FLUID MECHANICS AND HYDRAULIC MACHINERIES

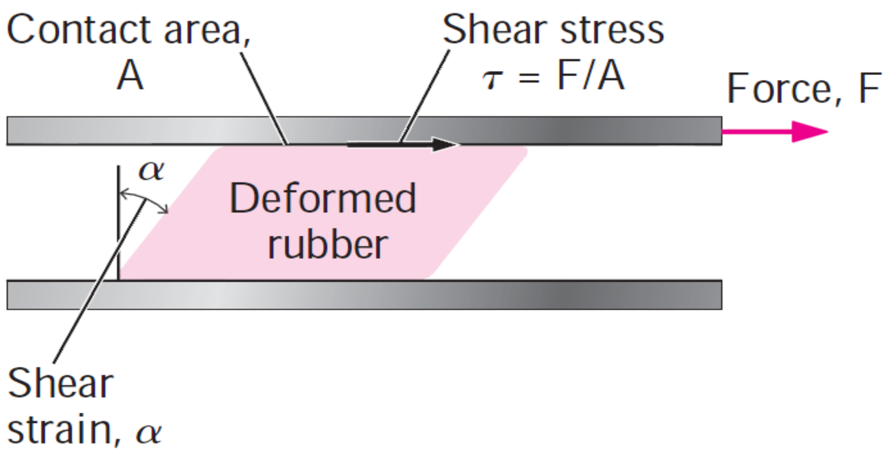
ENGG 111

Fluid

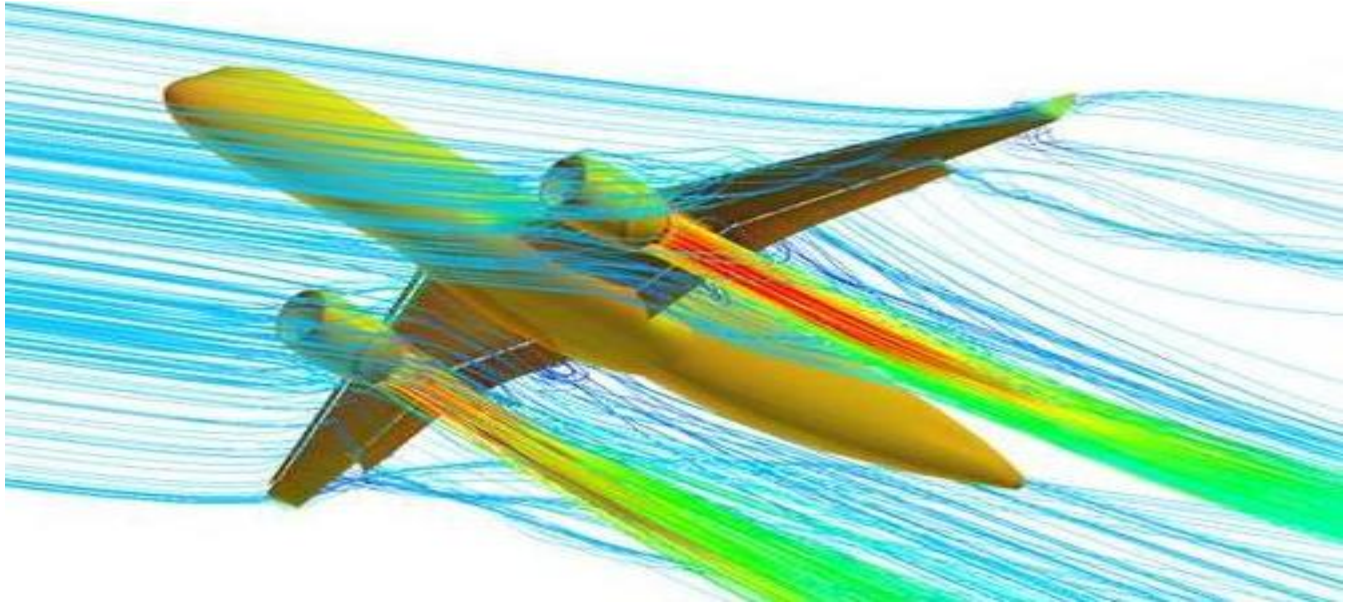
Fluid deforms continuously under the influence of a shear stress

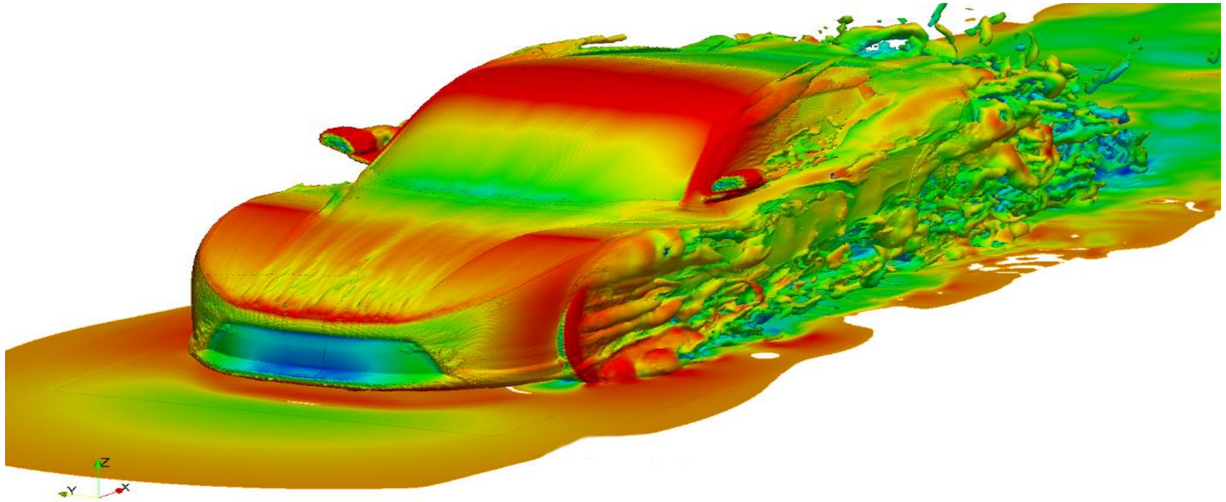
In solids, stress is proportional to strain, but in fluids, stress is proportional to strain rate

When a constant shear force is applied, a solid eventually stops deforming at some fixed strain angle, whereas a fluid never stops deforming and approaches a constant rate of strain.

