Fluid Mechanics

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Lecturer (10): Fundamental of fluid flow

Classifications of fluid

1. Steady or unsteady
2. Uniform or non uniform
3. Laminar or turbulent
4. One dimension, two dimension or three dimension
5. Rotational or irrational

Steady or unsteady

A flow whose properties like velocity, pressure, density, etc. at a point do not change with time is called steady flow: if any property of the flow changes with time it is called unsteady flow.

Steady flow : Local derivatives ($\partial\ /\partial t$) are zero in a flow field. (velocity, pressure, density, etc.) Properties at a fixed point do not change in time.

Unsteady flow : Local derivatives of properties are nonzero. Properties at a fixed point change in time.

Mathematically, we have:

FOR STEADY FLOW

$(\partial V / \partial t)_{xo, yo, zo} = 0;$

$(\partial P / \partial t)_{xo, yo, zo} = 0;$

$(\partial \rho / \partial t)_{xo, yo, zo} = 0$

FOR UNSTEADY FLOW

$(\partial V / \partial t)_{xo, yo, zo} \neq 0;$

$(\partial P / \partial t)_{xo, yo, zo} \neq 0;$

$(\partial \rho / \partial t)_{xo, yo, zo} \neq 0$

where

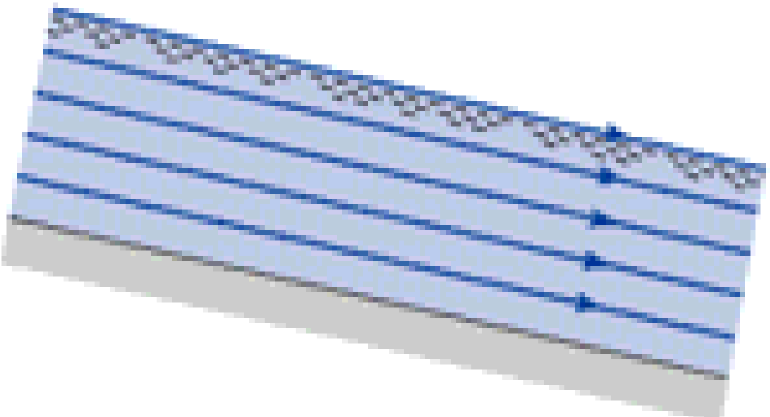
V is the velocity,

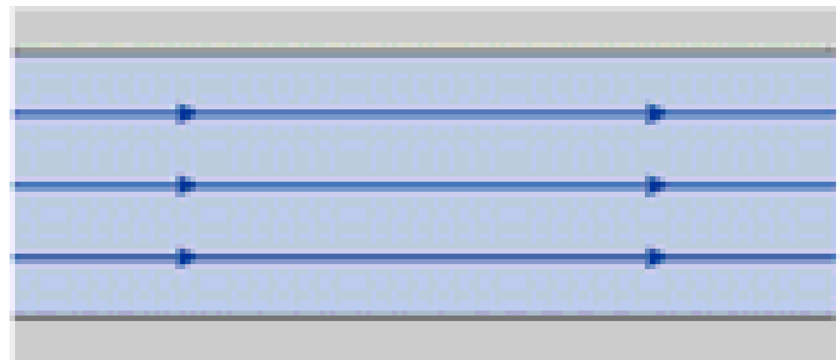
P is the pressure,

ρ is the density

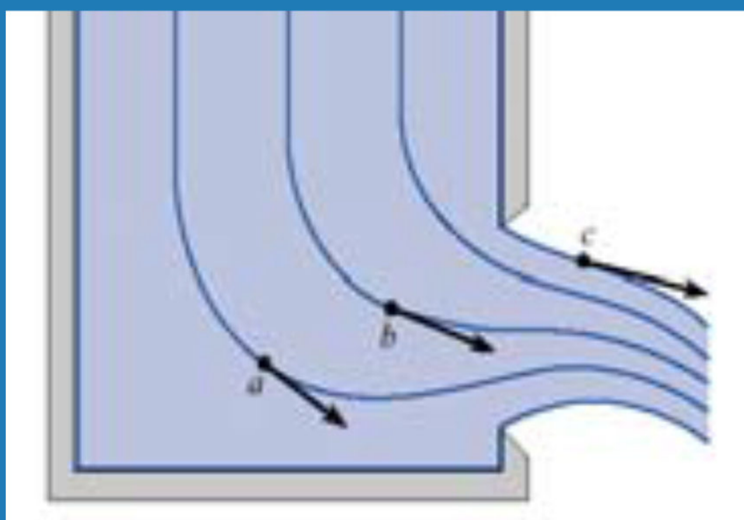
Uniform & non uniform

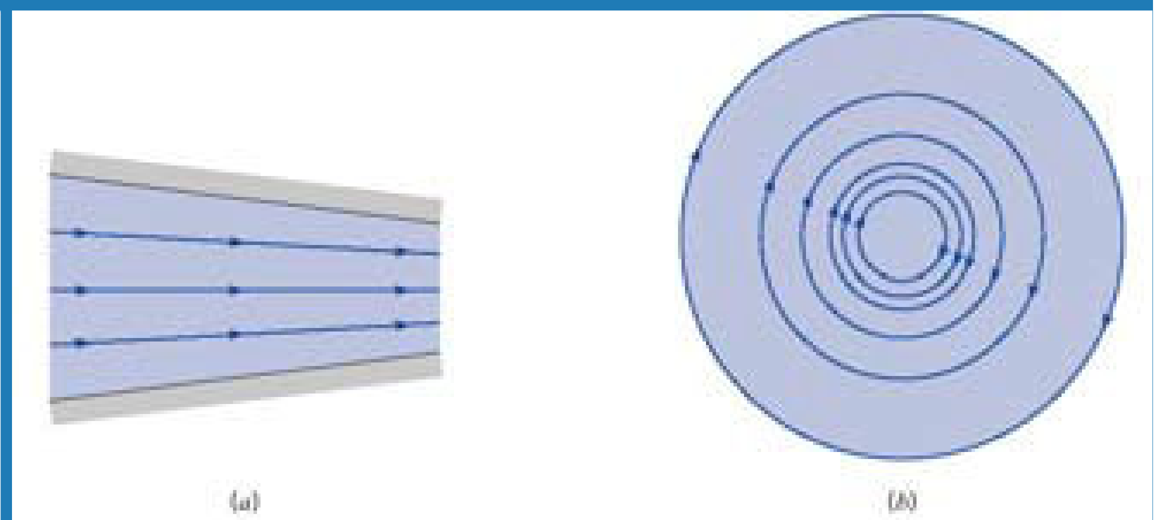
Uniform





Non Uniform





Uniform & non uniform

Uniformity means the way in which the properties, at any given time, change with *position*.

If for example, the velocity doesn't change within a particular zone, then the velocity is said to be uniform. If the velocity changes from place to place, then it is non-uniform.

***Uniform flow* occurs when the magnitude and direction of the velocity, at any given time, do not change from point to point in the fluid. This statement implies that other variables do not change with distance.**

***Non-uniform flow* occurs when velocity, depth, pressure,…… etc, at any given time, change from point to point in the fluid flow.**

Uniform & non uniform

Mathematically this can be expressed as:

