Kinematics of Fluid Flow

Classification of Flow

1. Laminar and Turbulent flow

2. Steady and Unsteady flow

3. Uniform and non-uniform flow

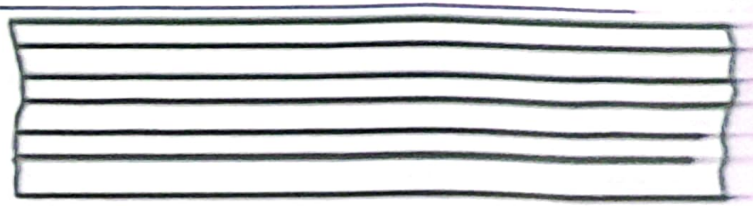
4. One-, Two- or Three dimensional flow

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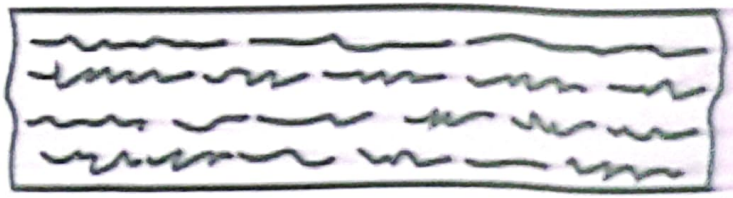
Classification of Flow

Laminar Flow:

- Fluid moves in layers or laminars
- One layer gliding smoothly over an adjacent layer
- Fluid particle moves in parallel paths.



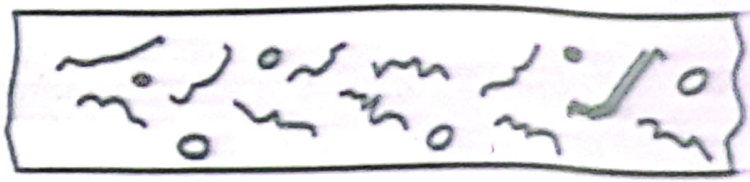
Laminar



Critical Zone

Turbulent Flow:

- Fluid particles move in a erratic, random or haphazard manner



Turbulent

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Classification of Flow: Laminar and Turbulent Flow

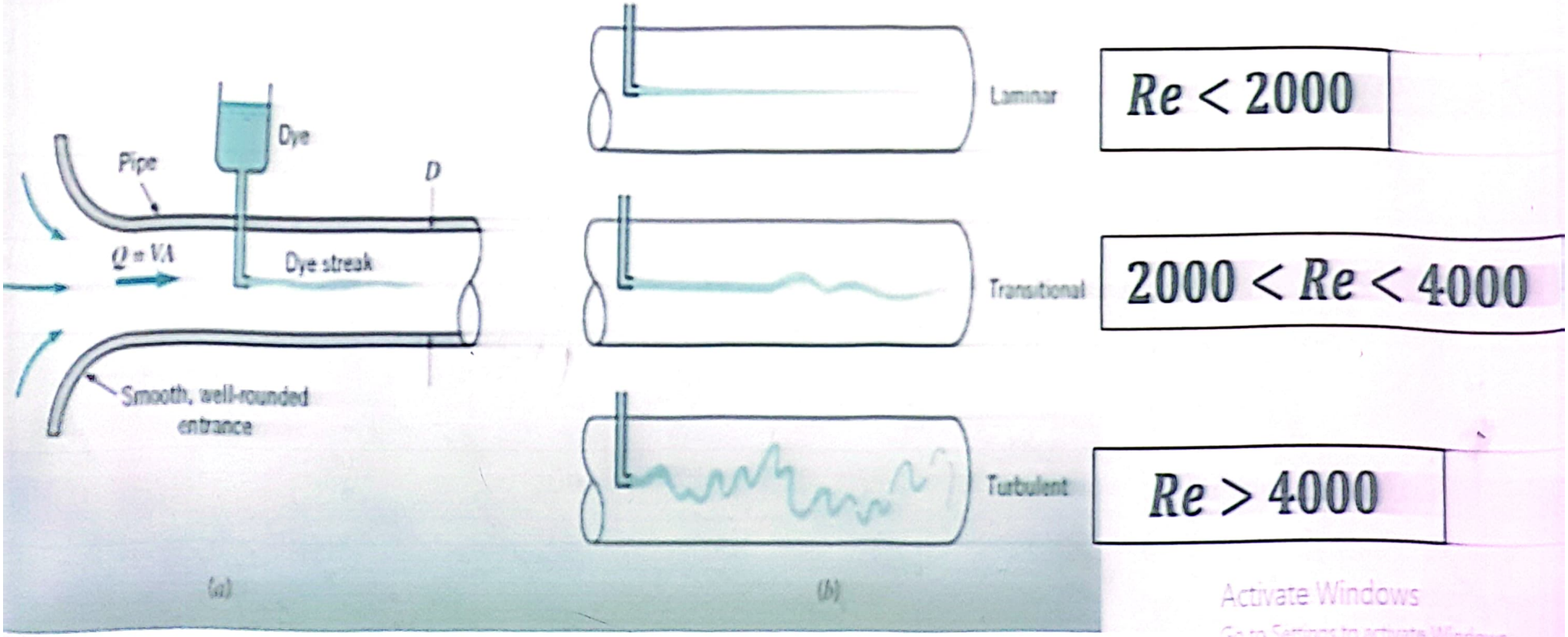
Reynold's Experment (1883), French Engineer Osborne Reynolds