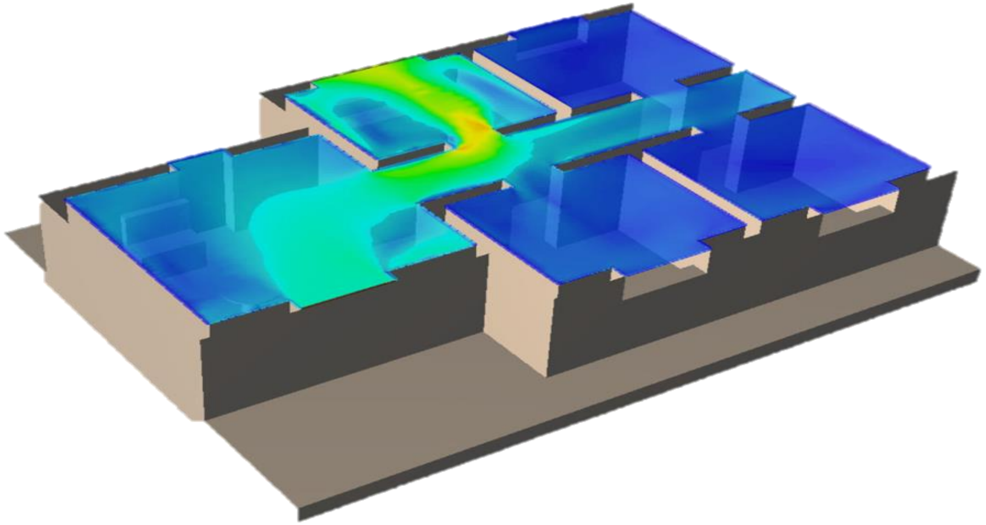


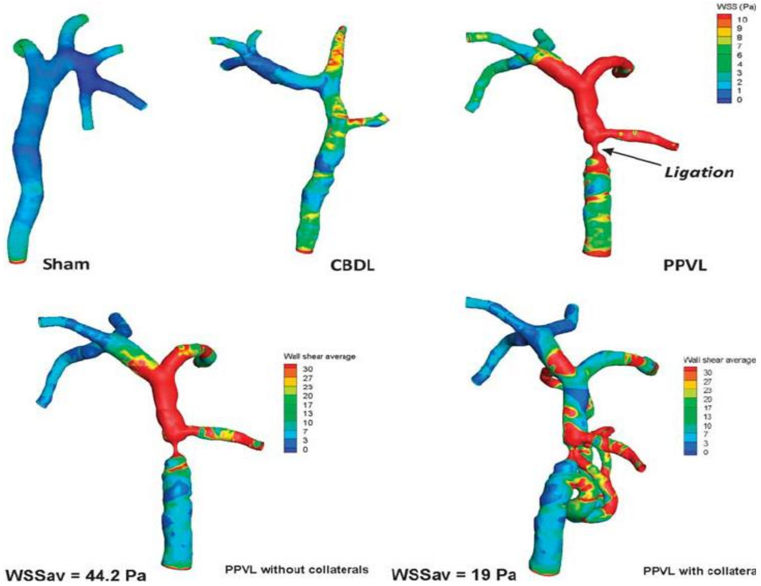
Applications of Fluid Mechanics

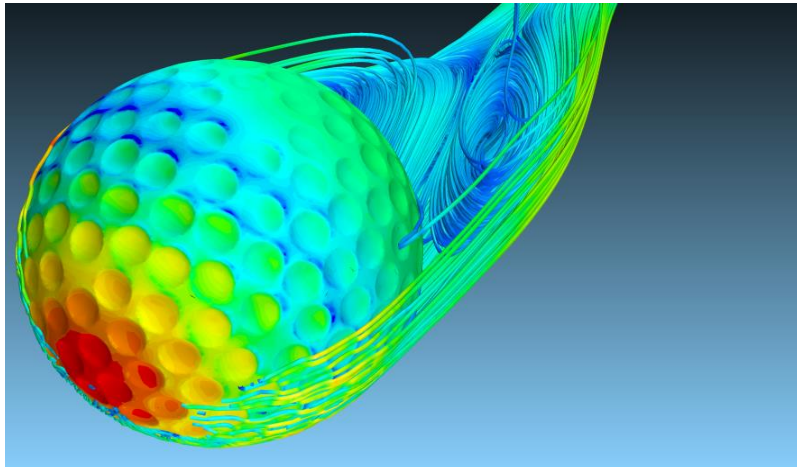




Applications of Fluid Mechanics

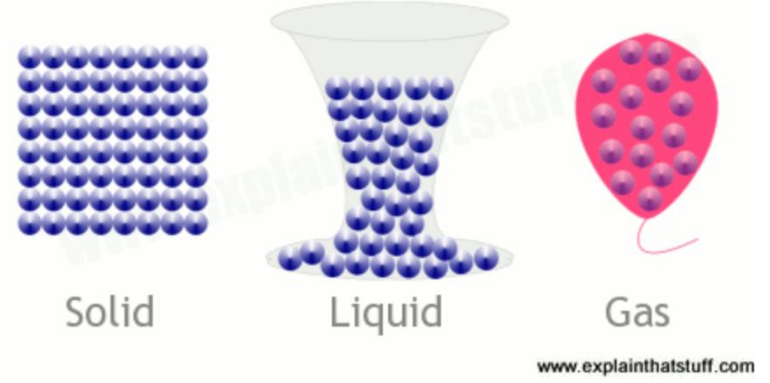


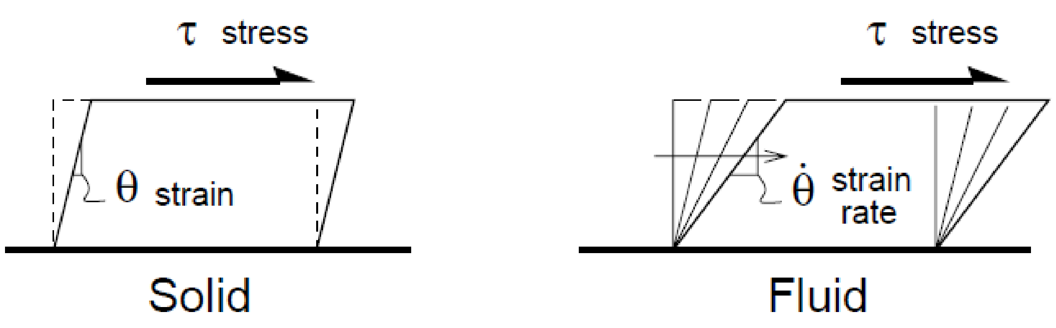




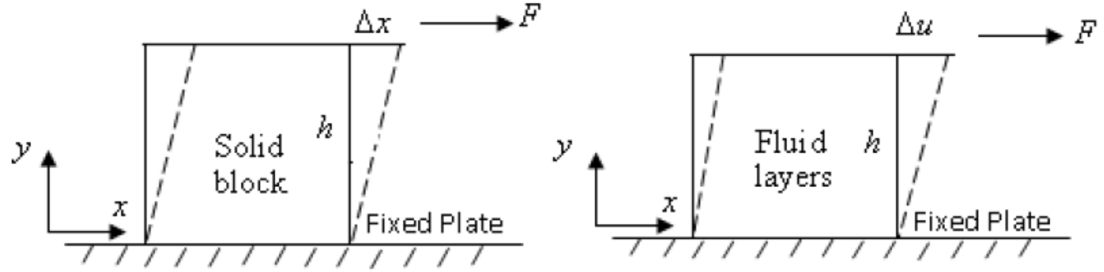
Solid, liquid and gas

- In **solids**, atoms are bonded fairly firmly together, though they do move about a bit. They have fixed shape.
- In **liquids**, the atoms are more randomly arranged and a little bit further apart (but not all that much). The forces between them are weaker and they can jiggle about and flow past one another quite easily.
- **Gases** have much more randomly arranged atoms than either liquids or solids. The forces between the atoms are very weak, so the atoms can speed around freely with lots of energy.





- Applied tangential force/area (or shear stress) produces a proportional deformation angle (or strain) θ.
- Applied shear stress produces a proportional continuously-increasing deformation (or strain rate) $\dot{\theta}$



The shear modulus of solid (*S*) and coefficient of viscosity for fluid (μ) can defined

$$S = \frac{\text{Shear stress}}{\text{Shear strain}} = \frac{(F/A)}{(\Delta x/h)}; \quad \mu = \frac{\text{Shear stress}}{\text{Shear strain rate}} = \frac{(F/A)}{(\Delta u/h)}$$

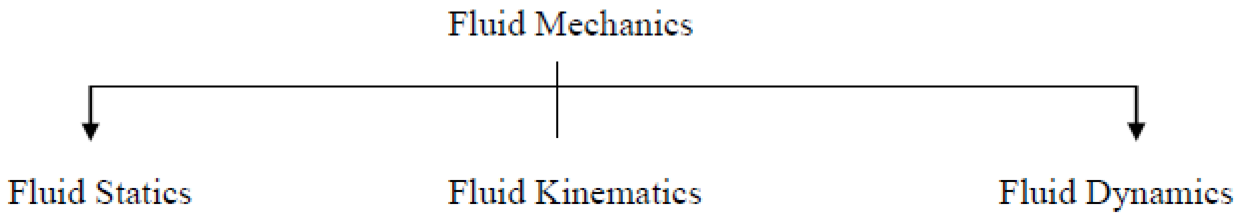
Here, the shear force ***(F)*** is acting on the certain cross-sectional area ***(A)***, ***h*** is the height of the solid block / height between two adjacent layer of the fluid element, ***Δx*** is the elongation of the solid block and ***Δu*** is the velocity gradient between two adjacent layers of the fluid.

Definition of fluids can be summarized as:

- Fluid has no definite shape
- Fluid does not have resistance against any attempt to change its shape
- Fluid is unable to retain an unsupported shape
- Fluid is the substance that changes its shape as well as direction uniformly whenever an external force is applied on it.
- Liquids, gases, dispersed solids and vapors, individually & collectively, are called fluids.

Fluid Mechanics

- The branch of science (or physics) which deals with the behavior of fluids (liquids, gases, vapors, dispersed solids etc.) is called fluid mechanics.
- Fluid Mechanics has three main branches:
  - ***i.*** ***Fluid statics*** **:** It studies behavior of *fluids at rest*
  - ***ii.*** ***Fluid kinematics*** **:** It studies behavior of *fluids in motion* but *no force acting on* them. (Only *viscosity* is studied in it).
  - ***iii.*** ***Fluid dynamics*** **:** It studies *fluids in motion* considering *all the forces* acting on them



Difference between liquids and gases

Although liquids and gases share some common characteristics, they have many distinctive characteristics on their own.

Liquid	Gas
Liquids are incompressible	Gases are compressible
A given mass of the liquid occupies a fixed volume, irrespective of the size and shape of the container.	A gas has no fixed volume and will expand continuously unless restrained by the containing vessel.
For liquids a free surface is formed in the volume of the container is greater than that of the liquid.	A gas will completely fill any vessel in which it is placed and therefore, does not have a free surface.

Classification of fluids

- According to behavior under the action of *externally* applied pressure (forces): In this class, fluids have two categories:
  - ***Compressible fluids:*** fluids which are dependent on temperature and pressure i.e. volume and density of these fluids change with pressure and temperature. *Gases are compressible fluids*.
  - ***Incompressible fluids:*** fluids which are independent of temperature and pressure i.e. volume and density of these fluids do not change with pressure and temperature .*Liquids are incompressible fluids.*

Classification of fluids

- According to the effect produced by the action of a *shear stress*. It determines way and pattern the fluid will flow. In this class, fluids also have two categories:
- ***Newtonian Fluids:*** Fluids which obey the Newton's law of viscosity are called as Newtonian fluids.
  - **Newton's law of viscosity** defines the relationship between the shear stress and shear rate of a fluid subjected to a mechanical stress. It states that the ratio of shear stress to shear rate is a constant, for a given temperature and pressure, and is defined as the viscosity or coefficient of viscosity.

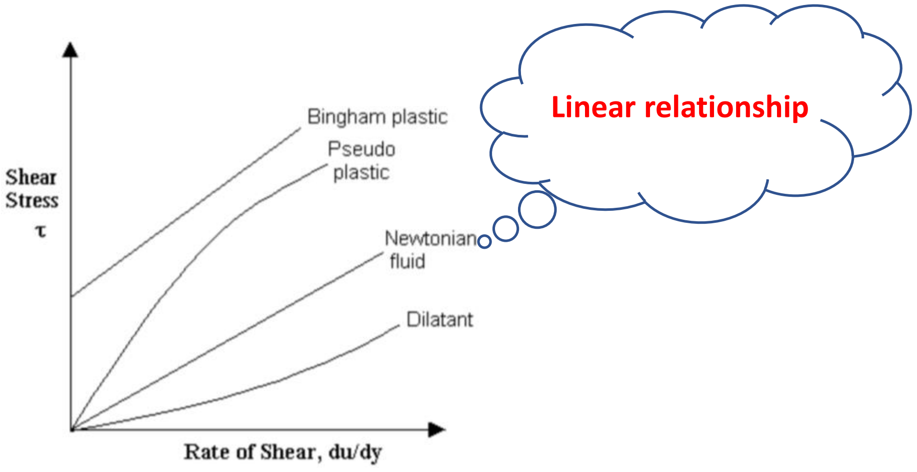
    Mathematically,

    $$\tau = \mu \frac{dc}{dy}$$

    where τ = shear stress,

    μ = viscosity of fluid,

    $\frac{dc}{dy}$ = shear rate, rate of strain or velocity gradient



  - Newtonian fluids obey Newton's law of viscosity.
  - The viscosity is independent of the shear rate.
  - All gases and most liquids which have simpler molecular formula and low molecular weight such as water, benzene, ethyl alcohol, hexane and most solutions of simple molecules are Newtonian fluids.

Adapted from: http://www.msubbu.in/ln/fm/Unit-I/NonNewtonian.htm
https://link.springer.com/referenceworkentry/10.1007%2F978-0-387-92897-5_143

Classification of fluids

- ***Non-Newtonian Fluids:*** fluids which *do not obey* Newton's law of viscosity are called non-Newtonian fluids.
- Non-Newtonian fluids do not follow Newton's law and, thus, their viscosity (ratio of shear stress to shear rate) is not constant
- The viscosity is dependent of shear rate.
- e.g. tooth-paste, jellies, slurries, polymer solutions, blood, suspensions of starch and sand etc.

Properties of fluid

1. Density or mass density (ρ):

- *Quantity of matter contained in unit volume* is called density. OR *mass per unit volume* is called density. Its symbol is ρ (rho).
- Mathematically;

$$\boldsymbol{Density}(\rho)=\frac{(\boldsymbol{mass\ of\ fluid})}{(\boldsymbol{volume\ of\ fluid})}$$

- **Dimension :** M/L^3
- **Units :** kg/m^3 , gm/cc

1-a. Specific Volume (v):

- *Volume per unit mass* is called specific volume .It is inverse of density.
- Mathematically:
- ***Specific Volume=*** $\frac{(\boldsymbol{volume\ of\ fluid})}{(\boldsymbol{mass\ of\ fluid})}$
- v=1/ ρ
- **Dimension :**L^3/M
- **Unit :** m^3 /kg, cc/gm etc.

1-b. Specific gravity (Relative density):

- *Ratio of the density of substance to some standard density* is called specific gravity.
- Mathematically:
- S.G. = Density of Substance/ Density of water at 4oC (*For liquids*)
- S.G. = Density of gas/ Density of air (*at same T&P*) (*For gases*)
- Specific gravity is dimensionless and hence has no units.
- (Note: *density of water is usually taken as 1.0 gm/cc or 1000kg/m3*)

1-c. Specific weight or weight density (w):

- *The ratio of the weight of fluid to its volume or Weight per unit volume* is called specific weight. It varies from point to point (as '**g**' varies).
- Mathematically:

$$\text{Weight per unit volume } (\boldsymbol{w}) = \frac{(\text{mass of fluid} \times \text{acceleration due to gravity})}{\text{Volume of fluid}}$$

- ***w*** = mass per unit volume × g
- **w = ρg**
- **Dimension:** $ML^{-2}T^{-2}$
- **Units:** N/m^3, dyne/cc etc.

