PHYSICS XI

FLUID DYNAMICS

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FLUID DYNAMICS:

"Fluid dynamics deals with the study of behavior and properties of fluids in motion".

Fluid dynamics has applications in aerodynamics, hydrodynamics, fluid flow in pipes and designing of aircraft and ships.

FLUID FRICTION:

"The resistive force experienced by the object during the motion through the fluids is" called fluid friction.

REAL FLUIDS ARE VISCOUS FLUIDS:

Real Fluids.

"Those fluids which have at least some viscosity are known as real fluids". All the fluids present in nature are real fluids.

Viscous fluids.

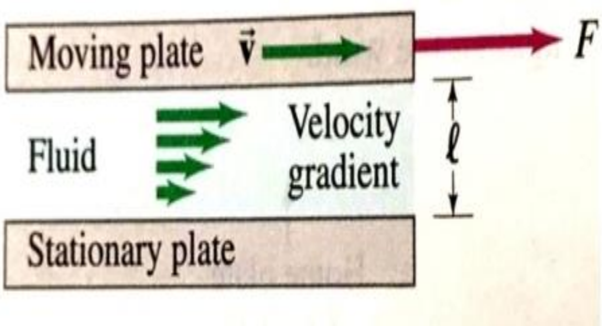
"Those fluids which have resistance to flow and deformation are called viscous fluids".

Viscous fluids have a high resistance to shear or flow and exhibit internal friction between adjacent layers of the fluid. This internal friction is responsible for the viscosity of the fluid.
All the real fluids are viscous fluids. Viscous fluids can be found in many aspects of our daily lives. Here are a few examples: Honey or Syrup, Motor Oil and Paint or Varnish.

VISCOUS FORCE IN A FLUID:

"The resistive force between the different layers of fluids is called viscous force".

Viscous force is an opposition between layers of a fluid. Viscous forces in a fluid are proportional to the rate of change of velocity of fluid's layers.



Viscosity:

"The resistive property of fluid due to the frictional effect between the different layers of" flowing fluid is called viscosity.

Some fluids flow more easily than others. For example honey is very thick and flows very slowly while water is very thin and flows very quickly.

Coefficient of viscosity:

"The tangential force required maintaining a unit velocity gradient between the layers of" fluid is known as coefficient of viscosity.

Or

"The numeric value of resistance to the flow of fluid is called coefficient of viscosity".

It is represented by Greek alphabet "η" (eta).

DERIVATION:

Consider a fluid between the two plane surfaces (plates) over each other. the layer of fluid in contact with the lower surface is stationary due to adhesive force, where as the next layer moves slowly over the first. Each upper layer will move with little more velocity as compared to lower layer.
The opposing force between the layers of fluid is directly proportional to the relative velocity "v" of layers, area of fluid in contact with each plate "A" and separation "l" between the plane surfaces.

$$F \propto v$$

$$F \propto A$$

$$F \propto \frac{1}{l}$$

By combining all the relations.

$$F \propto \frac{v\,A}{l}$$

$$F = \eta\left(\frac{v\,A}{l}\right)$$

Where "η" is known as coefficient of viscosity.

$$\eta = \frac{F\,l}{v\,A}$$

It is also written as.

$$\eta = \frac{\frac{F}{A}}{\frac{v}{l}}$$

Where "$\frac{v}{l}$" is called velocity gradient and define as.

"The rate of change of velocity with distance normal to the direction of flow of layers of" the fluid is known as velocity gradient.

Unit of coefficient of viscosity:

The SI base unit of "η" is N.s / m^2 = Pa. s (Pascal. second).
In CGS system unit of "η" is dyne. S / cm^2 = P (Poise).

Effect of temperature.

The viscosity of liquids decrease rapidly by the increase in temperature and increases in gases by the increase of temperature.

