Lecture No.4 /Fluid Kinematics /2nd Year /Chemical Eng

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Definition Fluid Kinematics: is a branch of "fluid mechanics" which deals with the study of velocity and acceleration of the particles of fluids in motion and their distribution in space without considering any force or energy involved.

Description of Fluid in Motion:

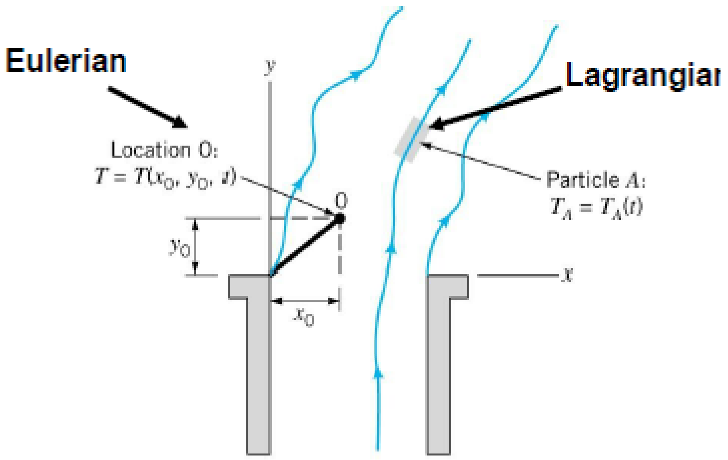
The motion of fluid particles may be described as following:

i. **Langragian method.**
ii. **Eulerian method.**

Langrangian method: following individual fluid particles as they move about and determining how the fluid properties of these particles change as a function of time.

Eulerian: the fluid motion is given by completely describing the necessary properties as a function of space and time. We obtain information about the flow by noting what happens at fixed points.

For ex. As shown in Measurement of Temperature Fig.1



If we have enough information, we can obtain Eulerian from Lagrangian or vice versa.

Eulerian methods are commonly used in fluid experiments or analysis—a probe placed in a flow.

Lagrangian methods can also be used if we “tag” fluid particles in a flow.

Types of Fluid Flow:

Fluids may be classified as follows:

1. **Steady & unsteady flows.**
   Steady flow. The type of flow in which the fluid characteristics like velocity, pressure, density, etc. at a point do not change with time is called *steady flow*, mathematically is given as, $\partial \mathbf{V}/\partial t = 0$

Unsteady flow. It is that type of flow in which the velocity, pressure or density at a point change w.r.t time , mathematically is given as $\frac{dv}{dt} \neq 0$, for ex. The flow in a pipe whose valve is being opened or closed gradually, as shown in Eq., $u = ax^2 + bxt$

2. **Uniform & Non-uniform flows**.

Uniform flow .the type of flow, in which the velocity at any given time does not change with respect to space is called *uniform flow*. mathematically is given as,$\left\{\frac{\delta v}{\delta s}\right\} t = constant = 0$, where $\partial v = change\ in\ velocity, \partial s = dispavement\ in\ any\ direction.$

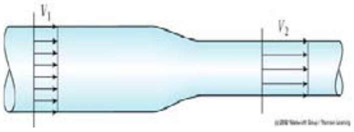
For ex. Flow through a straight pipe of constant diameter.

Non-uniform flow. It is that type flow in which the velocity at any given time change w.r.t space. Mathematically is written as, $\left\{\frac{\delta v}{\delta s}\right\} t = constant \neq 0$

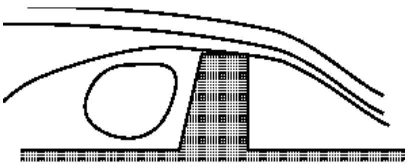
For ex., flow through a non-prismatic conduit, or flow around a uniform diameter pipe-bend or a canal bend.

3. **One, Two & Three Dimensional Flows.**

One dimensional flow. It is that type of flow in which the flow parameter such as velocity is a function of time & one space co-ordinate only, mathematically $uf(x), v = o, \& w = 0,$ where u,v, w are velocity in x,y,z directions respectively., for ex. Flow in a pipe where average flow parameters are considered for analysis, as shown in Fig.



Two dimensional flow. The flow in which the velocity is a function of time and two rectangular space coordinates is called *two-dimensional flow*. Mathematically is, $u = f1\,(x, y), v = f2(x, y), w = 0,$ for ex. Flow between parallel plates of infinite extent, and flow in the main stream of a wide river.



Three dimensional flow. It is that type of flow in which the velocity is a function of time and three mutually perpendicular direction, mathematically, $u = f1\,(x, y, z), v = f2(x, y, z), w = f3(x, y, z),$ for ex. Flow in a converging or diverging pipe or channel.