Viscosity

- It is property of a fluid which offers resistance to the movement of one layer of the fluid over another adjacent layer of the fluid.
- The viscosity of a fluid is a measure of its resistance to gradual deformation by shear stress or tensile stress. The shear resistance in a fluid is caused by inter-molecular friction exerted when layers of fluid attempt to slide by one another.
- *viscosity is the measure of a fluid's resistance to flow*
  - molasses is highly viscous
  - water is medium viscous
  - gas is low viscous
- There are two related measures of fluid viscosity
  - **dynamic** (**or absolute**)
  - **kinematic**

Adapted from: https://www.engineeringtoolbox.com/dynamic-absolute-kinematic-viscosity-d_412.html

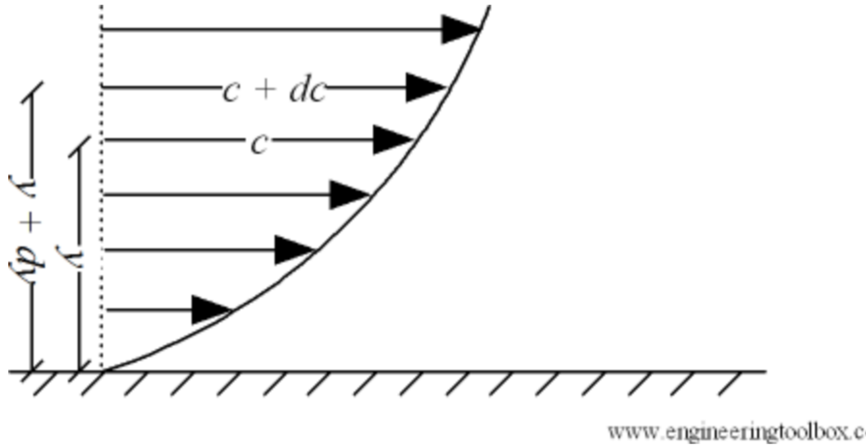
Dynamic or absolute viscosity

- Dynamic (absolute) viscosity is the tangential force per unit area required to move one horizontal plane with respect to an other plane - at an unit velocity - when maintaining an unit distance apart in the fluid.
- The shearing stress between the layers of a non turbulent fluid moving in straight parallel lines can be defined for a Newtonian fluid as

Shear Stress can be expressed as $\tau = \mu \frac{\mathrm{d}c}{\mathrm{d}y}$

Where,
τ= shearing stress in fluid *(N/m²)*
μ= dynamic viscosity of fluid *(N s/m²)*
dc = unit velocity (m/s)
dy = unit distance between layers (m)

$$\mu = \frac{\tau}{\left(\frac{\mathrm{d}c}{\mathrm{d}y}\right)}$$



The shear stress required to produce unit rate of shear strain
S.I. unit of viscosity: *Ns/m²* or poise, 10 *Ns/m²* **=**1 poise

Dynamic or absolute viscosity

- Significance
  - Internal stickiness of a fluid (cohesive force).
  - Represents internal friction in fluids.
  - Measure of resistance to relative translation motion of adjacent layers of fluid.
  - Depends of temperature (When temperature increases the liquid viscosity decreases while in gases increase in temperature the viscosity of gas increases)
  - Important to determine the amount of fluids that can be transported during specific time.

Kinematic viscosity

- Kinematic viscosity is the ratio of - *absolute (or dynamic) viscosity to density* - a quantity in which no force is involved. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with the fluid mass density like

$$v = \frac{\mu}{\rho}$$

where,

v = kinematic viscosity (m^2/s)

μ = absolute or dynamic viscosity ($N\ s/m^2$)

ρ = density (kg/m^3)

- In the SI-system the theoretical unit of kinematic viscosity is m^2/s - or the commonly used Stoke (St) where ,

  1 St (Stokes) = $10^{-4}\ m^2/s = 1\ cm^2/s$

Stoke comes from the CGS (Centimetre Gram Second) unit system

Effect of temperature on dynamic viscosity (μ)

- For liquid, effect of temperature,

$$\mu_T = \frac{\mu_0}{1 + AT + BT^2}$$

where A, B are constant for liquid

- For gas, effect of temperature,

$$\mu_T = \mu_0 + \alpha T + \beta T^2$$

where α and β are constant for gas

Types of flow

1. Uniform and Non-Uniform flow
2. Steady and unsteady flow
3. Laminar and Turbulent flows
4. Compressible and Incompressible flow
5. Ideal & Real flow

Uniform and Non-Uniform flow:

Uniform flow is defined as that type of flow in which the fluid parameter (pressure, velocity, density, viscosity and temperature) at any given time does not change with respect to space (i.e. length of direction of flow). Mathematically, for uniform flow,

$$\left(\frac{\partial v}{\partial s}\right)_{t=const} = 0 \qquad \left(\frac{\partial p}{\partial s}\right)_{t=const} = 0 \qquad \left(\frac{\partial \rho}{\partial s}\right)_{t=const} = 0$$

Where, ∂v , ∂p & $\partial \rho$ are the change of velocity, pressure and density & ∂s is the length of flow in the directions.

Uniform and non-uniform flow

- Non-Uniform Flow is in which the velocity at any given time changes with respect to space (i.e. length of direction of flow).
- Mathematically, for non-uniform flow,

$$\left(\frac{\partial v}{\partial s}\right)_{t=const} \neq 0 \qquad \left(\frac{\partial p}{\partial s}\right)_{t=const} \neq 0 \qquad \left(\frac{\partial \rho}{\partial s}\right)_{t=const} \neq 0$$

Where, ∂v , ∂p & $\partial \rho$ are the change of velocity, pressure and density & ∂s is the length of flow in the directions.

Uniform and Non-uniform flow

- For a uniform flow, by its definition, the area of the cross section of the flow should remain constant. So a fitting example of the uniform flow is the flow of a liquid thorough a pipeline of constant diameter. And contrary to this the flow through a pipeline of variable diameter would be necessarily non-uniform

Steady and unsteady flow

- Steady flow is defined as that type of flow in which the fluid parameter/characteristics like pressure, velocity, density etc. at a point do not change with time.
- Mathematically,

$$\left(\frac{\mathrm{d}P}{\mathrm{d}t}\right)_{x_0 y_0 z_0} = 0$$

Where P is the properties like pressure, velocity or density and $x_0 y_0 z_0$ are the fixed point in the field

e.g. flow of water in a pipeline due to centrifugal pump being run at uniform rotational speed, liquid efflux from a vessel in which constant level is maintained.

Steady and unsteady flow

- Unsteady flow is defined as that type of flow in which the fluid parameter/characteristics like pressure, velocity, density etc. at a point changes with time.
- Mathematically,

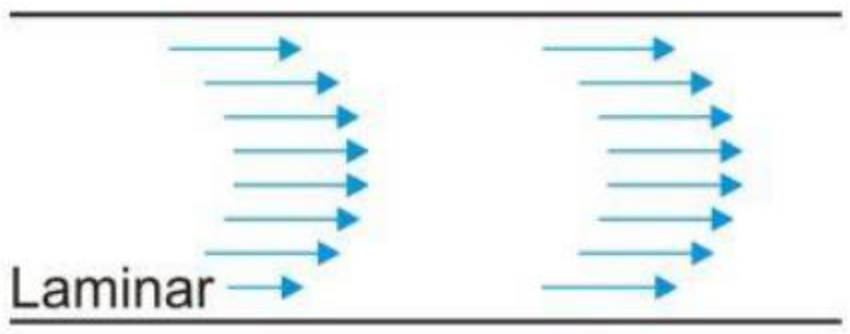
$$\left(\frac{\mathrm{d}P}{\mathrm{d}t}\right)_{x_0 y_0 z_0} \neq 0$$

Where P is the properties like pressure, velocity or density and $x_0 y_0 z_0$ are the fixed point in the field

Example: liquid falling under gravity out of an opening in the bottom of a vessel.

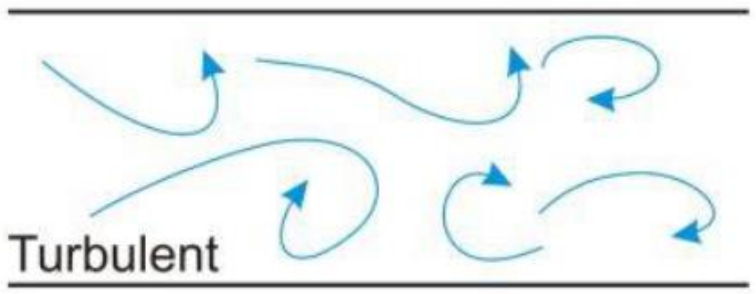
Laminar and Turbulent flows

- Laminar flow is that type of flow in which the fluid particles move along well-defined paths or streamline and all the streamlines are straight and parallel. Thus, the particles move in laminar or layer gliding smoothly over the adjacent layer
  - Characterized by laminas or layers gliding smoothly over the adjacent layers
  - The fluid particles move in well-defined path and retain the same relative position at successive cross section of the fluid passage.
  - The laminar flow is also called streamlined/viscous flow
  - Mostly occurs in smooth pipes with fluid having low flowrates & fluid having high viscosity.

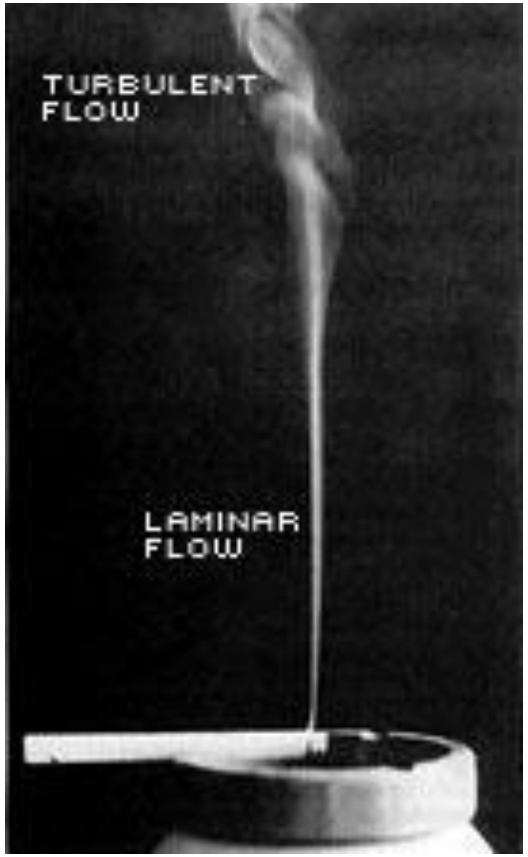


Laminar and Turbulent flows

- Turbulent flow is that type of flow in which the fluid particles move in a zig-zag way. Due to the movement of fluid particles in a zig-zag way, the eddies formation takes place which are responsible for high energy loss.
  - Flow path are erratic and unpredictable.
  - Individual fluid particles are subjected to fluctuating transverse velocity (s)
  - Motion of fluid is eddying/ sinuous rather than rectilinear
  - Random eddying motion is called turbulence.
  - Mostly seen in river, atmosphere and fire extinguisher cylinder.



Laminar and Turbulent flows



http://www.physlink.com/Education/AskExperts/ae464.cfm

For pipe flow, the type of flow is determined by non-dimensional number $\frac{VD}{v}$ called Reynolds number (Re)

Where,
V= Mean velocity of flow in pipe
D=Diameter of pipe
v = Kinematic viscosity of fluid

Dimensions: Re is dimensionless number

- Reynolds number less than 2000 (laminar)
- More than 4000 (turbulent)
- Between 2000-4000 (laminar & turbulent)

Compressible and Incompressible flow

- Compressible flow is that type of flow in which the density of the fluid changes from point to point or in other words the density (ρ) is not constant for the fluid. Thus mathematically for compressible flow

$$\rho \neq \text{constant}$$

- Incompressible flow is that type of flow in which the density is constant for the fluid flow. Mathematically,

$$\rho = \text{constant}$$

- Liquids are generally incompressible while gases are compressible.