$(\partial V / \partial s)_{t = constant} = 0$ for uniform flow

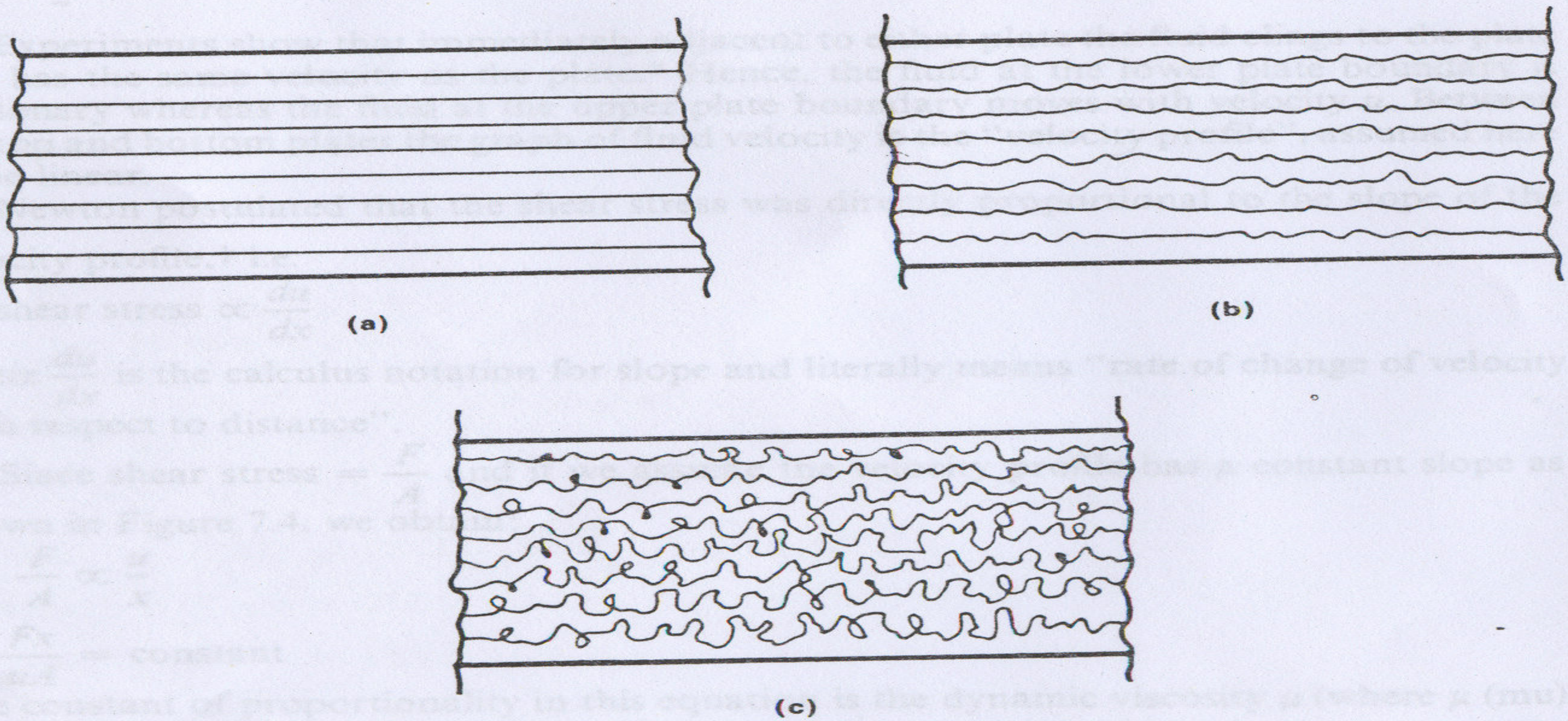
& $(\partial V / \partial s)_{t = constant} \neq 0$ for non - uniform flow

Where:

∂V the change in velocity

∂s is the displacement in any direction.

LAMINAR OR TURBULENT



Laminar or turbulent

In *laminar flow,* the fluid particles move along straight parallel paths in layers. The magnitudes of the velocities of adjacent layer are not the same. This type of flow is called stream-line flow or *viscous flow.*

Example: Flow through a capillary tube, flow a blood in veins and arteries, and groundwater flow.

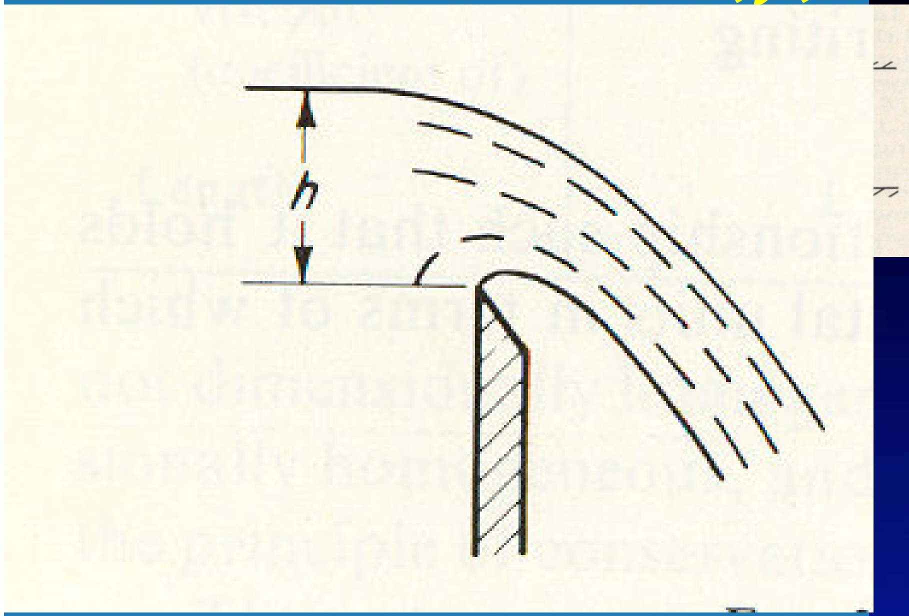
In *turbulent flow* the particles of the fluid move on a random fashion in all directions. It is impossible to trace the motion for an individual particle.