4. **Rotational & Irrotational flows:**

Rotational flow. A flow is said to be rotational if the fluid particles while moving in the direction of flow rotate about their mass centers. Flow near the solid boundaries is rotational, for ex. Motion of liquid in a rotating tank.

Irrotational flow. A flow is said to be irrotational if the fluid particles while moving in the direction of flow do not rotate about their mass centers. Flow outside the boundary layer is generally considered irrotational.

5. Laminar & Turbulent flows:

Laminar flow. It is also called *viscous or stream flow*. In this type of flow, layers of fluid move relative to each other without any macroscopic intermixing. For ex. Flow through a capillary tube, or ground water flow.

Turbulent flow. It is the most common type of flow that occurs in nature. This flow is characterized by random, erratic, unpredictable motion of fluid particles which result in eddy currents. There is general mixing up of fluid particles, in motion. The velocity changes in direction & magnitude from point to point. For ex. High velocity flow in a conduit of large size.

Note: the velocity of water in a pipe is gradually increased the flow will changes from L to t. flow, this point is called critical velocity.

Reynolds No.: the type of flow that exists in any case depends ypon the value of dimensionless number is called Reynolds No., (N_{Re})

Reynolds find by his experiments as shown in Fig., a dye is injected into the middle of pipe flow of water. The dye streaks will vary, as shown in Fig., depending on the flowrate, or velocity (v or u), density (ρ), viscosity (μ) and tube diameter (d). He found these variables are combined into the Reynolds No., which is dimensionless group as : **<u>(Note: read more notes in Textbook & Exp. Lab.).</u>**

$$\mathrm{Re} \equiv \frac{\rho \bar{V} d}{\mu} \qquad \rho = \text{density},\ \mu = \text{viscosity},\ \bar{V} = \text{section-mean velocity},\ d = \text{diameter of pipe}$$

He found in his experiments, the following characterized of flow on the basis Re. No. as following:

$$Re \begin{cases} < 2100 & laminar\ flow \\ between\ 2100\ and\ 4000 & transition\ flow \\ > 4000 & turbulent\ flow \end{cases}$$

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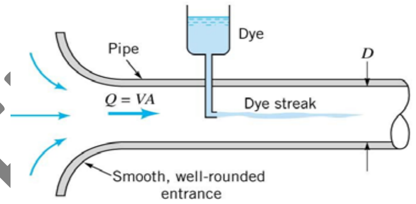
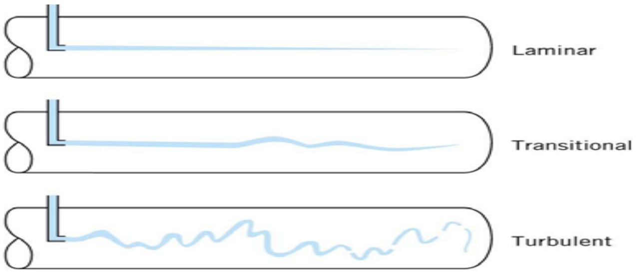




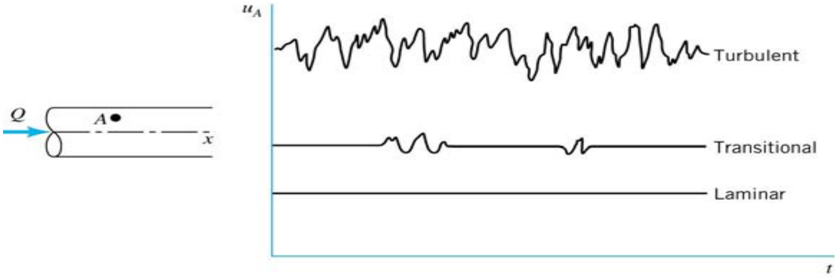


Fig. Time dependence of fluid velocity at a point.

<u>Example:1</u>

Water at 303 K is flowing at the rate of 10 gal/min in a pipe having an inside diameter (ID) of 2.067 in. Calculate the Reynolds number using both English units and SI units.

