Lecture Five & Six

Types of Flow

Classification of Flow Fluid flow can be classified based on different criteria:

A. Based on Flow Regime:

- Steady Flow
- Unsteady Flow

B. Based on Reynolds Number:

- Laminar Flow
- Turbulent Flow
- Transitional Flow

5.1 Based on Flow Regime (Associated with time)

5.1.1 Steady Flow

Flow velocity at any given point does not change with time. However, velocity can vary in space. For example, consider pipe with increasing diameter (expansion). Flow within the pipe can be steady with velocity constantly varying along the pipe. The figure below shows the velocity distribution at several cross sections and the velocity profile along the pipe. The velocity drops due to the increase of the flow area along the axis of the pipe but velocity at each point along the axis does not change with time.

Example:

Flow in a Well-Designed Pipeline: If a pump operates at a constant speed and the flow rate is steady, fluid flowing through the pipeline will experience steady flow, where the velocity at every point does not vary with time.

5.1.2 Unsteady Flow

Velocity of the fluid at any point within the flow domain changes with time. Example of this is the flow in a tea cup just after stirring to dissolve sugar or milk. The flow slows down and eventually come to rest if not disturbed.

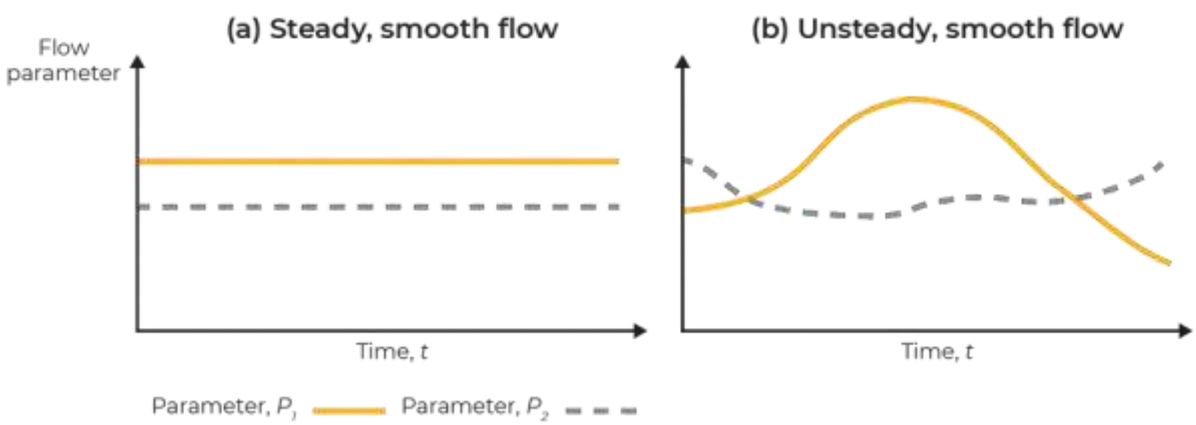
Unsteady flow refers to flow where the velocity of the fluid at any given point changes with time. This type of flow occurs when there are fluctuations in the flow rate or when the system is subject to changes in input conditions.

Notes:

- Unsteady flow can result from changing conditions such as system startup, shutdown, or transient disturbances.

Example:

- Flow During Pump Startup: When a pump is turned on, the flow in the pipe starts from zero and gradually increases, causing the flow to be unsteady initially.



5.2 Based on Reynolds Number

5.2.1 Laminar Flow

Laminar flow occurs when a fluid moves in parallel layers with minimal mixing between them. It is characterized by smooth and orderly motion, where each layer moves steadily without interference. This type of flow is observed when the Reynolds number (Re) is less than 2000.

