Fluid Dynamics

Introduction

Flow

Motion with relative movement between fluid particles where continuous deformation happens.

Classification of fluid flow

Density

Incompressible

Density doesn't vary significantly.

Examples:

- Pipe and channel flows of liquids
- Gas flows in pipes

$$\frac{|\Delta \rho|}{\rho} \ll 1$$

Compressible

Density varies significantly.

Examples:

- Pressure surges in pipes

Viscosity

Non-viscous

Fluid doesn't show any resistance to the flow.

Viscous

Fluid shows any resistance to the flow.

- **Newtonian**: μ is constant Examples: Water
- **Non-newtonian**: μ is not constant Examples: Paints, Clay, Plastics

Variation of parameters

The parameters:

- Velocity V
- Pressure P
- Flow rate Q

Temporal Variation

The variation of the parameters with time.

- **Steady**: no variation with time $V = f(x, y, z)$
- **Unsteady**: variation of flow parameters with time $V = f(t, x, y, z)$

Spatial Variation

The variation of the parameters with coordinates.

- **Uniform**: no variation with spatial parameters $V = f(t)$
- **Non-uniform**: spatial variation of flow parameters $V = f(t, x, y, z)$

Dimensional

If a variation of flow parameter in a certain direction can be neglected, that can reduce the calculations.

Nature of movement

- **Laminar**: Fluid particles move in a orderly fashion
- **Turbulent**: Fluid particles move disorderly

Rotation of particles

- **Rotational**: Usually due to shear forces. Flow of real fluids.
- **Non-rotational**: Flow of frictionless forces.

Flow patterns

Streamline

A line tangential to the flow velocity.

Streamtube

A passage enclosed by a collection of streamlines.

Pathline

Path traced by an individual fluid particle.

Streakline

Suppose a dye is injected into a fluid flow. Streakline indicates the positions of all particles passed through the point of injection.

> **Note**
>
> In steady flow: streamline, pathline and streakline all coincide.

Conservation Laws

In fluid dynamics, 4 laws are used to analyse the fluid flow.

- Laws of mechanics
- Conservation of mass
- Conservation of energy
- Conservation of momentum

These laws are applied to a specific volume of the fluid in motion, and it's called as control volume.

Control volume

A volume, through which a fluid flows.

- It's a fixed volume
- Can either be real or imaginary

Conservation of mass

Mass cannot be created nor destroyed.

Conservation of energy

Energy cannot be created nor destroyed, but can be converted from one form to another.

Conservation of momentum

Unless a resultant force is exerted on a mass, it cannot gain or lose momentum.

Momentum

$$M = \text{mass} \times \text{velocity} = mv$$

Derivations

Continuity equation

From the conservation of mass law, the below equation can be derived for an incompressible fluid:

$$Q = Av$$

Here:

- Q - Flow rate
- A - Cross-sectional area
- v - velocity

Bernoulli's equation

For an incompressible fluid in steady flow, total head on a point is constant throughout a streamline. Can be derived from the conservation of energy law.

$$\text{Total head } H = z + \frac{P}{\rho g} + \frac{v^2}{2g}$$

Here:

- z - Datum head. Height to the point from a reference level.
- $\frac{P}{\rho g}$ - Pressure head.
- $\frac{v^2}{2g}$ - Velocity head. Kinetic energy per unit weight.

> **Note**
>
> - Head is the energy per unit weight.
> - Piezometric head is equal to $\frac{P^*}{\rho g}$ where P^* is the piezometric pressure.

Steady flow momentum equation

$$F_S = \dot{M}_o - \dot{M}_i$$

Here:

- F_S - Force exerted on the fluid within the control volume
- $\dot{M}_o$ - Rate of change of momentum of the inflow fluid
- $\dot{M}_i$ - Rate of change of momentum of the outflow fluid

> **Note**
>
> Below equation can be useful in applications.
>
> $$\dot{M} = \rho Q v$$
>
> Where:
>
> - ρ - density
> - Q - flow rate
> - v - velocity

Power

$$P = \gamma Q H$$

Here:

- γ - specific weight of the fluid
- Q - flow rate
- H - total head

Losses

Energy losses in a fluid under motion.

Types

Local loss

Occurs when there is a sudden change in flow.

$$K_L \frac{v^2}{2g}$$

Here:

- K_L - local loss coefficient
- v - velocity
- g - gravitational acceleration

Friction loss

Occurs because of

- viscosity
- friction between fluid and pipe wall

When the fluid is under turbulent flow:

$$\lambda \frac{L}{D} \frac{v^2}{2g}$$

Here:

- λ - friction factor
- L - length of the pipe
- D - diameter of the pipe
- v - velocity
- g - gravitational acceleration