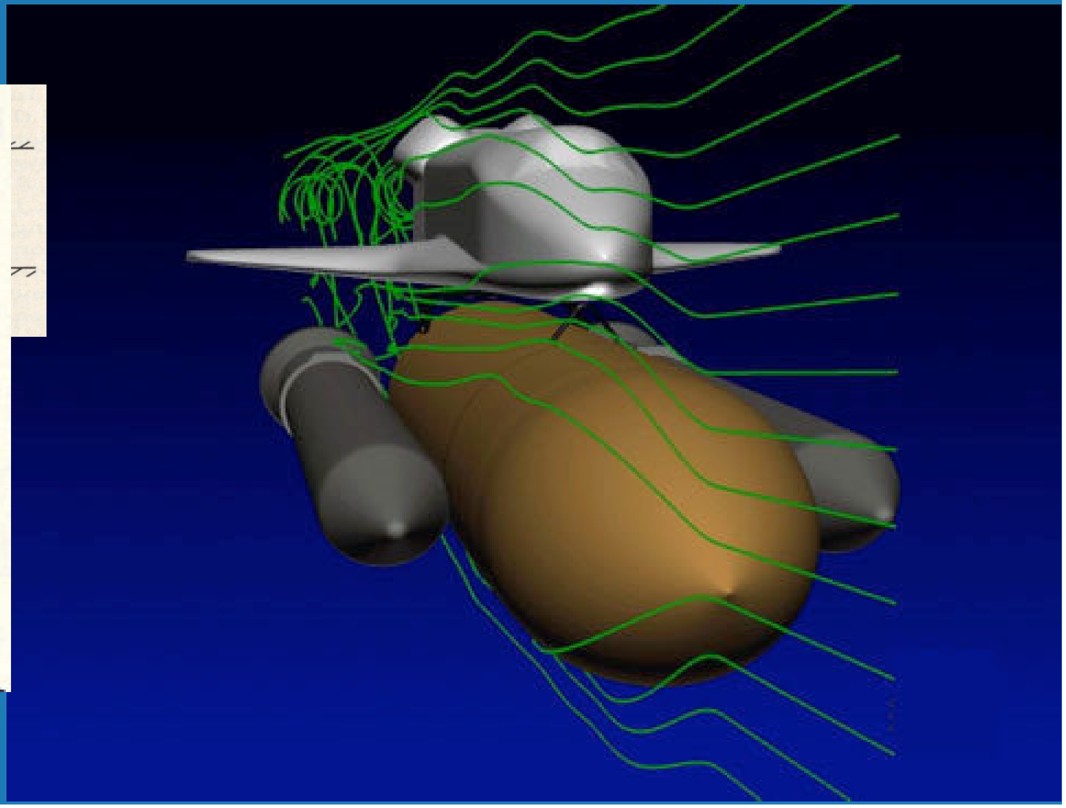
Nearly all fluid flow problems encountered in engineering practice have a turbulent character

Flow Classification as 1D, 2D and 3D

Depends on the number of space coordinates (x,y,z) required to specify the velocity field.

- **1D Flow :** V=Vx **or** V=Vy **or** V=Vz
- **2D Flow :** V=Vx,y **or** V=Vx,z **or** V=Vy,z
- **3D Flow :** V=Vx,y,z





Rotational or irrational

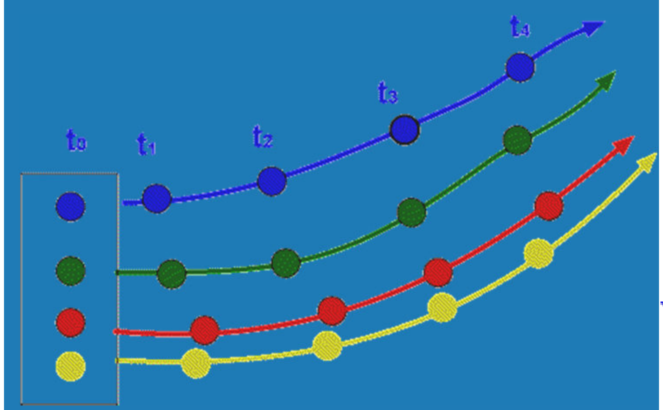
If the fluid particles within a flow have rotation about any axis, the flow is called *rotational* and if they do not suffer rotation, the flow is in *Irrational* motion.