DRAG FORCE:

"If a body moves through a fluid, it experiences an opposing force due to viscosity of fluid is called drag" force.
Even the less viscosity of air, causes a large drag force on the car as it moves at high speed.

STOKE`S LAW.

Stoke`s law describes the drag force experienced by a small sphere moving through a viscous fluid.
The drag force acting on the sphere moving through the fluid is directly proportional to its velocity, radius and viscosity of the fluid.
Drag force is given by,

$$Drag\ force = F = 6\pi\eta rv$$

TERMINAL VELOCITY:

It is the uniform velocity of an object (sphere) moving through the viscous medium (fluid) under the action of resultant of force of gravity and drag force due to viscosity.

DERIVATION:

Consider a solid sphere of mass "m" density "ρ" and radius "r" falls vertically downward under the influence of gravity in a long column of viscous fluid. The falling sphere is acted upon by two force, which are.
W = weight of the sphere acting downward.
F = drag force by fluid acting upward.
The drag force is proportional to the velocity 'v' of sphere. Initially the weight of sphere is greator than the drag force of fluid.
At the certain instant, the drag force becomes equal to the weight of sphere. The net force on sphere then becomes zero and now sphere falls with uniform velocity (terminal velocity).
By using Stoke`s law

$$F = 6\pi\eta rv ----(1)$$

The weight of sphere

$$W = mg$$

Where m = (4/3)πρr^3

$$W = \frac{4}{3}\pi\rho r^3 g ----(2)$$

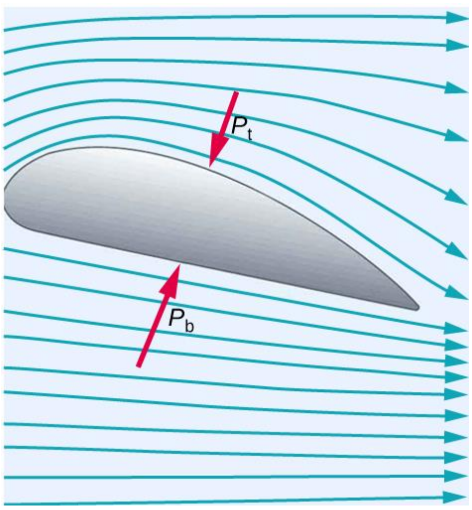
For terminal velocity.

$$F = W$$

From equation (1) and (2),

$$6\pi\eta rv = \frac{4}{3}\pi\rho r^3 g$$

$$6\eta v = \frac{4}{3}\rho r^2 g$$



$$v = \frac{\frac{4}{3}\rho r^2 g}{6\eta}$$

$$v = \frac{2r^2\rho g}{9\eta}$$

This is the required expression of the terminal velocity of a sphere moving through a viscous fluid.

FLUIDS IN MOTION OR FLUID FLOW:

The ability of fluid to flow when an external force is applied on it is called fluid flow.
Fluids can move or flow in many ways. Water may flow smoothly and slowly in a quiet stream or violently over a waterfall. The air may form a gentle breeze or a raging tornado.
To deal with such diversity, it is necessary to classify some of the basic types of fluid flows.

TYPES OF FLUID FLOW:

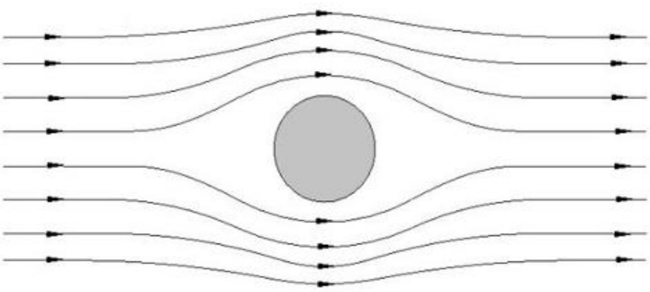
In steady flow, the velocity of the fluid particles at any instant is constant as time passes. Every particle passing through a certain point has the same velocity whereas at another location the velocity may vary, as in a river, which usually flows fastest near its center and slows near its banks.

