# VIII:Fluid Flows

## 1: Real and Ideal Fluids

- The most commonly used simplification is called an ideal fluid.
- An ideal fluid is incompressible(the constant $\rho$), non-viscous(negligible $\mu$), and has no surface tension.
- The real fluid with viscous in the real situation are called real fluid.

## 2: Newtonian and Non-Newtonian Fluids

- For solid, there is a linear relationship between the shear stress $\tau$ and shear strain $\gamma$.
- For liquid,the same relationship exists in the shear stress and shear strain(=velocity gradient),with the constant of dynamic viscosity $\mu$.
- Newton's law of viscosity: $\tau = \mu \frac{du}{dy}$
- Fluids obey Newton's law of viscosity are known as Newtonian Fluids.

## 3: No-slip Condition and Boundary Layer

- A fluid flowing over a stationary surface comes to a complete stop at the surface cause no-slip conditions.

- Boundary Layer: The flow region adjacent to the wall in which the viscous effects (velocity gradient) are significant.

# 4: Streamlines, Streamtubes, Pathlines, and Streaklines

- **Streamline:** A curve that everyone tangent to the local vector.
    - Streamlines as indicators of the **instantaneous direction of fluid motion** throughout the flow field.
    - Streamlines cannot be directly observed experimentally,except in steady flow fields.
- **Streamtube:** consist a bundle of streamlines like a communications cable consist of some fibre-optic cables.
    - Since streamlines are everywhere parallel to the local velocity, fluid cannot cross the streamline.
    - Fluid within the streamtube cannot cross the boundary of the tube.
    - Both streamlines and streamtube are instantaneous quantities, defined at a particular instant in time according to the velocity field at that instant.

- **Pathline:** The actual path traveled by an individual fluid particle over some time period.
    - Lagrangian concept- we simply follow the path of an individual fluid particle as it moves around the flow field.
- **Streakline:** The locus of fluid particles that have passed sequentially through a prescribed point in the flow.
    - Streakline are the most common flow pattern generated in a physical experiment.
    - If you insert a small tube into a flow and introduce a continuous stream of tracer fluid, the observed pattern is a streakline.
- **Streakline,streamline and pathline are identical in steady flow but cna be different in unsteady flow.

# 5: Classification of Fluid Flows

- Confinement:internal and external flow
- Dimensionality: 1 or 2 and 3-D flows
- Steadiness: steady or unsteady
- Uniformity: uniform and non-uniform
- Rotationality: rotational and irrotational
- Laminarity: laminar and turbulent
- Spatial regions: viscous and non-viscous

# 6: Internal and external flows

- Depending on whether the fluid is forced to flow in a confined channel or over a surface.
    - External flow: Unbounded fluid

- Internal flow: Completely bounded by solid surface.
- The flow of fluid in a duct is called **open channel flow** if the solid bound is partially filled(like river).

- Internal flows are dominated by the influence of the viscosity throughout the flow field, while in external field the viscous effect only limited to the boundary layers near solid surface.

# 7: 1,2 and 3-D Flows

- A flow field is beat characterized by its velocity distribution.
- **A flow is said to be 1,2 or 3-D if the flow velocity varies in 1,2 or 3-D ,respectively.**
- The variation of velocity in certain direction can be ignored in other directions.

# 8: Steady versus Unsteady Flow

- **Steady** means no change at a point with time
- The steady flow assumption regards flow parameters such as velocity, pressure and density as time independent.
- For steady flows, $\frac{\partial u}{\partial t} = 0$
- Many engineering devices operating for long time under the same conditions, and they are classified as **steady flow devices**.

# 9: Uniform versus Non-uniform flow

- Uniform means no change with location over a specified region.

- A flow is constant if its characteristics do not vary between different of the domain at any constant.
- Flow in a pipe with a uniform cross-section is usually uniform.
- Flow with free surface is uniform only in special situation where the cross-section and there is a complete balance of forces. Mostly it is non-uniform in free surface situations.

# 10: Rotational versus Irrotational Flow

- The flow is termed rotational or vortex flow if the particles within the flow have rotation about any axis.
- The rotation is measured as an average angular velocity of small linear elements perpendicular to the given axis.
- Irrotational or potential flow is flow without rotation.
  - Groundwater flow in porous media is usually considered to be irrotational.
  - Pipe and free-surface flows are usually rotational.

# 11: Laminar versus Turbulent Flow

- **Laminar flow**: The highly ordered fluid motion characterized by smooth layers of fluid. The flow of high-viscosity fluids such as oil at low velocities is typically laminar.
- **Turbulent flow:** The highly disordered fluid motion that typically occurs at high velocities and is characterized by velocity fluctuations. The flow of low-viscosity and high velocities is typically turbulent.

- **Transitional flow:** A flow that alternates between being laminar and turbulent.