Solution:

$$\text{flow rate} = \left(10.0\ \frac{\text{gal}}{\text{min}}\right)\left(\frac{1\ \text{ft}^3}{7.481\ \text{gal}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right) = 0.0223\ \text{ft}^3/\text{s}$$

$$\text{pipe diameter, } D = \frac{2.067}{12} = 0.172\ \text{ft}$$

$$\text{cross-sectional area of pipe} = \frac{\pi D^2}{4} = \frac{\pi(0.172)^2}{4} = 0.0233\ \text{ft}^2$$

$$\text{velocity in pipe, } v = \left(0.0223\ \frac{\text{ft}^3}{\text{s}}\right)\left(\frac{1}{0.0233\ \text{ft}^2}\right) = 0.957\ \text{ft/s}$$

For water at 303 K (30°C) ρ=0.996 g/cm^3 & μ=0.8007cp

$$\text{density, } \rho = 0.996(62.43)\ \text{lb}_m/\text{ft}^3$$

$$\text{viscosity, } \mu = (0.8007\ \text{cp})\left(6.7197 \times 10^{-4}\ \frac{\text{lb}_m/\text{ft}\cdot\text{s}}{\text{cp}}\right)$$

$$= 5.38 \times 10^{-4}\ \text{lb}_m/\text{ft}\cdot\text{s}$$

$$N_{\text{Re}} = \frac{Dv\rho}{\mu} = \frac{(0.172\ \text{ft})(0.957\ \text{ft/s})(0.996 \times 62.43\ \text{lb}_m/\text{ft}^3)}{5.38 \times 10^{-4}\ \text{lb}_m/\text{ft}\cdot\text{s}}$$

$$= 1.905 \times 10^4$$

Hence, the flow is turbulent. Using SI units,

$$\rho = (0.996)(100\ \text{kg/m}^3) = 996\ \text{kg/m}^3$$

$$D = (2.067\ \text{in.})(1\ \text{ft}/12\ \text{in.})(1\ \text{m}/3.2808\ \text{ft}) = 0.0525\ \text{m}$$

$$v = \left(0.957\ \frac{\text{ft}}{\text{s}}\right)(1\ \text{m}/3.2808\ \text{ft}) = 0.2917\ \text{m/s}$$

$$\mu = (0.8007\ \text{cp})\left(1 \times 10^{-3}\ \frac{\text{kg/m}\cdot\text{s}}{\text{cp}}\right) = 8.007 \times 10^{-4}\ \frac{\text{kg}}{\text{m}\cdot\text{s}}$$

$$= 8.007 \times 10^{-4}\ \text{Pa}\cdot\text{s}$$

$$N_{\text{Re}} = \frac{Dv\rho}{\mu} = \frac{(0.0525\ \text{m})(0.2917\ \text{m/s})(996\ \text{kg/m}^3)}{8.007 \times 10^{-4}\ \text{kg/m}\cdot\text{s}} = 1.905 \times 10^4$$

6. **Incompressible & Compressible flow:**

   Incompressible flow. When pressure changes in pipe is less than 10% , then the volume of an element of fluid is independent of its pressure and temperature, the properties can be considered as constant or taken as average value, then the fluid is called, *incompressible fluid*, for ex. Liquids or water.

Compressible flow. When pressure changes in pipe is greater than 10% then the volume of an element of fluid is dependent of its pressure and temperature, the properties cannot be considered as constant such as density, then the fluid is called compressible fluid. For ex all gases.

Ideal Fluid: it is frictionless and incompressible fluid or inviscid flow or nonviscous flow and its flow processes are reversible.

Real Fluid: the actual fluid in practice is viscous, and causes force friction with solid boundary.

Boundary-Layer: The layer of fluid in the immediate neighbourhood od an actual flow boundary that has its velocity relative to the boundary affected by viscous shear is *called the boundary layer (B-L).* The B-L may be laminar or turbulent, depending generally upon their Length, viscosity, the velocity of the flow near them, and the boundary roughness, as shown in Fig.

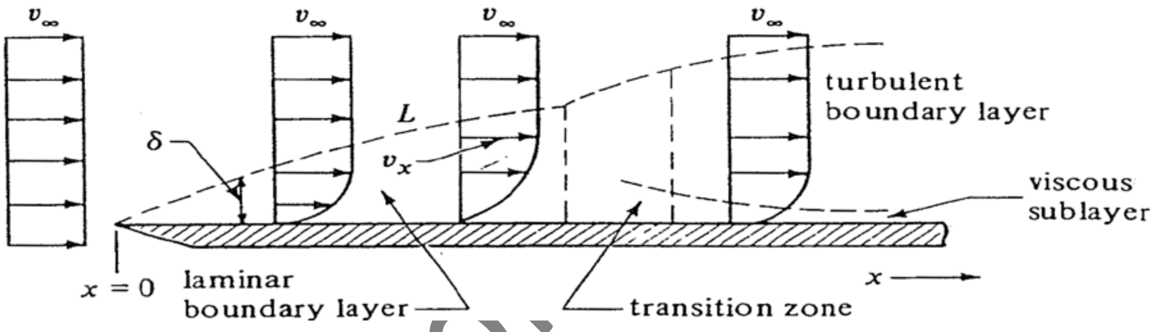


Fig. Boundary layer for flow past a flat plate.