STREAMLINE FLOW OR LAMINAR FLOW:

Such a flow of fluid in which it's all particles passing through a certain point with same velocity is known as streamline flow.
The path taken by the particles of fluid is known as streamline. Streamlines do not cross each other. The streamline may be a straight line or curved. The direction of stream lines as the direction of velocity of the fluid at that point.

Characteristics of laminar flow:

Streamline flow
Smooth velocity profile
Low mixing and diffusion
Predictable flow behavior
Low Reynolds number



TURBULENT FLOW:

Such a flow of fluid in which all the particles does not follow the same velocity at the certain point is called turbulent flow.
In turbulent flow there are continuous fluctuation in velocity and pressure at each point. If the velocity of fluid is greater than critical velocity, then motion losses all its order lines and becomes zigzag.

TRANSIENT FLOW:

Such a flow of fluid in which the flow velocity and pressure are changing with time is called transient flow.
When changes occur to a fluid system such as the starting or stopping of a pump, closing or opening a valve, or changes in tank levels then transient flow conditions exist.

UNSTEADY FLOW:

Such a flow of fluid in which its velocity, pressure and density vary at different locations and change over time is called unsteady flow.
Unsteady flow can occur in various fluid systems and is often associated with dynamic or transient conditions. Some examples of situations that involve unsteady flow include: Water waves, Pulsatile blood flow, Pipe filling and draining, Turbulent flow etc.

INCOMPRESSIBLE FLUID FLOW:

Mostly liquids are incompressible during which density of fluid remains constant even with varying pressure. In contrast, gases are highly compressible. However, there are certain situations in which the density of a flowing gas remains constant enough that the flow can be considered incompressible.

NON-VISCOUS FLUID FLOW:

An incompressible, non-viscous fluid is called an ideal fluid, with zero viscosity flows in an unhindered manner with no dissipation of energy.
Although no real fluid has zero viscosity at normal temperatures, some fluids have negligibly small viscosities.

TRANSITION FROM LAMINAR TO TURBULENT FLOW (TURBULENCE):

When the speed of flowing fluid exceeds a certain critical value, the flow is no longer laminar. For fluid in pipe, the flow pattern breaks down and becomes extremely irregular and complex and changes continuously with time. This irregular flow is called turbulence.
The transition from laminar to turbulent flow is often very sudden. A flow pattern that is stable at low speed suddenly becomes unstable when a critical speed is reached. Irregularities in the flow pattern can be caused by roughness in the pipe wall, variation in density of the fluid and many other factors. The turbulence in the flow of fluid is described by Reynold`s number.

REYNOLD`S NUMBER:

The ratio of inertial force to the viscous force of fluid is known as Reynold`s number.

Derivation:

Consider a fluid of viscosity ‘Ƞ’ density ‘ρ’ is moving with velocity ‘v’ in a pipe of cross sectional area ‘A’ and diameter ‘D = L’.