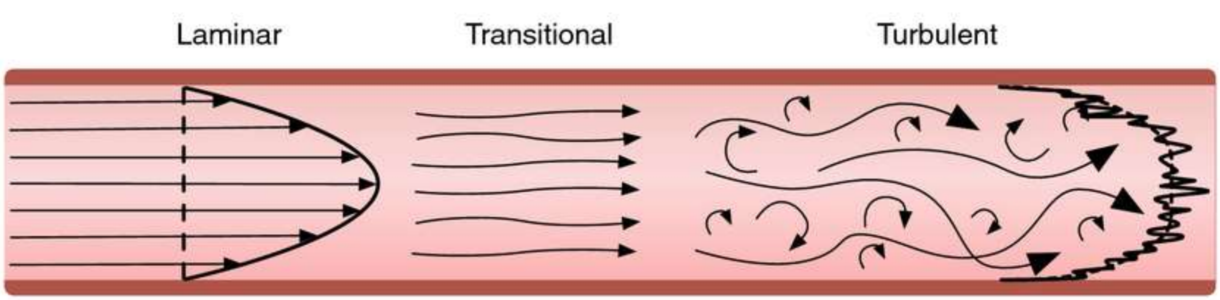
5.2.2 Turbulent Flow

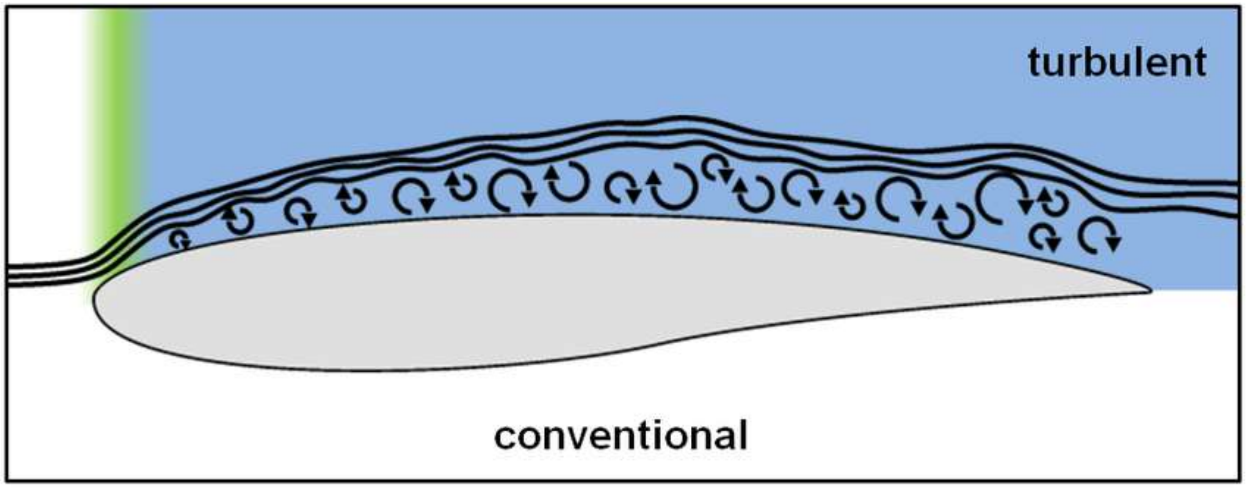
Turbulent flow occurs when the Reynolds number exceeds 4000, leading to chaotic and irregular fluid motion. Unlike laminar flow, turbulence is marked by significant mixing, eddies, and fluctuations in velocity and pressure.

