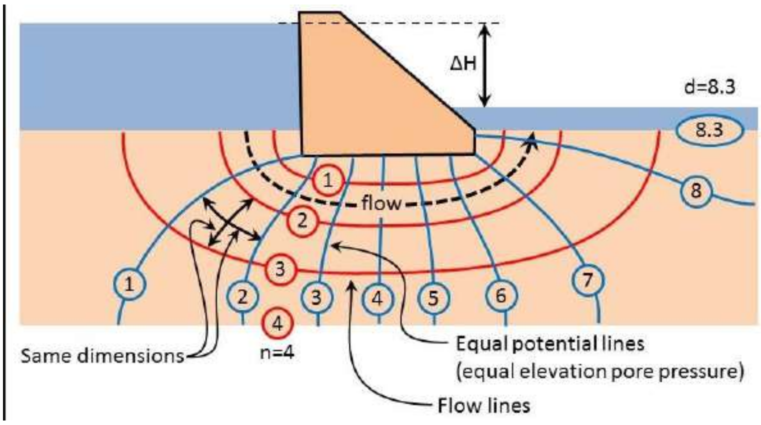


Fig.: Flow between two streamlines.

FLOWNET

A flownet is a grid obtained by drawing a series of streamlines and equipotential lines are known as a flow net.Equi-Potential Line is an imaginary line in a field of flow such that the total head is the same for all points on the line, and therefore the direction of flow is perpendicular to the line at all points.



The graphical properties of a flow net can be used in obtaining solutions for many seepage problems such as:

1. ***Estimation of seepage losses from reservoirs:*** It is possible to use the flow net in the transformed space to calculate the flow underneath the dam.

2. ***Determination of uplift pressures below dams:*** From the flow net, the pressure head at any point at the base of the dam can be determined. The uplift pressure distribution along the base can be drawn and then summed up.

3. ***Checking the possibility of piping beneath dams:*** At the toe of a dam when the upward exit hydraulic gradient approaches unity, boiling condition can occur leading to erosion in soil and consequent piping. Many dams on soil foundations have failed because of a sudden formation of a piped shaped discharge channel. As the stored water rushes out, the channel widens and catastrophic failure results. This is also often referred to as piping failure.

METHOD OF DRAWING FLOW NETS

1. **Hydraulic models:**

a. Streamlines can be traced by injecting a dye in a seepage model or Heleshaw apparatus.
b. They by drawing equipotential lines the flow net is completed.

2. **Analytical Method:**

a. It is only applied to problems with simple and ideal boundaries conditions.
b. The equation corresponding curve ǿ and Ψ are first obtained and the same are plotted to give the flow net pattern for the flow of fluid between the given boundary shape.

3. **Electrical Analogy Method:**

a) This method based on the fact that the flow of fluids and flow of electricity through a conductor are analogues. These two systems are similar in the respect that electric potential is analogues to the velocity potential. The electric current is analogues to the velocity of flow and the homogeneous conductor is analogues to the homogeneous fluid. This method only for a practical method of drawing a flow net for a particular set of boundaries.

4. **Graphical Method:**

a) This method requires a lot of erasing to get the proper shape of a flow net and also consume a lots of time. A graphical consists of drawing steam lines and equipotential lines such that they cut orthogonally and form curvilinear squares.