Compressible and uncompressible flow

- **Mach number** (m)**:**
- **Mach No.** $= \dfrac{\boldsymbol{ratio\ of\ local\ flow\ velocity}}{\boldsymbol{sonic\ velocity\ of\ fluid}}$
  - Mach number<0.3, compressibility effect is ignored.
  - Subsonic: m<1
  - Supersonic: m>1
  - Sonic: m=1

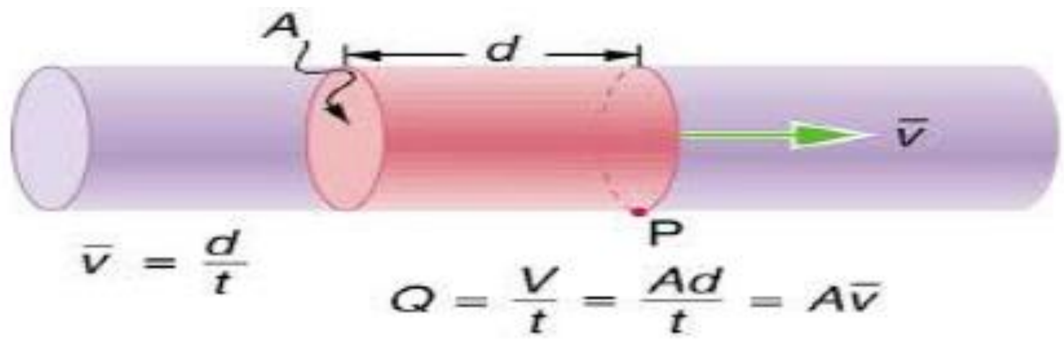
Ideal & Real flow

- In the **Ideal (friction-less) flows**, no stress is presumed to exist between adjacent fluid layers and between the fluid layers and the boundary. This assumption is valid only when the fluid is non-viscous (inviscid,) or when the velocity gradient normal to the direction of flow is zero. Only normal stress can exist in ideal flows.
- *(Fluids are generally viscous and such that shear stresses come into existence when the fluid particles are in motion.)*
- **Real flow** situations are characterized by the frictional resistance to fluid motion; this resistance to fluid motion; this resistance is due to viscosity of real fluid.

RATE OF FLOW OR DISCHARGE OR FLOW RATE (Q)

- Quantity of a fluid flowing per second through a section of pipe or channel.
- For an incompressible fluid (or liquid) the rate of flow or discharge is expressed as the volume of fluid flowing across the section per second.
- For compressible fluids, the rate of flow is usually expressed as the weight of fluid across the section.

  - For liquid the units of Q are m^3/s or lt/sec.
  - For gases the units of Q are kgf/s or N/s



$$m = \rho V$$
$$\dot{m} = \frac{\rho V}{t}$$

$$\dot{m} = \frac{\rho A d}{t}$$

$$\dot{m} = \rho A v$$

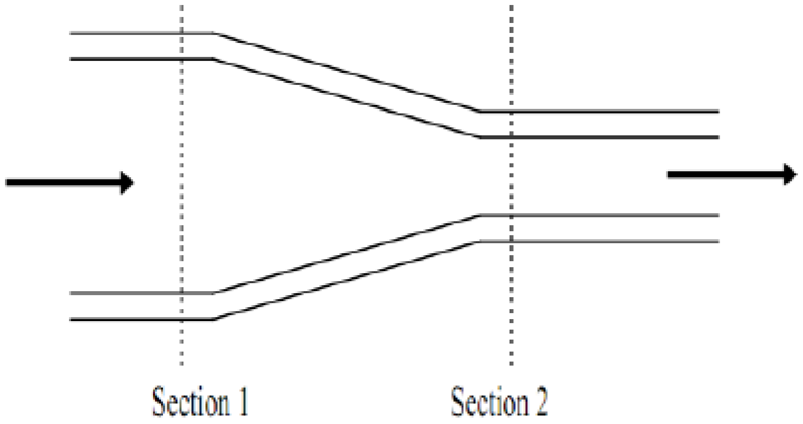
Consider a liquid flowing through a pipe in which

A= Cross sectional area of pipe
V=Average velocity of fluid across the section.
Then,
Discharge (Q)= Cross sectional area of pipe (A) ×Average velocity of fluid across the section(V)

Q=A × V

Continuity Equation

- The equation based on the principle of conservation of mass is called continuity equation.



- Let V_1 = Average velocity at cross-section 1-1

ρ_1 = Density at section 1-1

A_1 = Area of pipe at section 1-1

& V_2, ρ_2 and A_2 are corresponding values at section 2-2, Rate of flow at section 1-1 = $V_1 \rho_1 A_1$

Rate of flow at section 2-2 = $V_2 \rho_2 A_2$

- According to law of conservation of mass,

Rate of flow at section 1-1= Rate of flow at section 2-2

$V_1 \rho_1 A_1 = V_2 \rho_2 A_2$

Above equation is applicable to the compressible as well as incompressible fluids and is called continuity equation.

If the fluid is incompressible, then

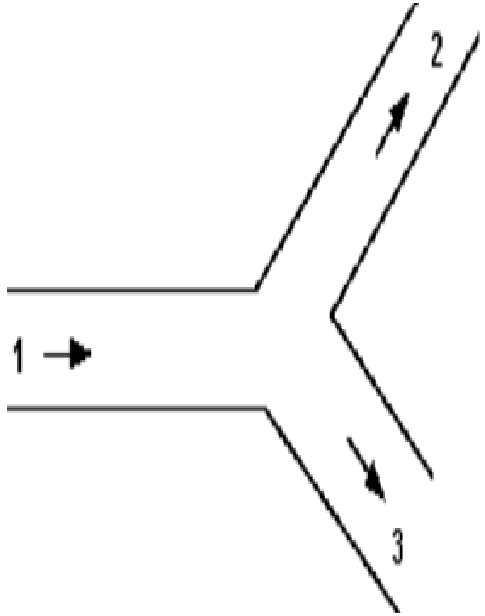
$$\rho_1 = \rho_2$$

, the continuity equation reduces to $V_1 A_1 = V_2 A_2$

- The use of continuity equation principle is to determine the velocities in pipe coming from junction,

Total mass flow into junction=Total mass flow out of the junction

$$\rho_1 Q_1 = \rho_2 Q_2 + \rho_3 Q_3$$



- When the flow is incompressible (e.g. if it is water),

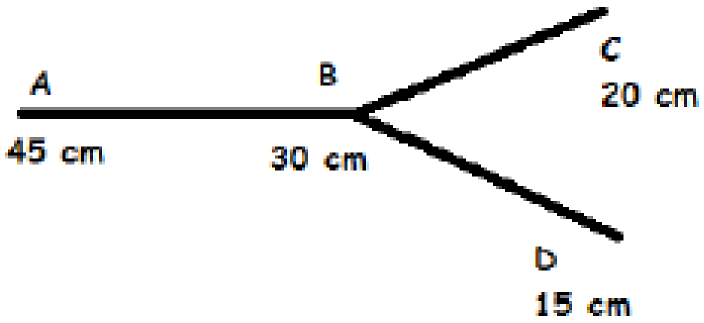
$\rho_1 = \rho_2 = \rho$

$Q_1 = Q_2 + Q_3$

$A_1 V_1 = A_2 V_2 + A_3 V_3$

Problem

- A pipe AB branches into two pipes C and D as shown in figure below. The pipe has diameter of 45 cm at A, 30 cm at B, 20 cm at C and 15 cm at D. Determine the discharge at A if the velocity at A is 2 m/s. Also determine the velocities at B and D, if the velocity at C is 4 m/s.

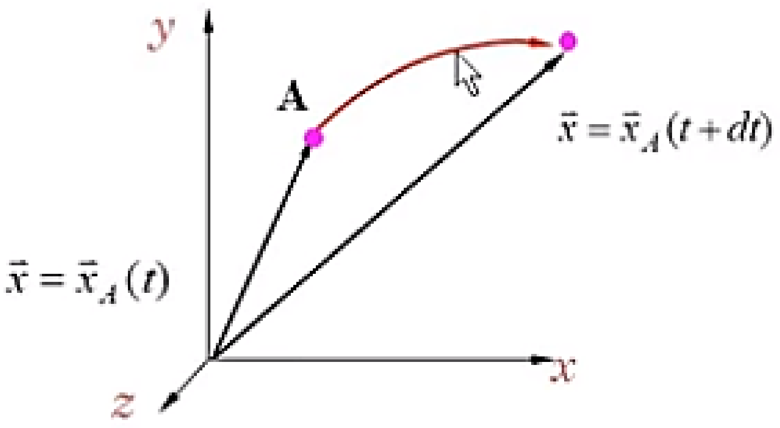


- **Problem**

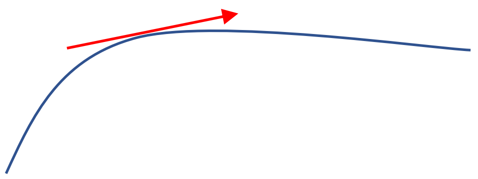
Water flows through a pipe AB 1.2 m diameter at 3 m/s and then passes through a pipe BC 1.5 m diameter. At C, the pipe branches. Branch CD is 0.8 m in diameter and carries one-third of the flow in AB. The flow velocity in branch CE is 2.5 m/s Find the volume rate of flow in AB, the velocity in BC, the velocity in CD and the diameter of CE.

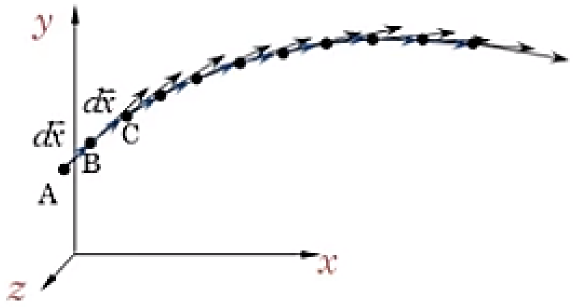
TYPES OF FLOW LINES

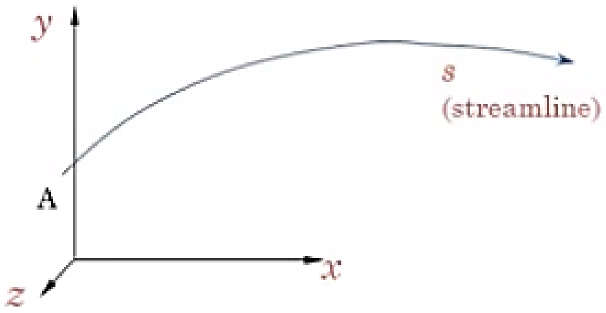
- Pathline
  - the path or trajectory, traced out by an identified fluid particles



- Streamline
  - It is an imaginary line drawn in the flow field such that the tangent drawn at any point on this line represents the direction of velocity vector of the fluid particle at that point.