- **At low velocities (small flows), dye filament moved in a straight line** through the tube showing the flow to be **Laminar.**
- **At higher velocities (large flows), dye filament wavered and broke,** eventually diffused throughout the fluid in the tube showing the flow to be **turbulent.**
- There is also a **transitional stage between laminar and turbulent** flows, in which the dye stream will wander about and show intermittent bursts of mixing, followed by a more laminar behavior.
- **Reynolds found** that transition from laminar to turbulent flow in a pipe **depends on: Velocity (V), pipe diameter (D) and viscosity of fluid.**

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Classification of Flow: Laminar and Turbulent Flow

Reynold's Experment (1883), French Engineer Osborne Reynolds



$Re < 2000$

$2000 < Re < 4000$

$Re > 4000$

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Classification of Flow: Laminar and Turbulent Flow

Flow behavior in natural or artificial systems depends on which forces (inertia, viscous, gravity, surface tension, etc.) predominate.

In slow-moving laminar flows, viscous forces are dominant, and the fluid behaves as if the layers are sliding over each other.

In turbulent flows, the flow behavior is chaotic and changes dramatically, since the **inertial forces are more significant** than the viscous forces.

The Reynolds number (*Re*), provides a useful way of characterizing the flow. It is defined as: $R_e = \frac{vd}{\nu}$

where (ν) is the kinematic viscosity of the water, v is the mean flow velocity and d is the diameter of the pipe.

The Reynolds number is a dimensionless parameter that is the ratio of the inertial (destabilizing) force to the viscosity (stabilizing) force.

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Classification of Flow: Laminar and Turbulent Flow

$$\text{REYNOLD'S NUMBER, } R_e = \frac{Inertia\ force}{Viscous\ force} = \frac{m\,a}{\tau A}$$

$$\text{OR, } R_e = \frac{m\,a}{\tau A} = \frac{(\rho L^3)(LT^{-2})}{\left(\mu\frac{du}{dy}\right)(L^2)} = \frac{(\rho L^3)(LT^{-2})}{\left(\mu\frac{LT^{-1}}{L}\right)(L^2)} = \frac{(LT^{-1})L\rho}{\mu}$$

$$\therefore R_e = \frac{VL\rho}{\mu} = \frac{VL}{\mu/\rho} = \frac{VL}{\vartheta}$$

WHERE L = CHARACTERISTIC LENGTH

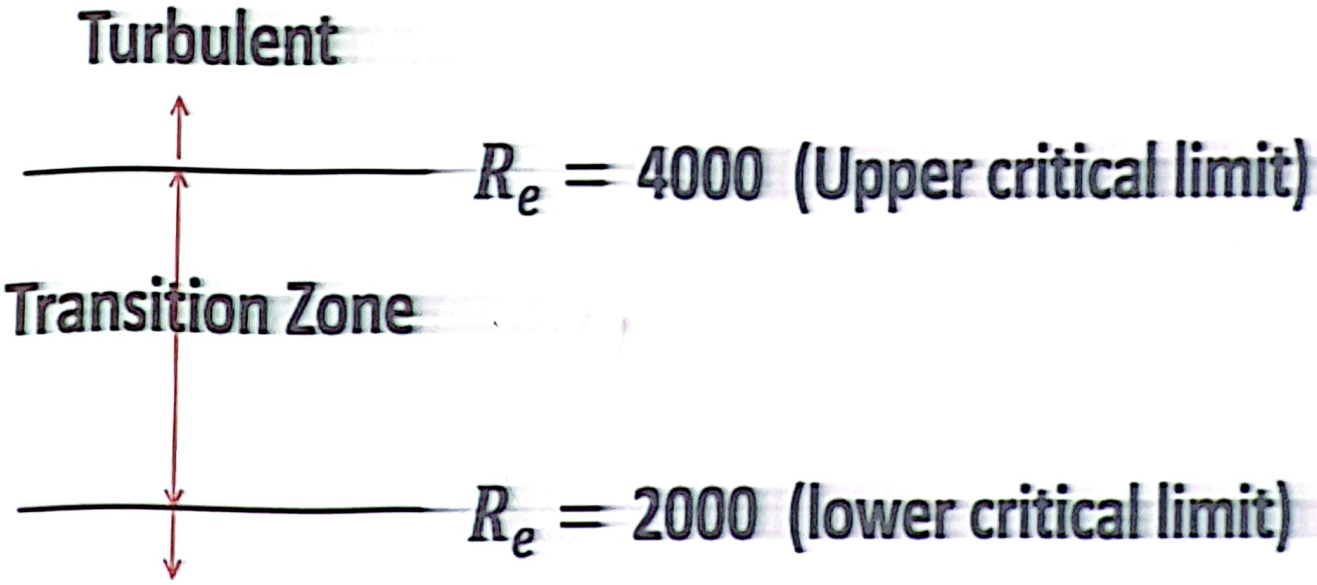
μ = ABSOLUTE OR DYNAMIC VISCOSITY (N.S/M^2)