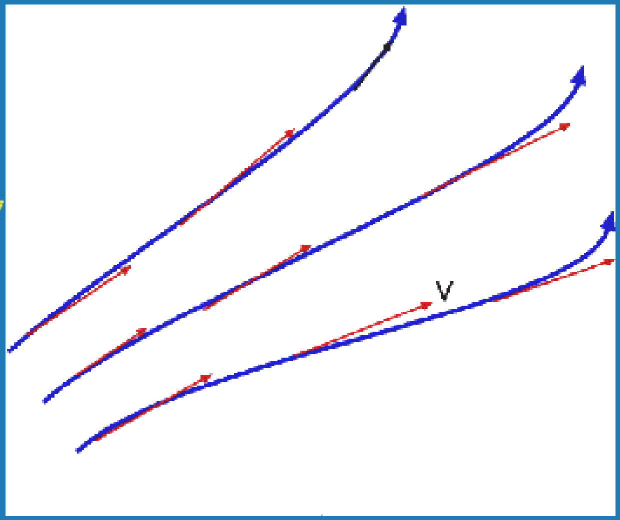
Streamlines

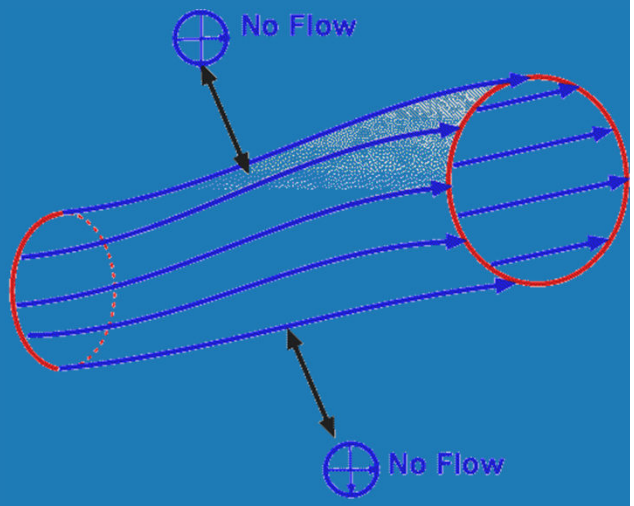
Path lines: trace made by a single particle over a period of time

Streamlines: Curve that is tangent to the direction of velocity at every point on the curve

Stream tubes: In 2-dimensional space, this is the area between two streamlines. It resembles a tube or passageway.