# 11: Laminar Flow

- Laminar flow or streamline flow occurs when a fluid in parallel layers with no disruption between the layers.
  - There are no cross-currents perpendicular to the direction of flow , no eddy or swills of fluid.
- Reynold number (Re)
  - The ratio of the inertial force to the shearing force of the the fluid.(=$\rho cD/\mu$)
  - How fast the fluid is moving relative to how viscous it is.
  - Velocity at a point is independent of time and no velocity fluctuation.
  - No component of velocity normal to mean flow direction.

# 12: Turbulent Flow

- Turbulence or turbulent flow is any pattern of fluid motion characterized by chaotic changes in pressure and flow velocity.
- Secondary, random velocity fluctuations superimposed on mean velocity. Much mixing, hence momentum interchange leads to more uniform velocity profiles.

# 13: Viscous versus Inviscid Region of Flow (Inviscid means no-viscous)

- **Viscous flow:** Flows in which the friction effects are significant.
- **Inviscid or non-viscous flow**: Flow of an inviscid fluid (viscosity is equal to 0) with no energy loss.
- **Inviscid flow regions**: In many flows of practical interest, there are regions(typically regions not close to solid surfaces) where viscous forces are negligibly small compared to inertial or pressure forces.

# 14: Continuity Equations

## 14.1 Conservation Equations of Fluid Flow

- Conservation laws:
  - Conservation of mass
  - Conservation of Energy
  - Conservation of Momentum
- These are called **The Fundamental Equations**.

## 14.2 The Fundamental Equations

- Conservation of Mass:
  - For steady flow of an incompressible fluid: $Q = \int_A u dA$, $Q = constant$ and $u$ is velocity of fluid.
  - For compressible fluid: $\dot{m}$=constant (kg/s)
- Conservation of Energy:
  - $\dfrac{p}{\rho g} + z + \dfrac{u^2}{2g}$=constant, The Bernoulli Equation.
- Conservation of Momentum
  - $\sigma \vec{F} = \dot{m}(\vec{u_2} - \vec{u_1}$

## 14.3 Control Volume

- A control volume is a fixed region in space bounded by a control surface or boundary.
- This boundary is positioned so that flow across it occurs only at locations where flow conditions are uniform.
- The size and the shape of a control volume are entirely **arbitrary** but frequently they are made to coincide with solid with solid boundaries.

# 14.4 Conservation of Mass

- Consider a control volume of fluid of density, $\rho$
- Mass of fluid within the control volume = $\int_{CV} \rho dV$
- If the fluid is flowing then the mass of fluid within the control volume may be changing.
- Let's consider the rate of increase of mass within the control volume:
  - Rate of increase mass = $\frac{\partial}{\partial t} \int_{CV} \rho dV$
- Now consider the net rate of mass inflow to the control volume through the control surface.
- Let CS denotes the control surface and let $\vec{v}$ be the velocity perpendicular to the control surface.
- Rate of mass inflow = -$\int_{CS} \rho \vec{v} dA$
- Matter is conserved, so:
  - $\frac{\partial}{\partial t} \int_{CV} \rho dV = - \int_{CS} \rho \vec{v} dA$
- The rate of the increase of mass within a control volume is equal to the net rate of mass flow to the same control volume through the control surface, which is the **continuity equation** for unsteady flow.
  - $\frac{\partial}{\partial t} \int_{CV} \rho dV + \int_{CS} \rho \vec{v} dA$=0
- For steady flow, $\frac{\partial}{\partial t} \int_{CV} \rho dV$=0, so $\int_{CS} \rho \vec{v} dA = 0$
- For incompressible fluid ($\rho$=constant), the equation can be reduced to: $\int_{CS} \vec{v} dA = 0$
  - Let us consider a portion of pipe as an example:

- $\int_{A_1} u_1 dA_1 = \int_{A_2} u_2 dA_2$

- The average velocity for a cross-section is given by $\vec{u}\frac{1}{A}\int_A udA$:
- As $Q = \int_A udA$ and $\int_{A_1} u_1 dA_1 = \int_{A_2} u_2 dA_2$, we can find $Q = \bar{u_1}A_1 = \bar{u_2}A_2$.
- **Discharge** is a very important concept in fluid mechanics:

$$Q = \bar{u}A$$

- Therefore for steady incompressible flow ($\rho$ is constant), $Q =$constant.

# 14.5 Continuity Equation for Unsteady,Compressible Flow

# 14.6 Continuity Equation for steady flow at a pipe junction

- For a CV with multiple inlets and outlets
  - The algebraic sum of ghe mass flow rates at any pipe junction is **zero**.
- If the flow is incompressible($\rho_1 = \rho_2 = \rho_n$) or ($\rho = constant$):

# 14.7 Discharge per Unit Width

$$q = \frac{Q}{b} = \frac{uA}{b} = \frac{uhb}{b} = uh$$