Chemical Engineering Fluid Dynamics and Heat Transfer
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Lecture - 02
Kinematics - 02

So, welcome back to the second lecture. In the last class we have talked about the flow field and the fluid particle.

Flow field: Region of space where at each point the velocity at any instance of time is known. It can be viewed as a collection of large number of particles, velocity of each is defined.

Fluid particle is hypothetical concept. Its collection of fluid molecules surrounded by an impermeable, but a flexible boundary. We know that fluid as a continuum. So, fluid particles can deform, though we consider that in a flow field there are infinite number of particles there is actually no space between them so, therefore, the concept of fluid particles in no way violates the concept of fluid as a continuum.

Method of description: Mainly two types of description

Lagrangian method: kinematic behaviour of each particle in a flow field is tracked, and a particle is identified by its initial position in space and time. So, we can write as

$$\vec{S} = S(\vec{S}_0, t)$$

$\vec{S}$ → Position vector of the particle at time t

$\vec{S}_0$ →intial position of the same particle at time $t=t_0$.and it is going to be different for every particle.

For cartesian coordinate system,

$x = (x_0, y_{0,} z_0, t): y = (x_0, y_{0,} z_0, t): z = (x_0, y_{0,} z_0, t)$

$\vec{S} = \hat{\imath}x + \hat{\jmath}y + \hat{k}z.$

Eulerian method: Instead of tracking the motion of each particle within the flow field, in this approach we seek the velocity and its variation at each and every location within the flow field. In this approach we are looking at a particular location, and we are tracking the variation of velocity with time. In the Lagrangian approach all hydrodynamic parameters are tagged to a particle or a fluid element in Eulerian approach they are tagged to a specific location.

Next, we are going to discuss about the types of flow:

1, Based on flow conditions (time dependence):it can be steady or unsteady flow

If at a particular location, the velocity does not change with time that is a steady flow. If it is unsteady, the velocity can change with time.

2.Based on flow geometry: Uniform or non-uniform flow.

3.Based on flow conditions: Laminar or turbulent.

If the Reynolds number less than 2100 for a pipe flow, then it is laminar and if it is greater than 4000, this is turbulent for a pipe flow. Functional form of Reynolds number for an internal flow:

$$N_{Re} = \frac{Dv\rho}{\mu}$$

$D \rightarrow diameter$

$v \rightarrow linear\ velcoity$

$\mu \rightarrow viscosity$

$\rho \rightarrow density$

4.Based on fluid property: Compressible or incompressible flow

So, if it is a compressible flow, then $\rho = f(x, yx, z, t)$ and that means density can vary as a function of coordinates or as a function of time and if it is an incompressible flow $\rho \neq f(x, yx, z, t)$.it is not a function of x, y, z and t. So, that means ρ is constant. Liquids are mostly incompressible. That means effect of pressure on the fluid is negligible, therefore density does not change.

5.Based on fluid Rheology: Newtonian fluid or non-Newtonian fluid

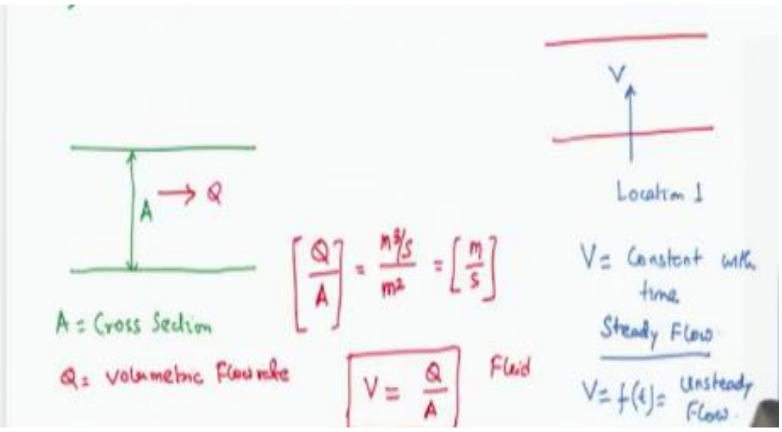
Now let us have a discussion in detail about uniform and non-uniform flow.