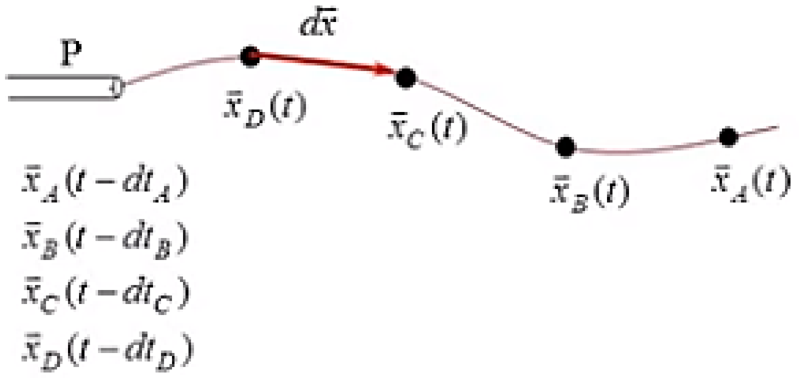






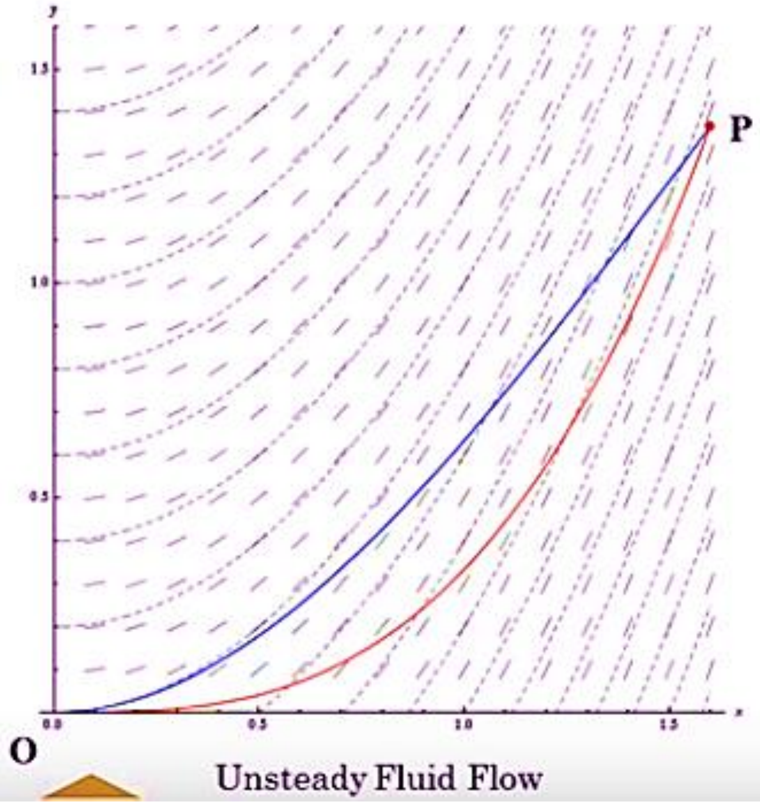
- For steady flow streamline pattern do not change with time,
- Whereas, for unsteady flow streamline pattern changes continuously with that of time
- So, streamline is specified at that particular instance of time

- Streakline
  - The line joining fluid particles that once passed through the same fixed point in space.



NOTE: In steady flow, there is no geometrical difference between pathline, streamline and streakline (they are identical)

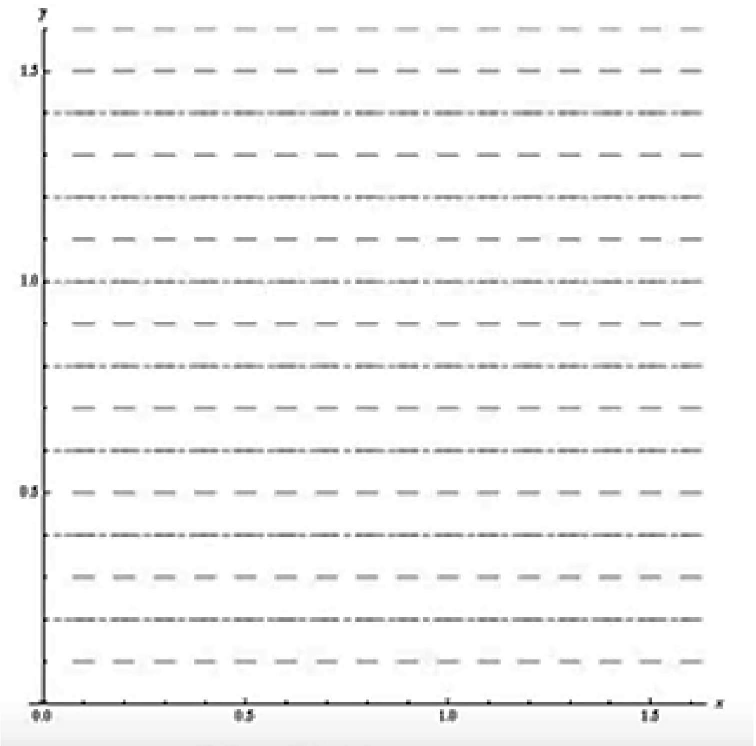
Unsteady Fluid Flow:



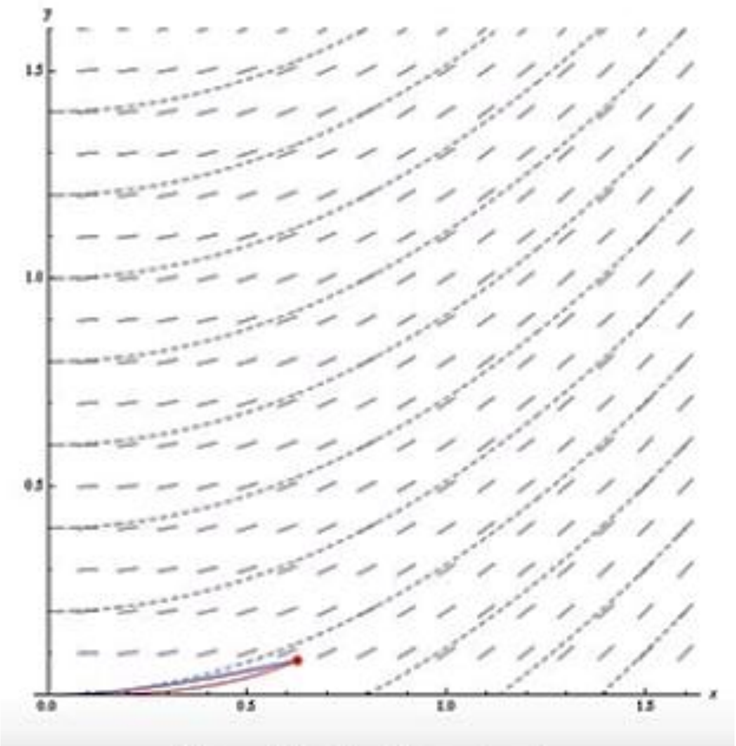
Streamlines: Grey dashed lines

Pathline: Red line

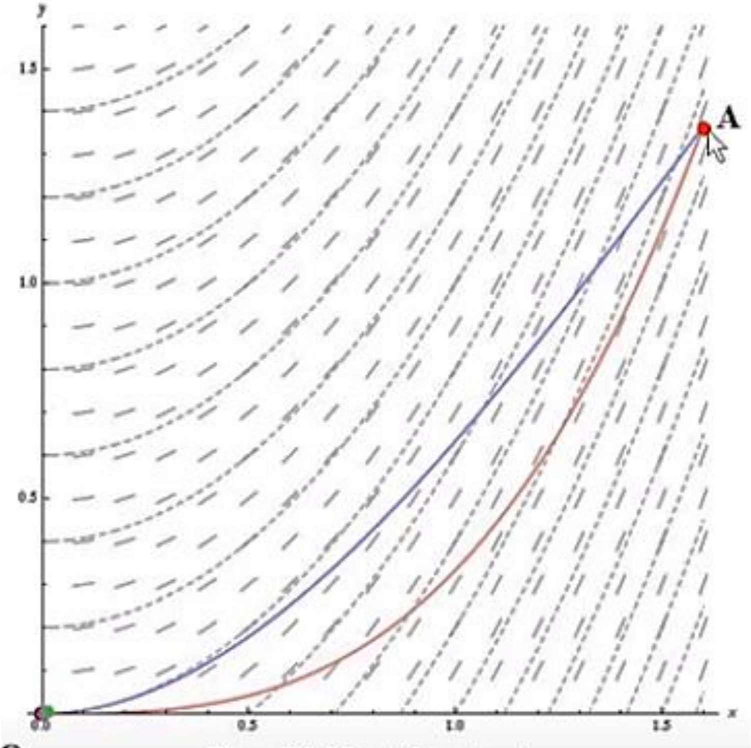
Streakline: Blue line



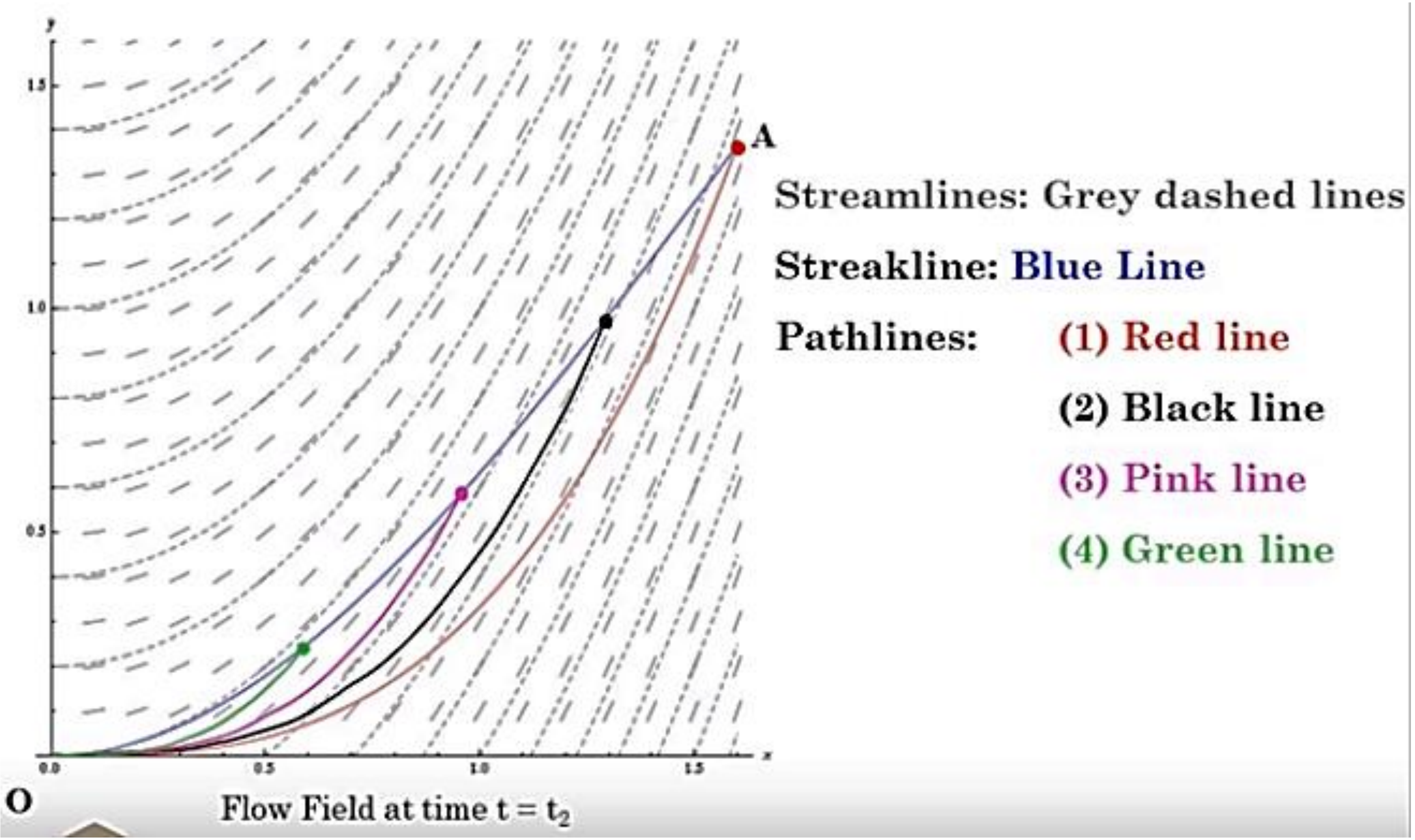
Flow Field at time $t = t_0$



Flow Field at time $t = t_1$



Flow Field at time $t = t_2$



Blue line is streakline corresponding to point O

Bernoulli’s Equation

- **Bernoulli’s theorem**, in fluid dynamics is a relation among the pressure, velocity, and elevation in a moving fluid (liquid or gas), where the compressibility and viscosity (internal friction) of are negligible and the flow of which is steady, or laminar.
- the total mechanical energy of the flowing fluid, comprising the energy associated with fluid pressure, the gravitational potential energy of elevation, and the kinetic energy of fluid motion, remains constant.