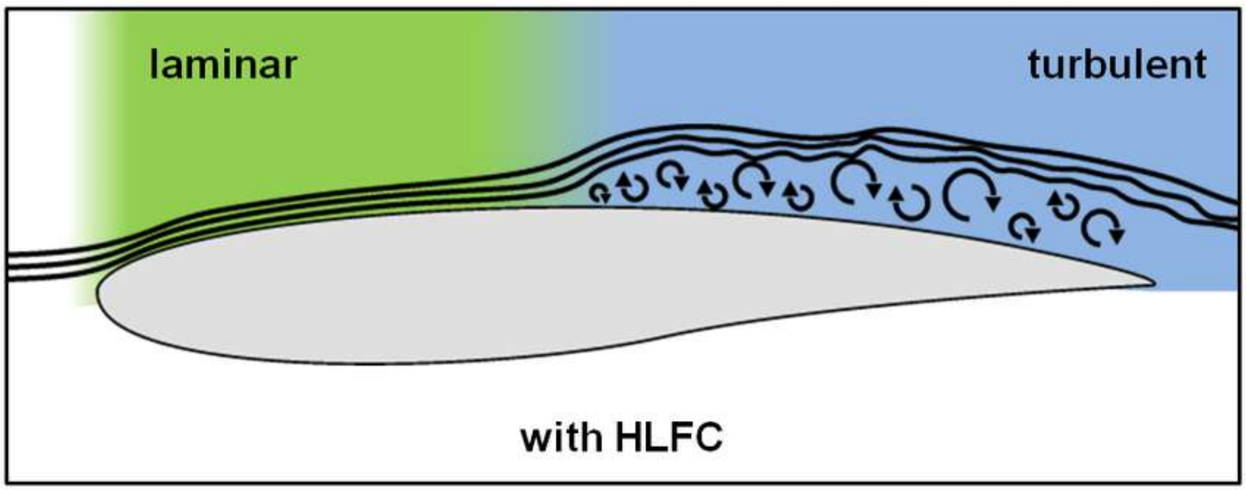
5.2.3 Transitional Flow

Transitional flow is the intermediate state between laminar and turbulent flow, occurring when the Reynolds number (Re) is between 2000 and 4000 (although the exact range may vary based on system conditions). In this region, flow exhibits characteristics of both laminar and turbulent behavior, with fluctuations and disturbances that may eventually lead to full turbulence.

Understanding these types of flow is essential in process control, fluid transportation, and various engineering applications. Proper selection and control of flow regimes can lead to optimized energy consumption, improved system efficiency, and enhanced safety in fluid-handling operations.







Comparison Between Laminar and Turbulent Flow:

Feature	Laminar Flow	Turbulent Flow
Reynolds Number	< 2000	> 4000
Flow Pattern	Smooth	Chaotic, irregular
Mixing	Minimal	High
Examples	Blood flow, oil transport	River flow, industrial mixing

5.3 Reynolds number (Re)

The Reynolds number (Re) is a **dimensionless quantity** used in fluid mechanics to predict the flow regime—whether it will be laminar, turbulent, or transitional. “It represents **the ratio** of **inertial forces** (responsible for the tendency of the fluid to continue moving once it is set in motion) to **viscous forces** within a fluid and provides insight into the relative importance of these forces in a given flow situation”. It is given by:

$$\mathbf{Re = \rho V D/\mu}$$

$$\text{Or} \quad \mathbf{Re = VD/\nu}$$

where:

- ρ = Fluid density (kg/m³)
- V = Flow velocity (m/s)
- D = diameter for pipe flow (m)
- μ = Dynamic viscosity (Pa.s)(kg/m·s)
- ν= Kinematic Viscosity (m²/s)

Exercise: What is the physical meaning of Re?

Reynolds number helps determine how a fluid moves through a system based on its velocity, density, viscosity, and characteristic length (such as pipe diameter).

➢ **Low Re (Re < 2000, Laminar Flow):**

- **Viscous forces dominate** → The fluid moves smoothly in parallel layers with minimal mixing.
- The motion is predictable, and there is less energy loss due to friction.

- **High Re (Re > 4000, Turbulent Flow):**
  - **Inertial forces dominate** → The fluid moves chaotically with eddies and vortices.
  - There is significant mixing, which enhances mass and heat transfer but increases resistance.
- **Transitional Flow (2000 < Re < 4000):**
  - A mixture of both behaviors, where the flow starts showing turbulence intermittently.

***Example* 1:**

Crude oil flowing through a pipeline, calculate the Reynolds number and determine whether the flow is laminar or turbulent.

- **Dynamic viscosity of crude oil (μ):** 0.25 Pa·s (or kg/(m·s))
- **Density of crude oil (ρ):** 850 kg/m³
- **Pipeline diameter (D):** 0.5 m
- **Flow velocity (V):** 2 m/s

Sol:

$$Re = \frac{\rho V D}{\mu}$$

$$Re = \frac{(850\,\text{kg/m}^3) \times (2\,\text{m/s}) \times (0.5\,\text{m})}{0.25\,\text{Pa}}$$

