Fluid Dynamics

Fluid Dynamics is the beginning of the determination of forces which cause motion in fluids. This section includes forces such as Inertia, Viscous, Bernoulli's theorems, Vortex motion, forced motion, etc. Fluid dynamics also include the momentum correction factor, jet impact, etc.

Dynamics is that branch of mechanics that treats the motion of bodies and the action of forces in producing or changing their motion. The analysis in fluid dynamics is also carried out in different domains like aerodynamics, hydrodynamics, etc.

Difference Between Fluid Dynamics and Fluid Kinematics

Fluid dynamics and kinematics are branches of fluid mechanics in which fluid flow analysis has been carried out by different means. Only the way of analysis and a few parameters differ in fluid kinematics and dynamics. Based on these, the difference between them can be listed as follows:

- In fluid dynamics, motion-causing forces are considered, but these forces are ignored in fluid kinematics.
- In fluid dynamics, continuity and energy equations are used for the analysis, while in fluid kinematics, these equations are not used.

Types of Flow Rate

- **Mass flow rate:** dm/dt = Mass/Time taken to accumulate the same mass
- **Volume flow rate - Discharge**
    - More commonly, we use volume flow rate, Also known as discharge. The symbol normally used for discharge is Q.
    - discharge (Q) = Volume/Time

Continuity Equation in Fluid Dynamics

This principle of conservation of mass says matter cannot be created or destroyed. This is applied in fluids to fixed volumes, known as control volumes (or surfaces) when the properties of fluid remain the same. The control volume is defined as the space for which flow analysis is carried out, and in this space, fluid flow mass enters and out are considered for the analysis.

- For any control volume, the principle of conservation of mass defines,

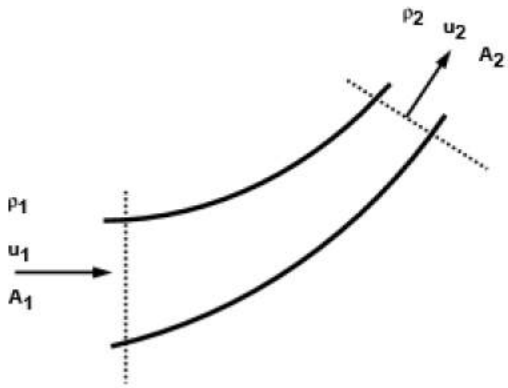
Mass entering per unit time = Mass leaving per unit time + Increase of mass in control volume per unit time

- For steady flow, there is no increase in the mass within the control volume,

Mass entering per unit time = Mass leaving per unit time

Applying Continuity Equation to a stream-tube

Mass enters and leaves only through the two ends (it cannot cross the stream tube wall).



for steady flow,

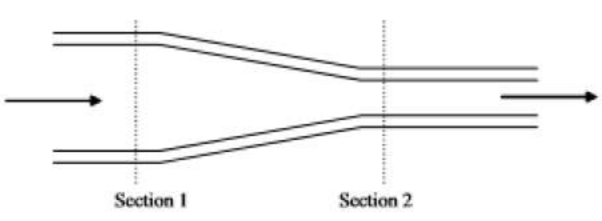
$\rho_1 \partial A_1 u_1 = \rho_2 \partial A_2 u_2$= Constant= Mass flow rate

This is the continuity equation.

Applications of Continuity Equation

Fluid flow analysis becomes easier by using continuity equations in the flow. It has various applications in real life. A few of them are explained here.

Application 1: Flow through a tube

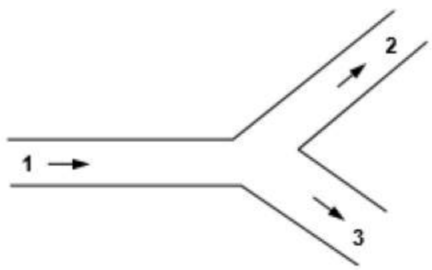


A liquid is flowing from left to right. By the continuity, $\boldsymbol{\rho_1 A_1 u_1 = \rho_2 A_2 u_2}$

As we are considering a liquid,

$\rho_1=\rho_2$

$Q_1 = Q_2$
$A_1u_1=A_2u_2$
Application 2: Velocities in pipes coming from a junction



mass flow into the junction = mass flow out

$\rho_1Q_1= \rho_2Q_2 + \rho_3Q_3$

When incompressible fluid is flowing through the pipes (i.e. $\rho_1 = \rho_2 = \rho_3$)