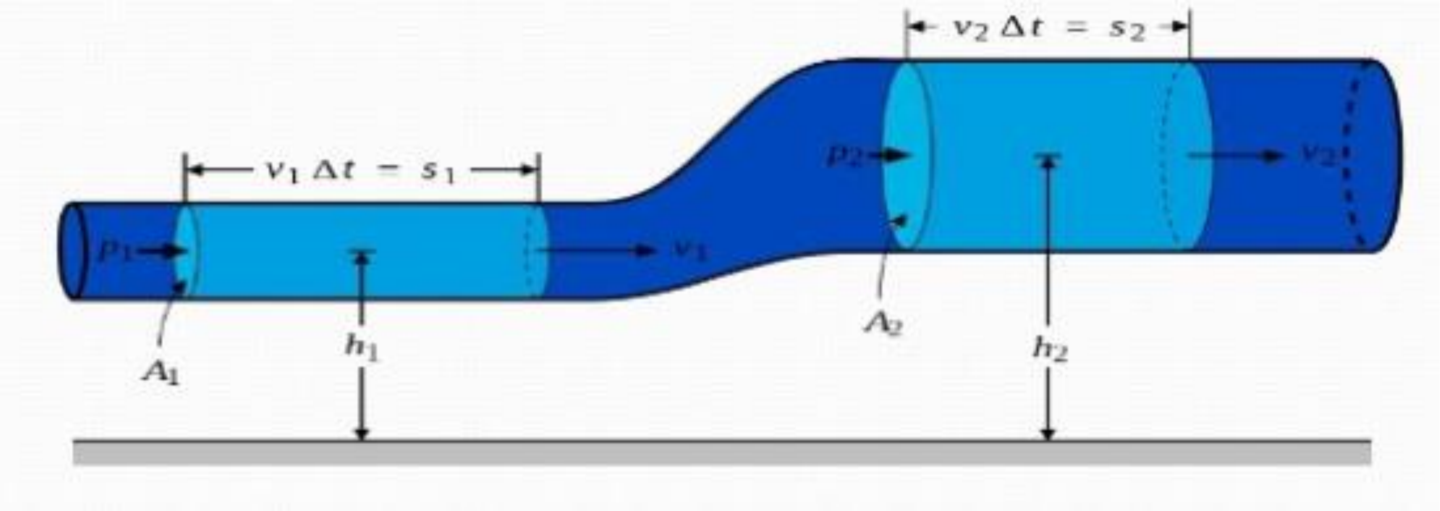
- For a steady flow of incompressible, ideal fluid the sum of the pressure energy (P), the kinetic energy per unit volume ($\rho v^2/2$) and the potential energy per unit volume (ρgh) remain constant.
- i.e.

  $P + \rho v^2/2 + \rho gh = \text{constant}$

  where P= pressure ,

$$KE/\ Volume = 1/2mv^2/V = 1/2v^2(m/V) = 1/2\rho v^2$$

$$PE/Volume = mgh/V = (m/V)gh = \rho gh$$



$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

P= static pressure of fluid at the cross section;
ρ= density of the flowing fluid in;
g= acceleration due to gravity;
v= mean velocity of fluid flow at the cross section in;
h= elevation head of the center of the cross section with respect to a datum.

- Also,

  Pressure energy per unit weight+ Kinetic energy per unit weight+ Potential Energy per unit weight= Total Energy per unit weight

$$\frac{P}{\rho g} + \frac{v^2}{2g} + h = \text{constant}$$

$$\frac{P}{\rho g} = \text{pressure head}$$

$$\frac{v^2}{2g} = \text{velocity head}$$

$$h = \text{potential head}$$

Note: unit weight is weight per unit volume

Special cases

- When a fluid is at rest. This means $v_1=v_2=0$.
  - $P_1-P_2= \rho g(h_2-h_1)$
- When the pipe is horizontal.$h_1=h_2$.This means there is no Potential energy by the virtue of height.
  - $P+(1/2)\ \rho\ v^2$ = constant.

- **Problem**

Water flows through a horizontal pipeline of varying cross-section. If the pressure of water equals 6cm of mercury at a point where the velocity of flow is 30cm/s, what is the pressure at another point where the velocity of flow is 50cm/s?

- **Problem**

*A ho*rizontal water pipe of diameter 15 cm converges to diameter 7.5 cm. If the pressures at two sections are 400 kPa and 150 kPa respectively, calculate the flow rate of water.

- **Problem**

A pipe 300 m long has a slope 1 in 100 and tapers from 1 m diameter at the high end to 0.5 m at the low end. Quantity of water flowing is 5400 liters per minute. If the pressure at the high end is 70 kPa, find the pressure at the low end.

- **Hint : Slope = rise / run**

Turbomachine

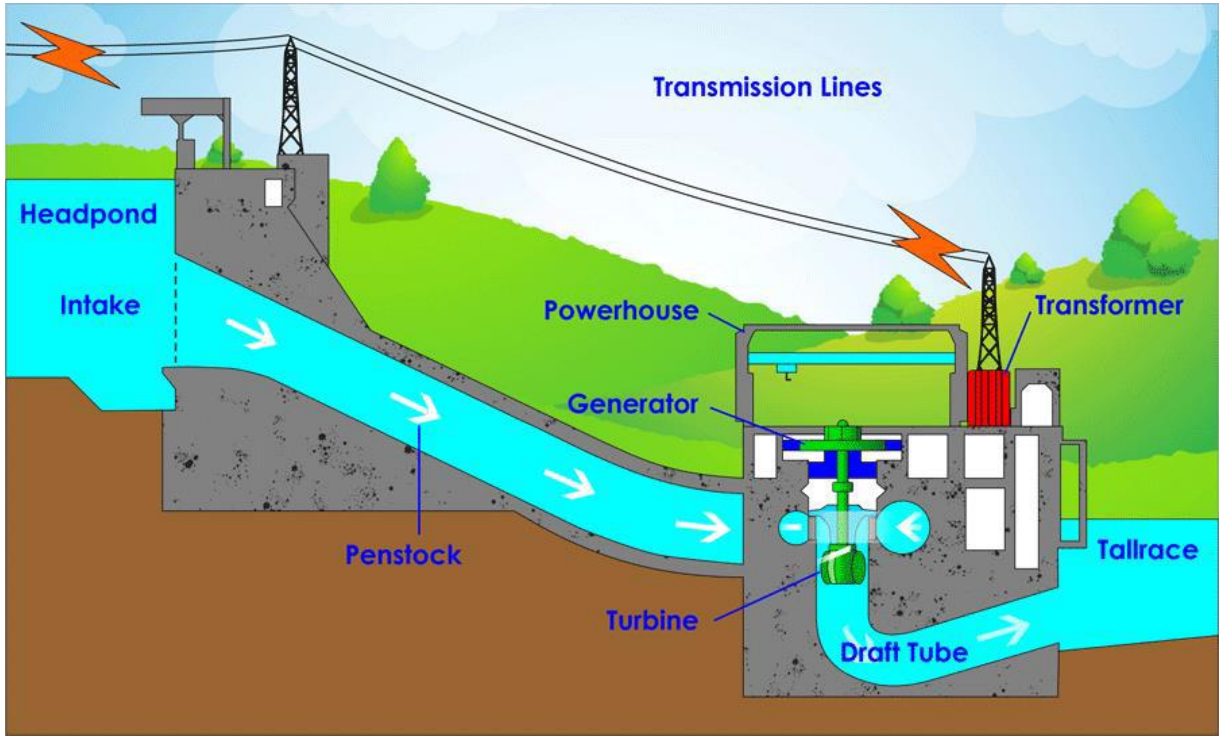
- A turbomachine is a device that exchange energy with a fluid using continuously flowing fluid and rotating blades.
- In other words, A turbomachine is a device where mechanical energy in the form of shaft work, is transferred either *to* or *from* a continuously flowing fluid by the dynamic action of rotating blade rows.
- If the device extracts energy from the fluid it is generally called turbine.
- If the device delivers energy to the fluid it is called compressor, fan, blower or pump depending on the fluid used and the magnitude of the change in pressure that results

Types- based on Fluid machine interaction

- Open turbo-machines
  - Extent of fluid machine interaction is infinite
  - E.g. propellers, windmills, unshrouded fans
- Closed turbo-machines
  - Extent of fluid machine interaction is finite
  - E.g. pumps, turbines, compressors

Hydropower

- Power derived from the energy of falling water or fast running water, which may be harnessed for useful purposes



Hydropower for electrical energy

Energy conversion:

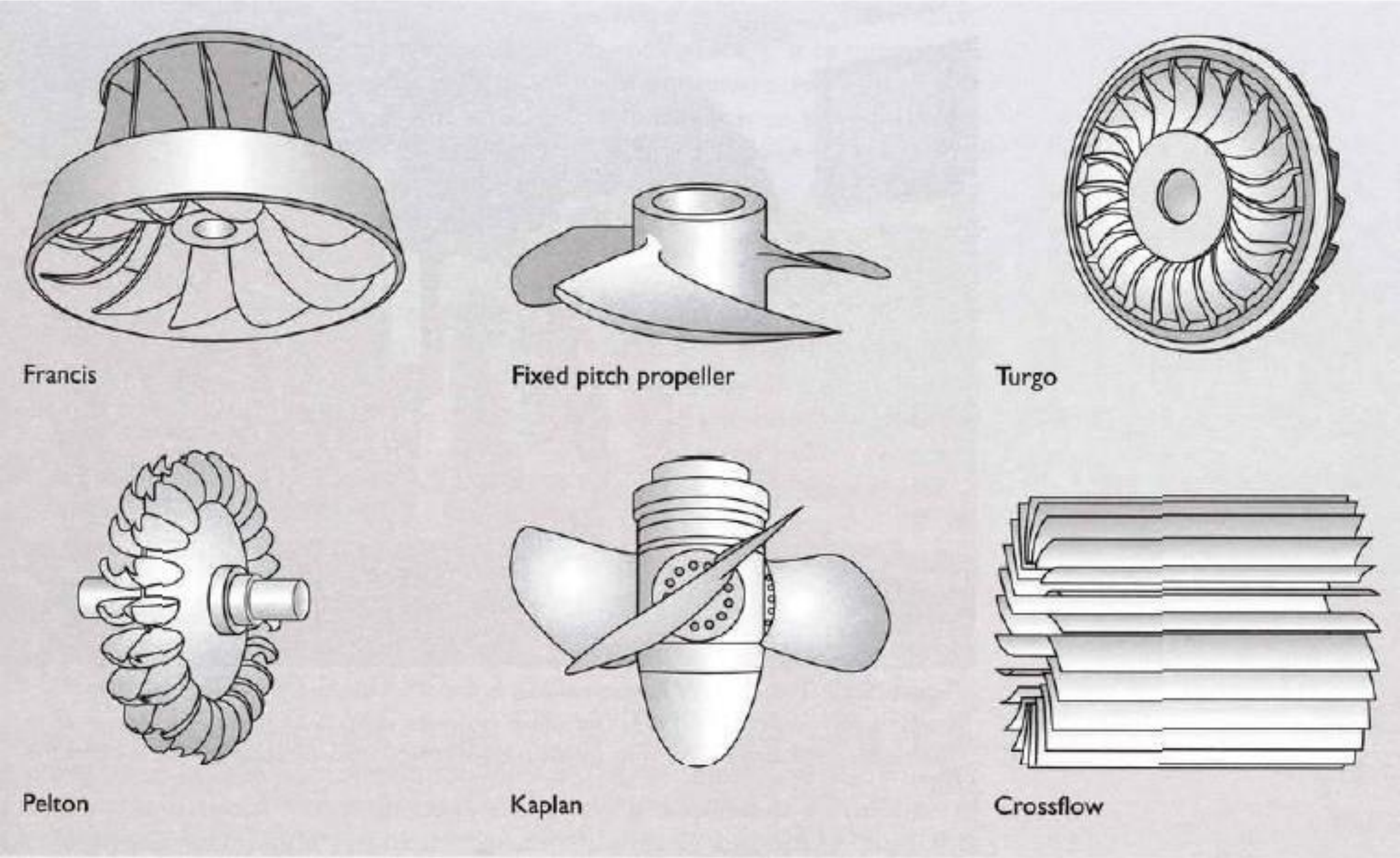
Potential energy
Kinetic energy
Mechanical energy
Electrical energy