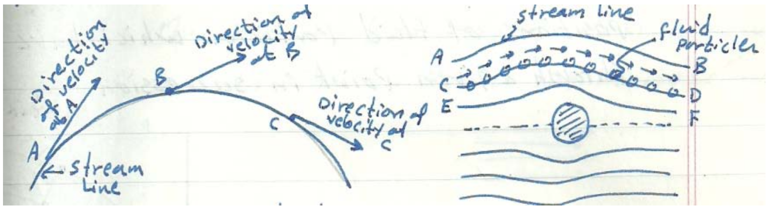
Types of Flow Lines or Flow Visualization:

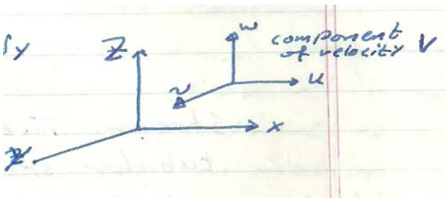
There are four different types of flow lines that may be help to describe a flow field:

i. Stream line
ii. Streak line
iii. Path line
iv. Time line

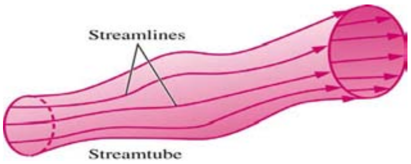
Stream Line: A stream line is a continuous line in a fluid which shows the direction of the velocity of the fluid at each point along the line, as shown in Fig.

if v the resultant velocity at any point in space in a fluid body, then the time taken by the particle to describe the distance ds is given as: dt=ds/v



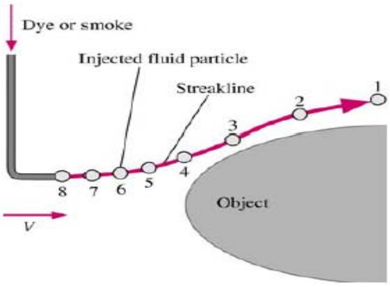


dt=$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w}$

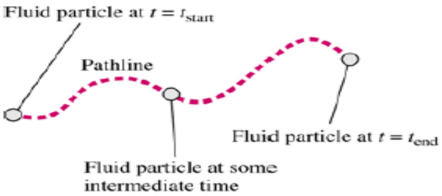


thus, the differential Eqn. of stream line is given by:$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w}$

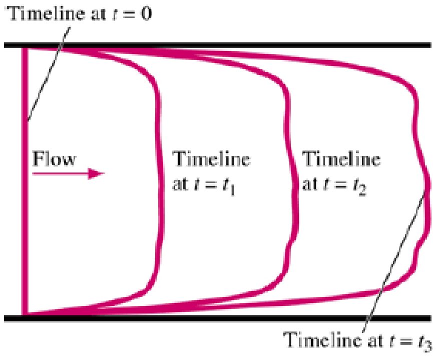
Streak line: The streak line is the locus of the positions of fluid particles which have passed through a given point in succession. As shown in Fig.



Path line: A path line means the path or a line actually described by a single fluid particles as it move during a period time, as shown in Fig.



Time line: A set of adjacent fluid particles that were marked at the same (earlier) instant in time. Timelines are particularly useful in situations where the uniformity of a flow (or lack thereof) is to be examined. As shown in Fig.



<u>**Note:**</u> For steady flow, streamlines, streak lines, and path lines are all identical. However, for unsteady flow, these three flow patterns can be quite different. In a steady flow, all particles passing a given point will continue to trace out the same path since nothing changes with time; hence the path lines and streak lines coincide. In addition, the velocity vector of a particle at a given point will be tangent to the line that the particle is moving along; thus the line is also a streamline.

Ex.2

Reynolds Number for Milk Flow. Whole milk at 293 K having a density of 1030 kg/m^3 and viscosity of 2.12 cp is flowing at the rate of 0.605 kg/s in a glass pipe having a diameter of 63.5 mm.

(a) Calculate the Reynolds number. Is this turbulent flow?
(b) Calculate the flow rate needed in m^3/s for a Reynolds number of 2100 and the velocity in m/s.

Ans. (a) $N_{Re} = 5723$, turbulent flow

Ex.3

Pipe Diameter and Reynolds Number. An oil is being pumped inside a 10.0-mm-diameter pipe at a Reynolds number of 2100. The oil density is 855 kg/m^3 and the viscosity is 2.1×10^{-2} Pa · s.
(a) What is the velocity in the pipe?
(b) It is desired to maintain the same Reynolds number of 2100 and the same velocity as in part (a) using a second fluid with a density of 925 kg/m^3 and a viscosity of 1.5×10^{-2} Pa · s. What pipe diameter should be used?