$$Reynold`s\ number = \frac{inertial\ force}{viscous\ force}$$

$$R_e = \frac{F_i}{F_v}$$

Where,

$$F_i = \rho A v^2$$

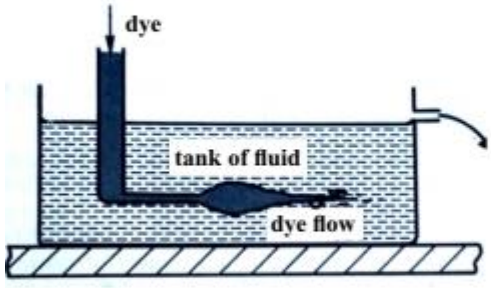
And

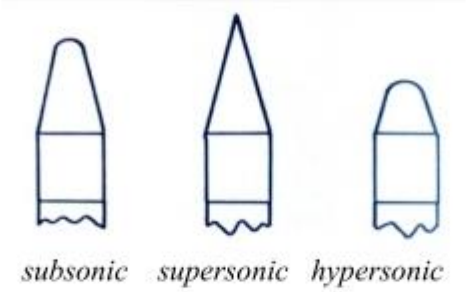
$$F_v = \eta A \frac{v}{l}$$

Now,

$$R_e = \frac{\rho A v^2}{\eta A \frac{v}{l}}$$

$$R_e = \frac{\rho v l}{\eta}$$





For the different flows of fluid.
if $R_e < 2300$, the flow of fluid is laminar.
If $2300 < R_e < 4000$, the flow is transient.
If $R_e > 4000$, the flow is turbulent.

DEMONSTRATION OF FLUID FLOW:

The flow of liquid can easily be demonstrated with the apparatus shown in figure. A dye flows from the tube into the tank and by altering the pressure head the flow can be made either turbulent or laminar. As you can see in figure, the flow becomes turbulent when the line ceases to be straight.

STREAMLINING OF BODIES:

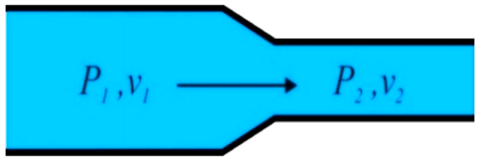
The streamlining of bodies are most important in the design of cars, submarines and nose cones of aircrafts and rockets, since a reduction in drag can reduce vibration and also save large amounts of fuel. Figure shows the best shapes for rocket cones for the subsonic, supersonic and hypersonic flight respectively.

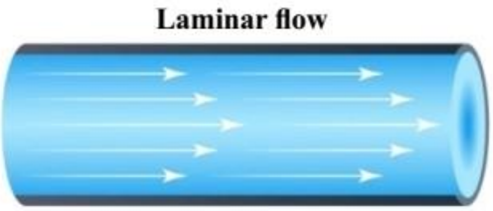
Fluid flow and resistance to motion in fluids involve turbulent rather than laminar conditions:

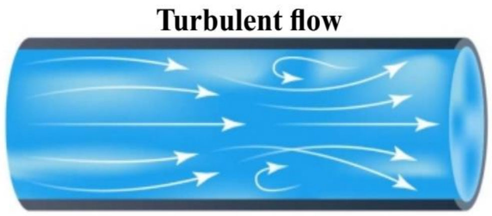
In practical examples of fluid flow and resistance to motion in fluids, turbulent conditions are more prevalent than laminar conditions.
Several factors contribute to the prevalence of turbulent flow in practical scenarios:

HIGH REYNOLDS NUMBERS:

Turbulent flow is more likely to occur at higher Reynolds numbers, which is a dimensionless parameter that measures the ratio of inertial forces to viscous forces in the fluid. In many real-world applications, such as in industrial processes, transportation, and natural phenomena like rivers and atmospheric flows, the Reynolds numbers are often large enough to induce turbulent behavior.







ROUGH SURFACES:

When fluid flows over rough surfaces, such as in pipes, channels, or around objects, it can lead to turbulent flow due to the disruption of the fluid layers. Turbulence enhances the mixing of fluid components and affects the resistance to motion.

HIGH VELOCITIES:

High flow velocities can promote turbulent behavior, especially in situations where the fluid encounters sudden changes in cross-sectional area or flow direction as shown in figure.

AGITATION AND STIRRING:

In industrial processes, mixing and agitation systems, turbulent flow is deliberately induced to ensure efficient mixing of substances and heat transfer.

PRESSURE GRADIENTS:

Rapid changes in pressure along the flow path can lead to turbulent flow patterns, as the fluid tries to adjust to the varying conditions.