Classification of hydropower, according to capacity

- Large (> 100 MW)
- Medium (10 –100 MW)
- Small (1 MW–10 MW)
- Mini (100 –1 MW)
- Micro (5 –100 kW)
- Pico (< 5 kW)

Hydraulic Turbines

- Turbo-machines which uses the energy of flowing water present in the form of pressure/kinetic energy and converts into mechanical energy which is in the form of rotation of runner

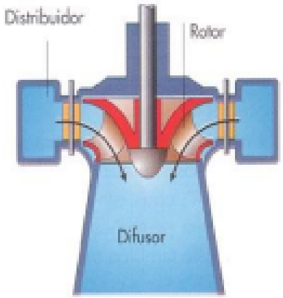

Francis
Fixed pitch propeller
Turgo
Pelton
Kaplan
Crossflow

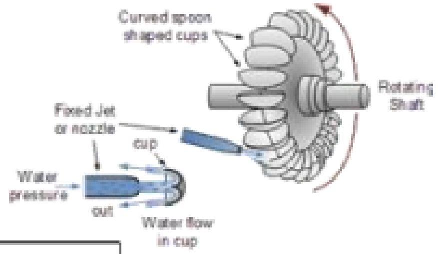
Classification of Hydraulic Turbines

Hydraulic turbines are classified on the basis of:

- **Operating principle**
  - Impulse
  - Reaction
- **Head [H]**
  - High Head
  - Medium Head
  - Low Head
- **Discharge [Q]**
  - Low Discharge
  - Medium Discharge
  - High Discharge
- **Flow Direction**
  - Axial flow
  - Radial Flow
  - Tangential Flow
  - Mixed Flow
- **Specific Speed[Ns]**
  - Low specific speed
  - Medium specific speed
  - High specific speed
- **Disposition of turbine shaft**
  - Vertical shaft turbine
  - Horizontal shaft turbine
- **Name of the originator**
  - Pelton: Lester Allen Pelton
  - Francis: James Bichens Francis
  - Kaplan: Dr. Victor Kaplan

Classification of Hydraulic Turbines

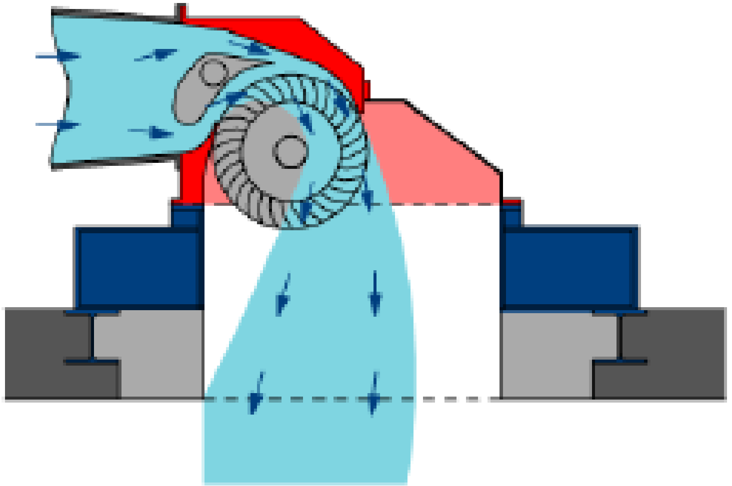


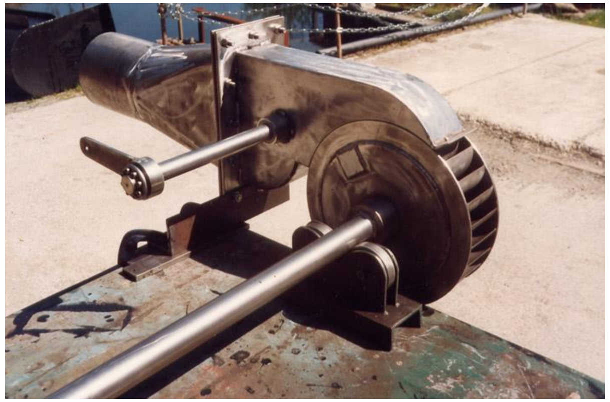


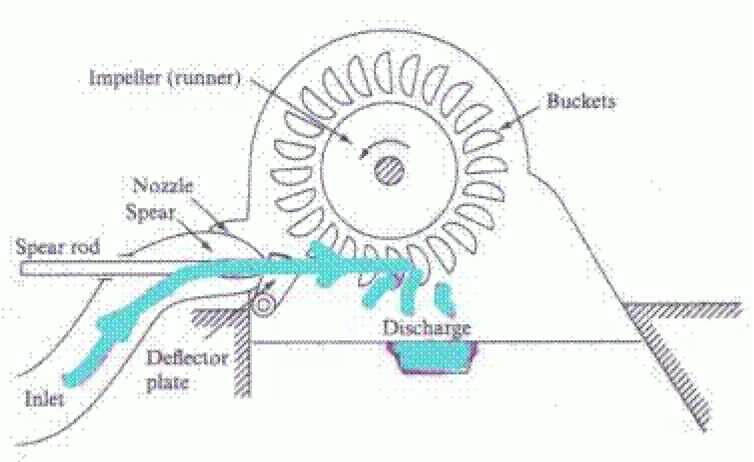
- **Hydraulic Turbines**
  - **Reaction Turbine**
    - Axial Flow Turbine
      - Propeller Turbine
      - Kaplan Turbine
      - Tube Turbine
      - Bulb Turbine
      - Straflo Turbine
    - Francis Turbine
  - **Impulse Turbine**
    - Pelton Turbine
    - Turgo Turbine
    - Cross-Flow Turbine

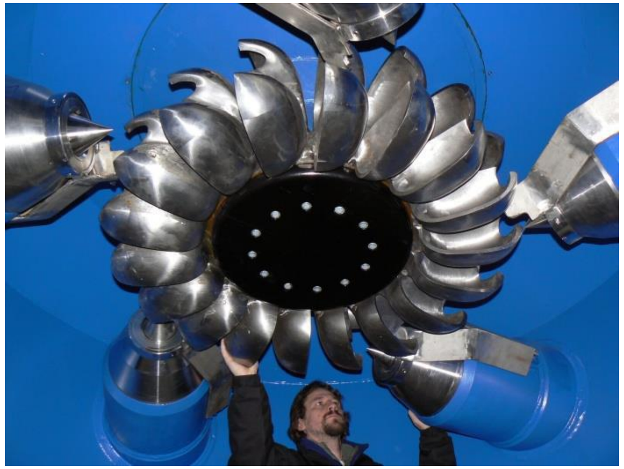
Impulse Turbines (Partial Turbines)

- Hydraulic energy is completely converted to kinetic energy before transformation in the runner
- Examples: Pelton, Cross-flow, Turgo









Reaction Turbines (Full Turbines)

- Two different effects cause the energy transfer from the flow to mechanical energy on the turbine shaft
- Drop in pressure from inlet to outlet of the runner -> Reaction part
- Changes in the directions of the velocity vectors of the flow through the canals between the runner blades -> Impulse part
- Examples: Francis, Kaplan, Propeller, Bulb

Differences between impulse and reaction turbines

Impulse turbine

- All available energy is converted into kinetic energy before striking the runner
- Pressure remains constant both at inlet and exit
- Water is admitted partially to the runner (Partial runner)
- Turbine is above water level
- Change of pressure across the blade does not take place
- Casing has no hydraulic function to perform
- *Eg: Pelton turbine, Crossflow turbine*

Reaction turbine

- A portion of fluid energy is converted into kinetic energy while the other remains as pressure energy (reaction ratio)
- Pressure changes from inlet to exit
- Water is admitted fully to the runner (Full runner)
- The turbine is submerged in water
- Change of pressure across the blade take place
- Casing keeps the water at high pressure
- *Eg: Francis Turbine, Kaplan turbine*

Hydraulic pumps

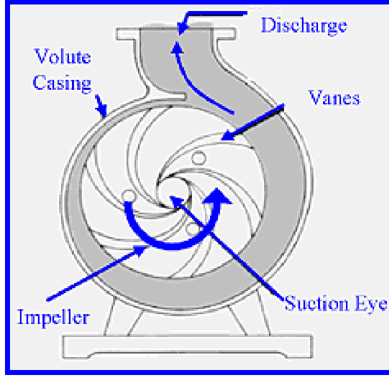
- A hydraulic pump is a mechanical device that converts mechanical power into hydraulic energy.
- Pump increases the mechanical energy of the fluid.
- Work has to be done on the pump to enable it to impart energy to fluid.
- In most of the cases the pump is used for raising fluids from a lower level to higher level, which is possible by creating low pressure at inlet/suction end and a high pressure at outlet/delivery end.

General working mechanism

- When a hydraulic pump operates, it performs two functions.
- First, its mechanical action creates a vaccum at the pump inlet which allows atmospheric pressure to force liquid from the reservoir into the inlet line to the pump.
- Second, its mechanical action delivers this liquid to the pump outlet and forces it into the hydraulic system.

1. Classification based on displacement:

- Non-positive displacement pumps (hydrodynamic pumps)
  - discharge liquid in a continuous flow
  - A **non-positive-displacement pump** produces a continuous flow. However, because it does not provide a positive internal seal against slippage, its output varies considerably as pressure varies.
  - In a hydrodynamic pump, liquid velocity and movement are large; output pressure actually depends on the velocity at which the liquid is made to flow.
  - e.g. axial flow pump, propeller pump, centrifugal pump



- Positive displacement pumps (hydrostatic pumps)
  - discharge volumes of liquid separated by periods of no discharge
  - A **positive-displacement pump** is one that displaces (delivers) the same amount of liquid for each rotating cycle of the pumping element. Constant delivery during each cycle is possible because of the close-tolerance fit between the pumping element and the pump case.
  - Hydrostatic means that the pump converts mechanical energy to hydraulic energy with comparatively small quantity and velocity of liquid
  - e.g. gear pumps, vane pumps, piston pumps