$$Re = \frac{850 \times 2 \times 0.5}{0.25} = \frac{850}{0.25} = 3400$$

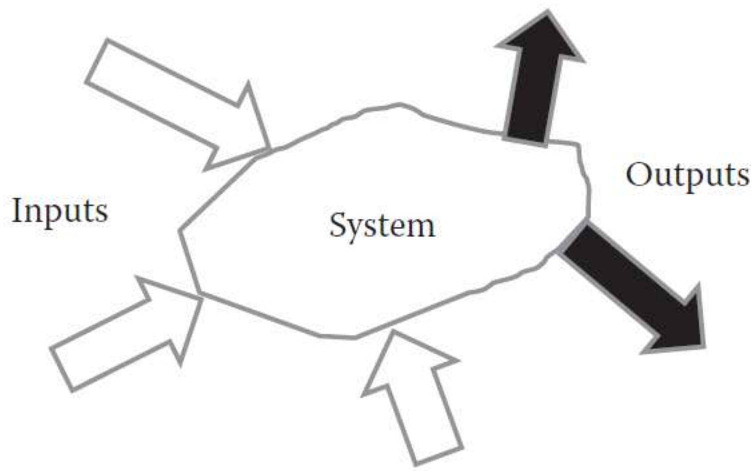
Since the Reynolds number is 3400, the flow is **transition region** because it between 2000 and 4000 and it is about to reach turbulent region.

Conservation of mass

"Mass can neither be created nor destroyed in a closed system"

6.1 Continuity Equation

Mass of the fluid entering to a closed system must equal the mass of the fluid exiting, plus any change in the stored mass inside the system.



$$\begin{Bmatrix}\text{Rate of } X \\ \text{into the system}\end{Bmatrix} - \begin{Bmatrix}\text{Rate of } X \\ \text{out of the system}\end{Bmatrix} = \begin{Bmatrix}\text{Rate of accumulation} \\ \text{of } X \text{ in the system}\end{Bmatrix}$$

- ❖ For a system at **steady state**, there will be no accumulation of mass in the system

$$\begin{Bmatrix}\text{Rate of } X \\ \text{into the system}\end{Bmatrix} - \begin{Bmatrix}\text{Rate of } X \\ \text{out of the system}\end{Bmatrix} = 0$$

$$\Sigma\, \dot{m}\ (\text{in}) = \Sigma\, \dot{m}\ (\text{out})$$

When:

$$\dot{m} = \rho \cdot A \cdot V$$

and

$$Q = A \cdot V$$

$$\Sigma\, \rho \cdot A \cdot V\ (\text{in}) = \Sigma\, \rho \cdot A \cdot V\ (\text{out})$$

where:

- $\dot{m}$ = Mass flow rate (Kg/s)
- Q = Flow rate (m^3/s)
- A = Cross-sectional area (m^2)
- V = Average velocity (m/s)
- P = Density (Kg/m^3)

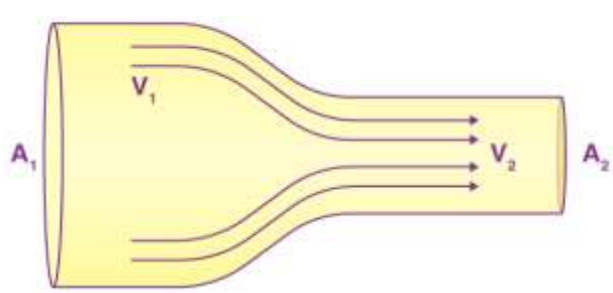
***Example*:**

Water is flowing in a pipe which have two sections as shown in figure:

Section 1: Diameter D_1=0.3 m, velocity V_1= 2 m/s

Section 2: Diameter D_2=0.15 m

Find the velocity V_2 at section 2.



Sol:

$$\Sigma\ \rho\cdot A\cdot V\ (in) = \Sigma\ \rho\cdot A\cdot V\ (out)$$

$$\rho\cdot A\cdot V|_1 = \rho\cdot A\cdot V|_2$$

$A_1 = \frac{\pi}{4} D_1^2 = \frac{\pi}{4}(0.3)^2 = 0.0707\ m^2$

$A_2 = \frac{\pi}{4} D_2^2 = \frac{\pi}{4}(0.15)^2 = 0.0177\ m^2$

When: $\rho 1 = \rho 2$

$$A\cdot V|_1 = A\cdot V|_2$$

$$(0.0707)(2) = (0.0177)V_2$$

$$V_2 = 8\ m/s$$

Home Work: Water is flowing at a velocity of 7 ft/s in both 1 in. and 2 in. ID pipes, which are joined together and fed into a 3 in. ID pipe, as shown in Figure. Determine the water velocity in the 3 in. pipe.