$Q_1= Q_2+ Q_3$

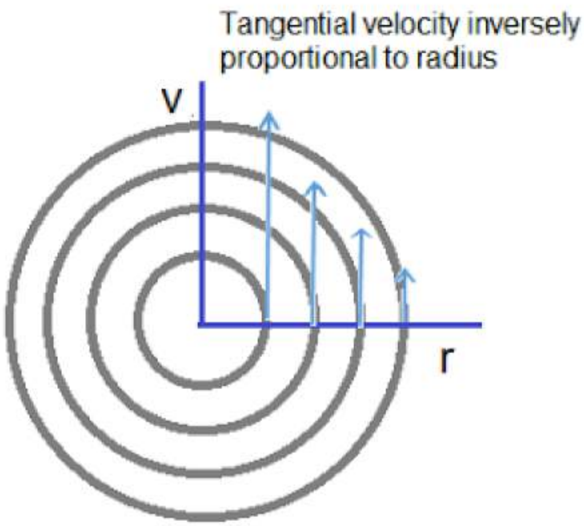
$A_1u_1=A_2u_2+ A_3u_3$

Types of Fluid Flow

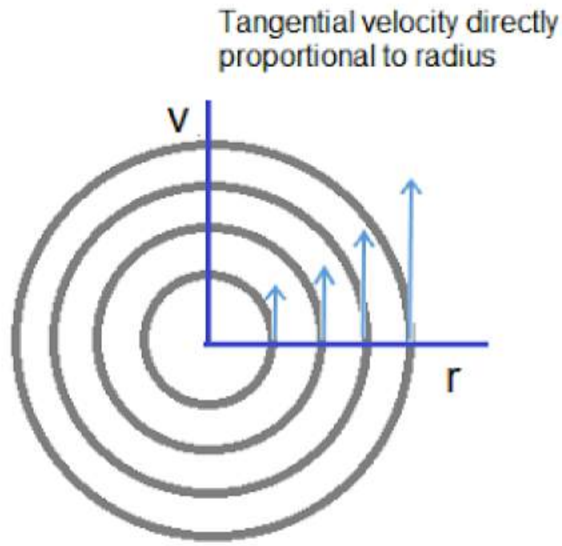
Fluid flows can be classified into various types based on the different parameters. So, based on the fluid's rotational motion, types of fluid flow can be classified as vortex flow or non-vortex flow.

Vortex flow

This is the flow of rotating mass of fluid or flow of fluid along the curved path. Vortex flow can also be classified as free or forced vortex flow. These are explained below.



Free vortex



Forced vortex

Free vortex flow

- No external torque or energy is required. The fluid rotates under certain energy previously given to them. In free vortex mechanics, overall energy flow remains constant. There is no energy interaction between an external source and a flow or any dissipation of mechanical energy in the flow.
- Fluid mass rotates due to the conservation of angular momentum.
- Velocity is inversely proportional to the radius.

So, for a free vortex flow, **vr = constant**

Hence, **v = c/r**

- At the centre, (r = 0) of rotation, velocity approaches infinite; that point is called a singular point.
- The free vortex flow is **irrotational** and therefore, also known as the irrotational vortex.
- In free vortex flow, Bernoulli's equation can be applied.

Examples include a whirlpool in a river, water flowing out of a bathtub or a sink, flow in the centrifugal pump casing, and flow around the circular bend in a pipe.

Forced vortex flow

- Maintaining a forced vortex flow requires continuous energy or external torque.

- All fluid particles rotate at the constant angular velocity ω as a solid body. Therefore, a flow of forced vortex is called a solid body rotation.
- Tangential velocity is directly proportional to the radius.
  - $v = r\,\omega$
  - ω = Angular velocity.
  - r = Radius of fluid particle from the axis of rotation.
- The surface profile of vortex flow is parabolic.
- In a forced vortex, the total energy per unit weight increases with an increase in radius.
- A forced vortex is not irrotational; rather, it is a **rotational flow** with constant vorticity 2ω.

An example of forced vortex flow is rotating a vessel containing a liquid with constant angular velocity flow inside the centrifugal pump, etc.

Energy Equations in Fluid Dynamics

Energy equations in fluid dynamics are used for flow analysis, and energy equations in the flow consist of the Bernoulli equation, Euler's equation, Naviour-stokes equation, etc. This is the equation of motion in which the forces due to gravity and fluid pressure are considered. The common fluid mechanics equations used in fluid dynamics are given below

Gravity force F_g, Pressure force F_p, Viscous force F_v, Compressibility force F_c, and Turbulent force F_t.

$F_{net} = F_g + F_p + F_v + F_c + F_t$

- If the fluid is **incompressible**, then $\mathbf{F_c = 0}$

∴ $\mathbf{F_{net} = F_g + F_p + F_v + F_t}$

This is known as the **Reynolds equation of motion**.

- If the fluid is **incompressible and turbulence** is negligible, then $\mathbf{F_c = 0, F_t = 0}$

∴ $\mathbf{F_{net} = F_g + F_p + F_v}$

This equation is called as **Navier-Stokes equation**.

- A viscous effect will also be negligible if the fluid flow is considered ideal. Then

$\mathbf{F_{net} = F_g + F_p}$

This equation is known as **Euler's equation**.

Euler’s equation can be written as:

$dp/\rho + gdz + vdv = 0$

Bernoulli’s Equation

It is based on the law of conservation of energy. This equation is applicable when the following assumptions have been made:

- Flow is steady and irrotational
- Fluid is ideal (non-viscous)
- Fluid is incompressible

It states that in a steady, ideal flow of an incompressible fluid, the total energy at any point is constant.

Total energy consists of pressure, kinetic, and potential or datum energy. These energies per unit weight of the fluid are:

- Pressure energy = $p/\rho g$
- Kinetic energy = $v^2/2g$
- Datum energy = z

Bernoulli’s theorem is written as:

$p/\rho g + v^2/2g + z = \text{constant}$

Bernoulli’s equation can also be obtained from Euler’s equation

Assumptions in the application of Bernoulli’s equation

- Flow is steady
- Density is constant (incompressible)
- Friction losses are negligible
- It relates the states at two points along a single streamline (not conditions on two different streamlines)