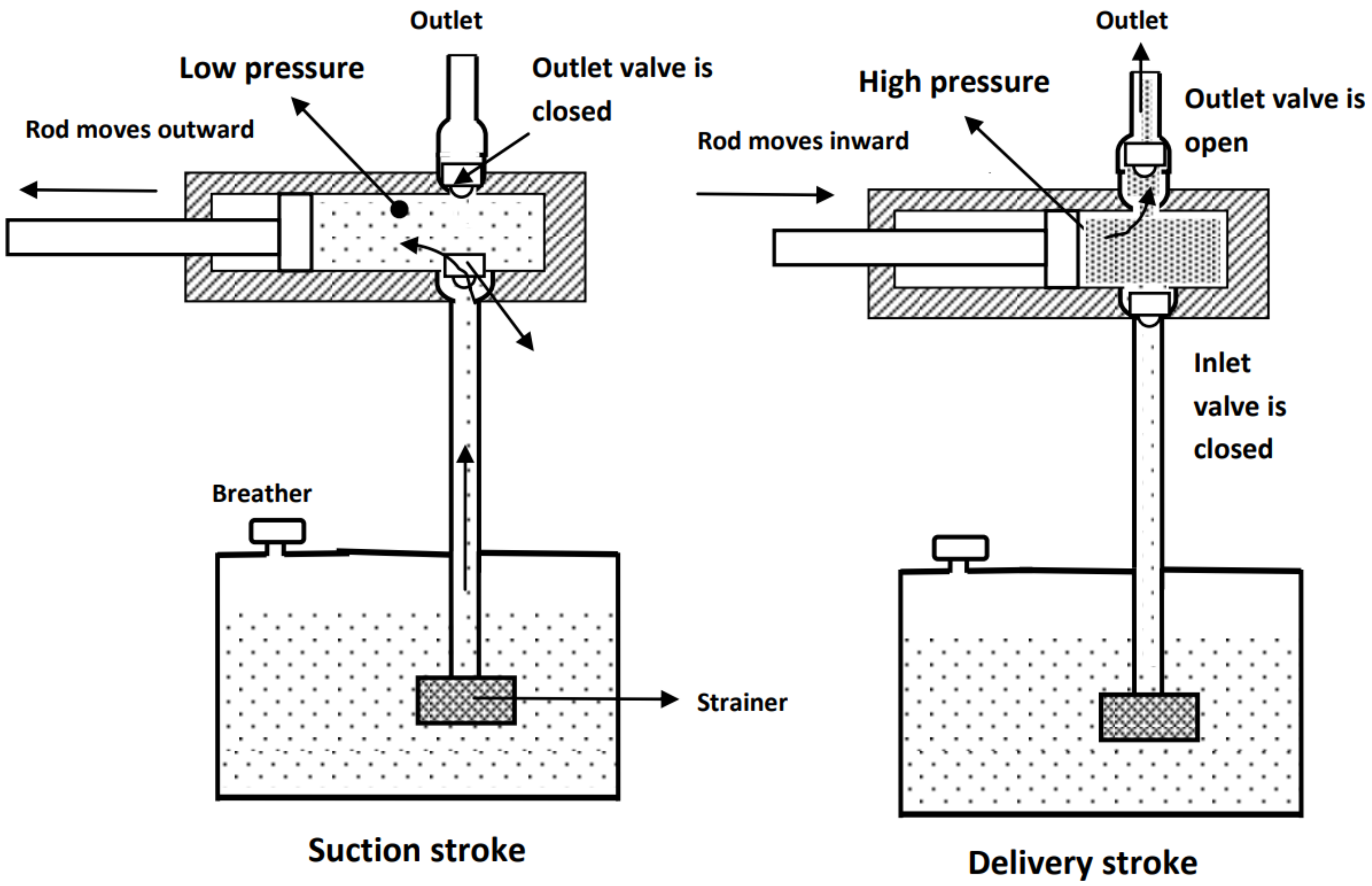
https://www.hydraulicspneumatics.com/200/TechZone/HydraulicPumpsM/Article/False/6401/TechZone-HydraulicPumpsM

2. Classification based on delivery:

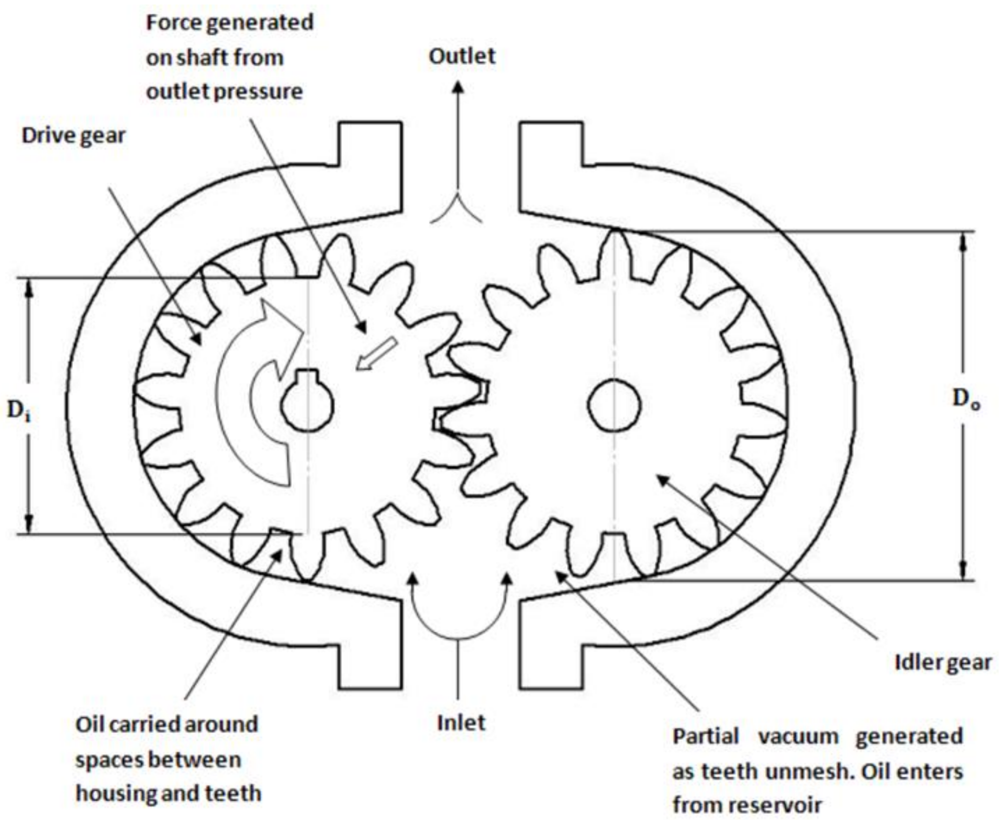
- Constant delivery pumps.
  - always deliver the same quantity of fluid in a given time at the operating speed and temperature.
  - generally used with relatively simple machines, such as saws or drill presses or where a group of machines is operated with no specific relationship among their relative speeds.
  - Power for reciprocating actuators is most often provided by constant volume pumps.
- Variable delivery pumps.
  - output of variable volume pumps may be varied either manually or automatically with no change in the input speed to the pump.
  - Variable volume pumps are frequently used for rewinds, constant tension devices or where a group of separate drives has an integrated speed relationship such as a conveyor system or continuous processing equipment.

3. Classification based on motion:

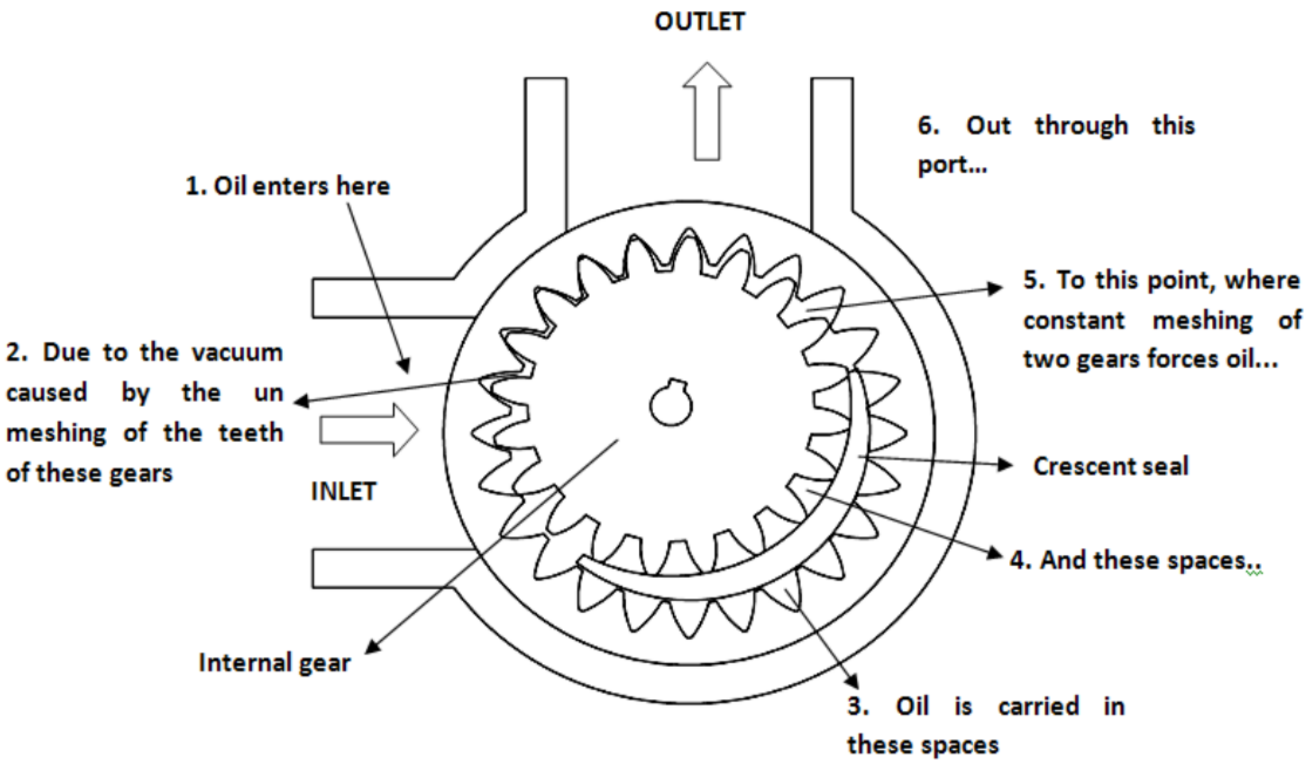
- Reciprocating pump (piston, plunger, diaphragm)
- Rotary pump (internal gear, external gear, lobe, vane)



Operation of reciprocating pump



Operation of external gear pump



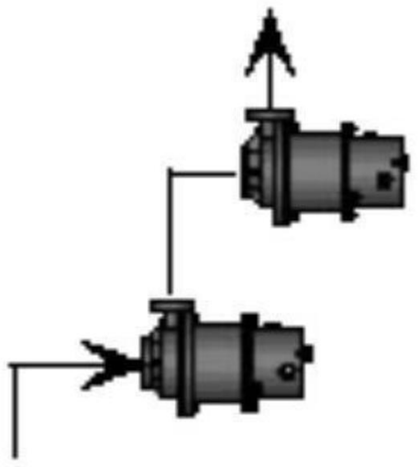
Operation of internal gear pump

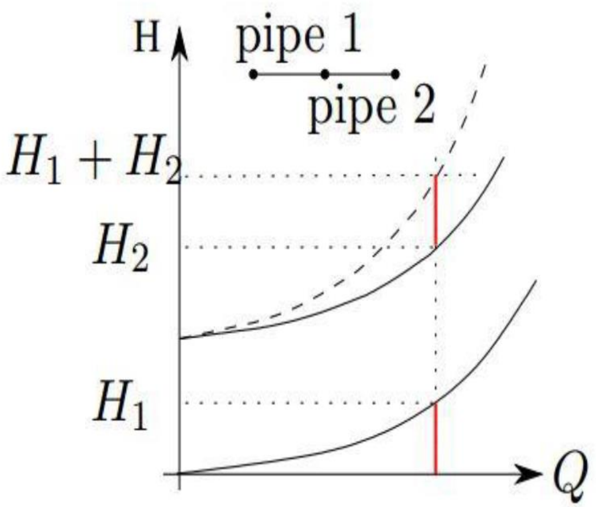
https://nptel.ac.in/courses/112106175/Module%201/Lecture%207.pdf

Arrangement of Pump

Series

- When two pumps are operated in series, the head supplied by the pump is increased
- When two identical pumps with same head and discharge is connected in series, the net head supplied is doubled keeping the discharge constant





Arrangement of Pump

Parallel

- When two pumps are arranged in parallel, discharge through the pump is increased.
- When two identical pumps (which could create same head and discharge) are arranged in parallel the total discharge through the pump is twice the discharge through single pump, with constant head