υ = KINEMATIC VISCOSITY (M^2/S)

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Classification of Flow: Laminar and Turbulent Flow

For practical purposes $R_e = \frac{VD\rho}{\mu}$ (D = diameter of the pipe)



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Classification of Flow: Laminar and Turbulent Flow

REYNOLD'S NUMBER, $R_e = \frac{Inertia\ force}{Viscous\ force} = \frac{m\,a}{\tau A}$, $or, R_e = \frac{vd}{\nu}$

As R_e increases, the inertial force becomes relatively larger, and the flow destabilizes and becomes fully turbulent.

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EXAMPLE 1. Water of kinematic viscosity $1.15 \times 10^{-6} m^2/s$ flows in a circular pipe of 30 mm diameter. Calculate the largest flow rate for which laminar flow can be expected. What s the equivalent flow rate of air? ($\upsilon_{AIR} = 1.37 \times 10^{-5}\ M^2/S$)

Given, $\boldsymbol{v} = 1.15 \times 10^{-6} m^2/s$ and $\boldsymbol{D} = \mathbf{0.03}\ \boldsymbol{m}$

$$\therefore A = \frac{\pi D^2}{4} = 0.0007065\ m^2$$

$$R_e = \frac{vd}{v},\ 2000 = \frac{v \times 0.03}{1.15 \times 10^{-6'}} \therefore v = 0.077\ m/s$$

Flow Rate, $Q = AV = 0.0007065 \times 0.077 = 5.4 \times 10^{-5} m^3/s$

$$\text{Again, } 2000 = \frac{v_{air} \times 0.03}{1.37 \times 10^{-5'}} \therefore v_{air} = 0.91\ m/s$$

$$\therefore Q_{air} = 0.0007065 \times 0.91 = 6.4 \times 10^{-4} m^3/s$$

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EXAMPLE 2. Oil with $\mu = 9.6 \times 10^{-3}\ N.s/m^2$, $s = 0.90$, flows at $4.2\ L/s$ througha pipe of 5 cm diameter. Calculate N_R and classify the flow.

Given, $\mu = 9.6 \times 10^{-3}\ N.s/m^2$, $Q = 4.21\ L/s = 4.21 \times 10^{-3} m^3/s$ and $D = 0.05\ m$,

$$\therefore A = \frac{\pi D^2}{4} = 0.00196\ m^2,$$

we know, $\rho = 900\ Kg/m^3$

$$\therefore v = \frac{Q}{A} = \frac{4.21 \times 10^{-3}}{0.00196} = 2.147\ m/s$$

$$N_R = \frac{2.147 \times 0.05 \times 900}{9.6 \times 10^{-3}} = 10068, \text{ Turbulent flow}$$

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EXAMPLE 3

GIVEN μ = 0.057 N.S/M^2, S = 0.90, D = 75 MM

Q = 350 L/MIN.

IS THE FLOW LAMINAR OR TURBULENT?

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MEKI

Kinematics of Fluid Flow

Steady flow and UnSteady flow

Steady flow is defined as the type of flow in which fluid characteristics like velocity, pressure, density, etc. at a point do not change with time.
Unsteady flow is a type of flow in which the velocity, pressure, and density at a point change with time.

STEADY FLOW: occurs when the condition at any point in the fluid do not change with time.

$$\frac{\partial V}{\partial t}=0, \qquad \frac{\partial \rho}{\partial t}=0, \qquad \frac{\partial T}{\partial t}=0, \qquad \frac{\partial P}{\partial t}=0$$

UNSTEADY FLOW: condition at any point in the fluid change with time.

$$\frac{\partial V}{\partial t}\neq 0$$

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Kinematics of Fluid Flow

Uniform flow and Non-uniform flow

Uniform flow is defined as the type of flow in which the **velocity at any given time has the same magnitude and direction.**

Non-uniform flow is the type of flow in which **velocity changes from time to time** at any given instant of time.

UNIFORM FLOW: Velocity is same at every section at any instant of time.

$$\frac{\partial V}{\partial s} = 0, \text{ where, } s = \text{distance}$$

NON-UNIFORM FLOW: Velocity vector varies from place to place at any instant of time.

$$\frac{\partial V}{\partial s} \neq 0$$

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MEKI

Kinematics of Fluid Flow

Types of Fluid

Newtonian or non – Newtonian Fluid

Newton's Law of Viscosity $\tau = \mu \frac{dV}{dy}$

Where μ **= viscosity of fluid**

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Kinematics of Fluid Flow

Steady uniform flow: Flow through a long pipe at a constant rate.

Unsteady uniform flow: Flow through a long pipe at a changing rate.

Steady non-uniform flow: Flow through a conical pipe at a constant rate.

Unsteady non-uniform flow: Flow through a conical pipe at a changing rate.

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