Case1:

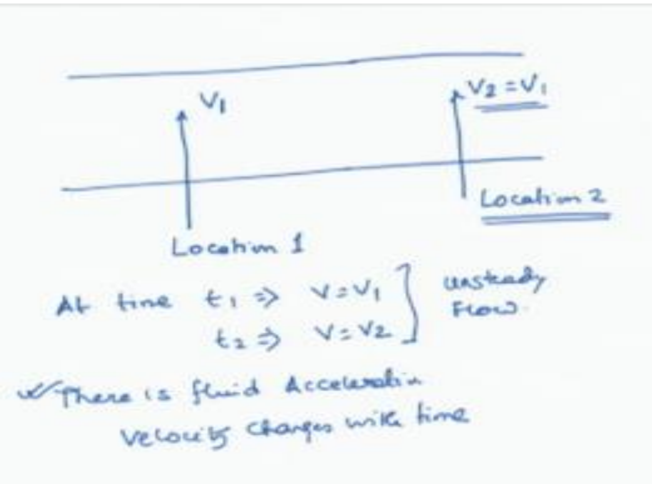
For that consider a pipe of uniform cross-sectional area A and diameter D with volumetric flow rate of Q.

$$\frac{Q}{A} = \frac{m^3/s}{m^2} = \frac{m}{s}$$

So, we can say that linear velocity of the fluid, $V = \frac{Q}{A}$



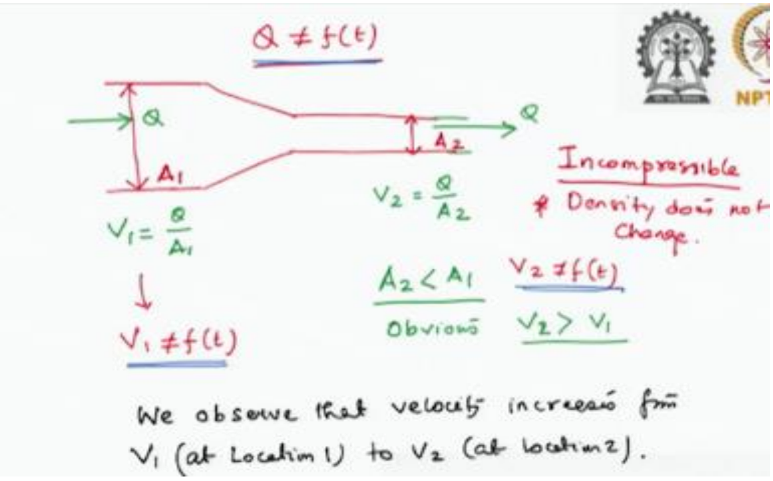
In a pipe flow at a particular location if V remain constant with time, that is a steady flow. And if V changes with time or V varies as function of time, then its unsteady flow.



In this figure, at location1, at time $t_1 \rightarrow v = v_1$ and at time $t_2 \rightarrow v = v_2$. So, we can say that this is an unsteady flow and there is fluid acceleration as the velocity changes with time.

Case2:

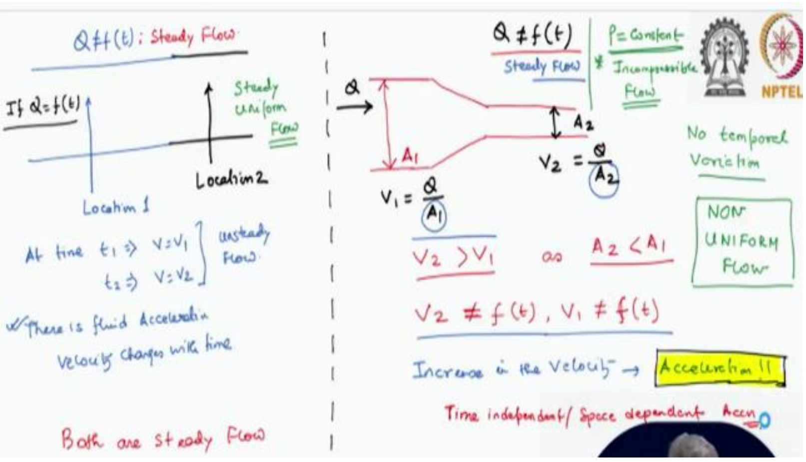
Next,consider flow of incompressible fluid through a pipe of non uniform cross sectional area .Q is the volumetric flow rate and Q is considered to be constant over time .



As the cross section at location 1(A_1) is higher than the cross section at location 2(A_2), Since the flow rate is constant there will be an increase in the velocity at location 2. So, we observe that velocity increases from V_1 at location 1 to V_2 at location 2. So, this increase in the velocity causes the acceleration. But the velocities V_1 and V_2 are both independent of time. This satisfies the condition of steady flow.

Both situations are examples for steady flow and in the first case the velocity not only does not change with time, but also does not depend on the spatial coordinate of the observer or the probe. Since the cross section of the pipe is same, at any location the velocity will be same. So, this is called uniform flow. So, the first case will be an example for steady uniform flow.

In the second case, there is no temporal variation or time dependent variation of velocity, but the velocity changes as a function of space or the location of the observer. So, this is an example of non-uniform flow.



In second case, here you have a steady flow that is the velocity is time independent, but the velocity changes, as it is increasing from location 1 to location 2. So, there is a non-time dependent acceleration or space dependent acceleration. We will discuss about this time dependent acceleration or space dependent acceleration in the next class.

Thank you.