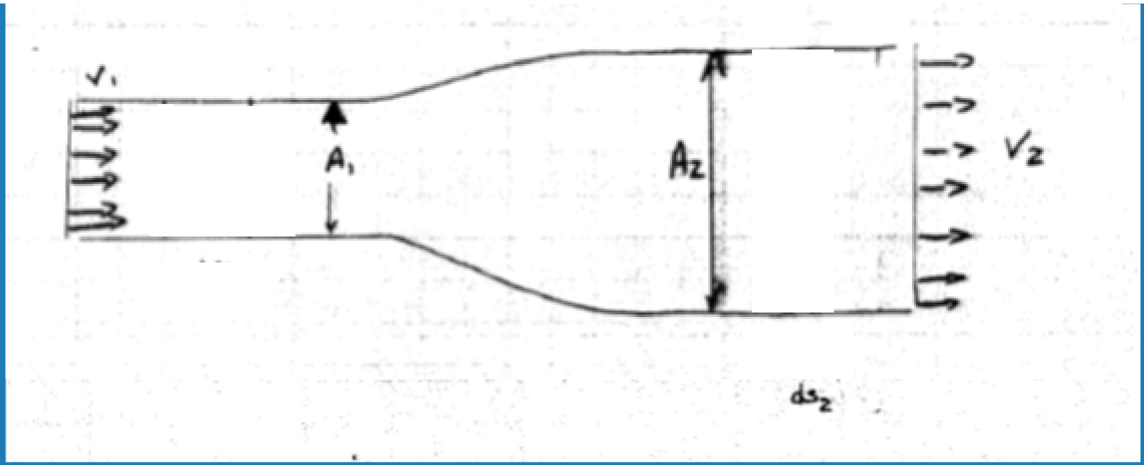


For Steady Flow, a path line and a streamline are identical

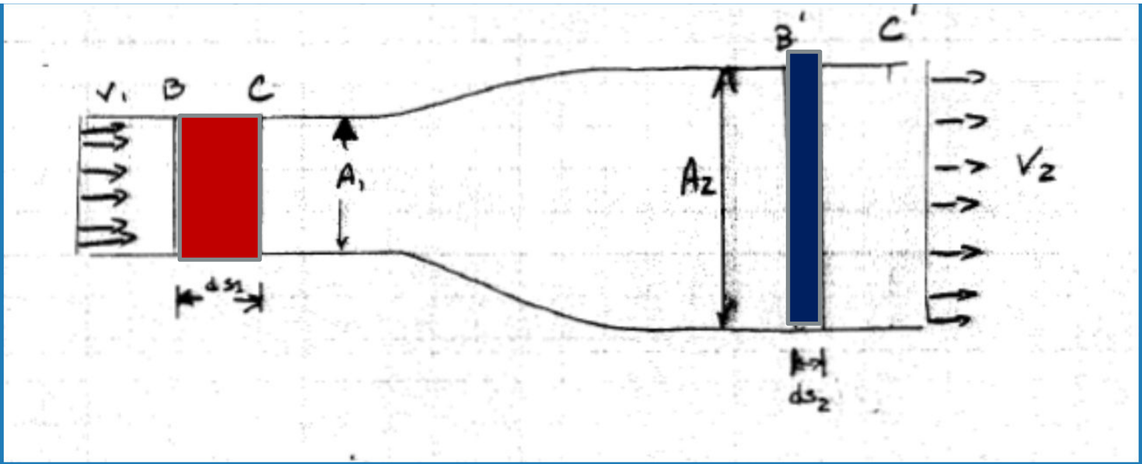
Continuity Equation

Matter can neither be created nor destroyed is the principle of conservation of mass

Application of the conservation of mass to steady flow in the stream tube results in the Equation of Continuity



- In a small interval of time, Δt, fluid at the beginning of the pipe moves Δs_1, which $\Delta s_1 = v_1 \Delta t$, where v_1 is velocity in the area of pipe that has a cross sectional area = A_1
- If A_1 is the cross sectional area of the beginning of the pipe. The mass contained in the red area is $M_1 = \rho_1 A_1 \Delta S_1 = \rho_1 A_1 v_1 \Delta t$ where ρ is the density of the fluid
- Similarly, the fluid moving through the enlarged section of pipe in Δt time has a mass equal to $M_2 = \rho_2 A_2 \Delta S_2 = \rho_2 A_2 v_2 \Delta t$.



- Because mass is conserved and the flow is steady, the mass that crosses A_1 in Δt is the same as the mass that crosses A_2 in Δt or $M1 = M_2$. Or: $\rho_1 A_1 v_1 \Delta t = \rho_2 A_2 v_2 \Delta t$

Δt is constant

$\rho_1 = \rho_2$

- For a steady flow in an incompressible fluid, ρ is constant.

$A_1 v_1 = A_2 v_2 = Q$ where Q=Flow rate

Continuity equation can be applied to steady flow, compressible or non compressible flow within fixed boundaries (Q) = $A_1 v_1 = A_2 v_2$

(Q) = A1v1= A2v2

Therefore, for fluids of constant density it is seen that along a stream tube the product of velocity and cross-section area is constant.

This product AV ,Q, is the quantity **(volume measure)** of fluid which passes a reference point per unit time and is called the ***flow rate or discharge*** and has the dimensions L^3/T .

Units of discharge commonly used are cubic meters per second (cubic feet per sec.), gallons per minute (gpm) and million gallons per day (mgd) can also be used in water supply works.

1 Gallon [Fluid, US] = 3785.411784 Cubic Centimeters

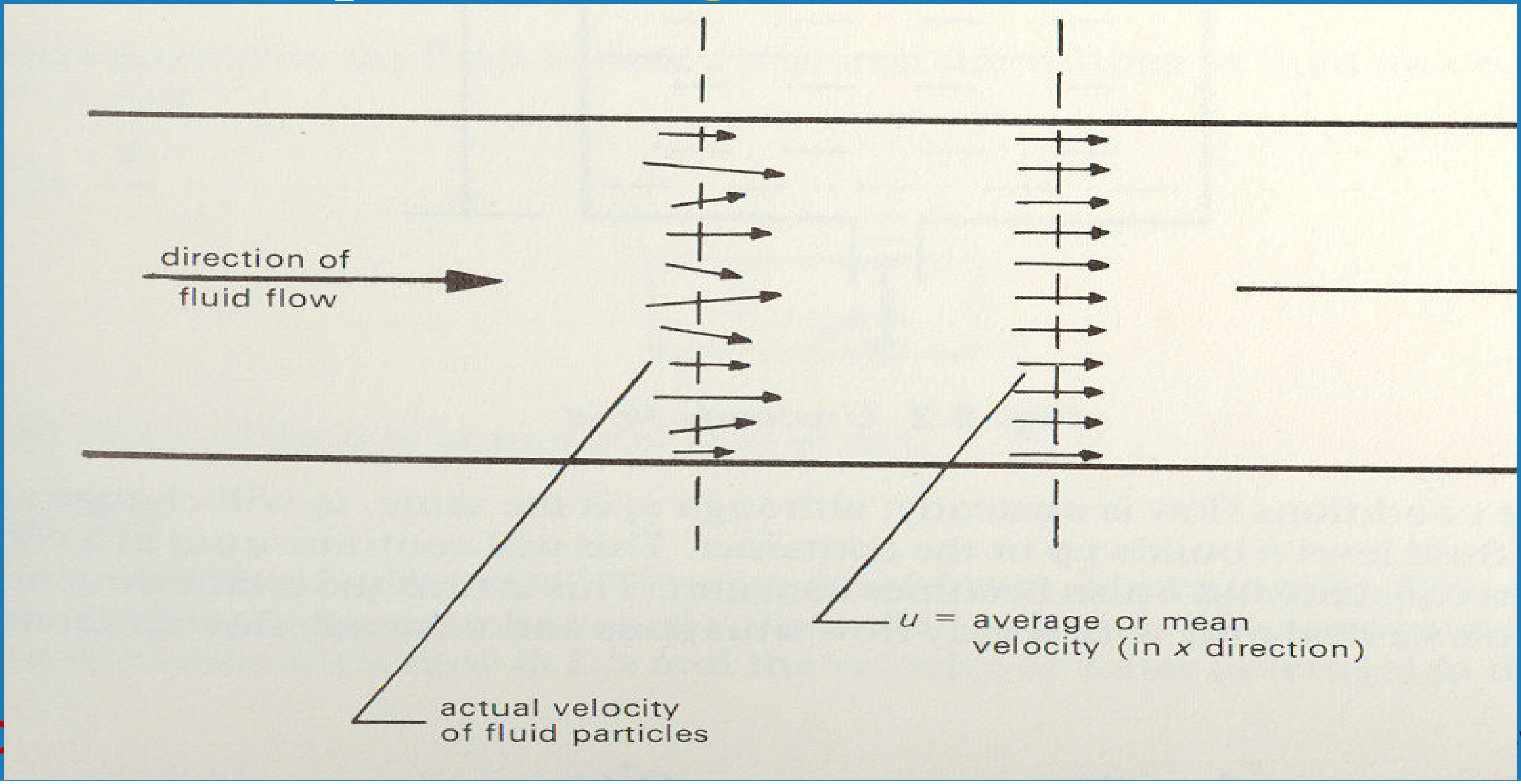
1 Gallon [Dry, US] = 4404.8838 Cubic Centimeters

1 Gallon [UK] = 4546.09 Cubic Centimeters

(Q) = $\rho 1$ A1v1= $\rho 2$ A2v2

Mass flow rate **is the quantity (mass measure) ρ A V of fluid which passes the reference point per unit time; the units are expressed in kg/s.**

Weight flow rate **is the quantity (weight measure) γ A V of fluid which passes the reference point per unit time; the units are expressed in kg/s or N/s.**



Thank you