EXAMPLES OF PRACTICAL SITUATIONS INVOLVING TURBULENT FLOW INCLUDE:

- Airflow around vehicles, airplanes, and wind turbines.
- Fluid flow in pipes, especially in scenarios with high flow rates or rough internal surfaces.
- Rivers and streams, where the irregularities in the bed and banks induce turbulence.
- Ocean currents and waves, which often involve turbulent motion.
- Mixing processes in chemical reactors, industrial tanks, and bioreactors.
- Combustion in engines and furnaces, where turbulent mixing of fuel and air improves combustion efficiency.

While laminar flow can occur in specific situations, such as slow and smooth flow in small tubes or in some laboratory setups, turbulent flow dominates in most real world fluid flow applications due to its complex and dynamic behavior, which significantly influences resistance to motion and various other fluid phenomena.

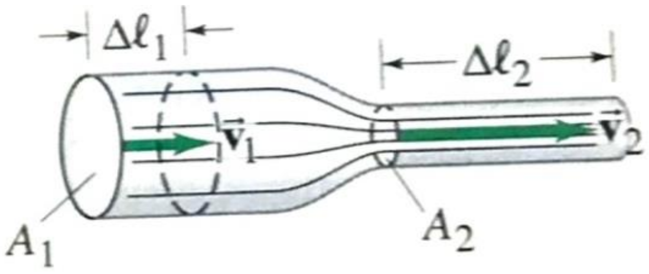
EQUATION OF CONTINUITY:

In fluid dynamics the equation of continuity based upon law of conservation of mass and it is stated as;

> ***"When the fluid is flowing through a pipe then its total rate of mass flow at any instant and at any cross-sectional area of pipe remains same"***

Derivation:

Suppose a steady laminar flow of a fluid through an enclosed tube or pipe as shown in figure the speed of the fluid varies with the diameter of the tube variation. The mass flow rate is given by.



$$Mass\ flow\ rate = \frac{\Delta m}{\Delta t} - - - - (i)$$

The volume of a fluid passing through area 'A_1' in a time 'Δt' is '$A_1\ \Delta l_1$', where 'Δl_1' is the distance the fluid moves in time 'Δt'. The velocity of fluid passing through 'A_1', is v_1. Then the mass flow rate.

By the definition of density

$$\rho = \frac{\Delta m}{\Delta V}$$

$$\rho_1 = \frac{\Delta m_1}{\Delta V_1}$$

$$\Delta m_1 = \rho_1\ \Delta V_1$$

Where

$$\Delta V_1 = A_1\ \Delta l_1$$

Then

$$\Delta m_1 = \rho_1\ A_1\ \Delta l_1 - - - - (1)$$

From average velocity.

$$v_1 = \frac{\Delta l_1}{\Delta t}$$

$$\Delta l_1 = v_1\ \Delta t$$

Substitute in equation (1).

$$\Delta m_1 = \rho_1\ A_1\ v_1\ \Delta t$$

$$\frac{\Delta m_1}{\Delta t} = \rho_1 A_1 v_1 ----(2)$$

The volume of a fluid passing through area 'A_2' in a time 'Δt' is '$A_2 \Delta l_2$', where 'Δl_2' is the distance the fluid moves in time 'Δt'. The velocity of fluid passing through 'A_2', is v_2. Then the mass flow rate.

$$\frac{\Delta m_2}{\Delta t} = \rho_2 A_2 v_2 ----(3)$$

The mass flow rate through A_1 and A_2 must be equal.

$$\frac{\Delta m_1}{\Delta t} = \frac{\Delta m_2}{\Delta t}$$

From equation (2) and (3)

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

If the fluid is incompressible which is an excellent approximation for liquids under most circumstances, then $\rho_1 = \rho_2 = \rho$, the equation of continuity is.

$$A_1 v_1 = A_2 v_2$$

This is called the equation of continuity.

THE VOLUME RATE OF FLOW.

The volume of fluid passing through a given point per second is equal to the product of area and velocity.

$$\frac{\Delta V}{\Delta t} = A \frac{\Delta l}{\Delta t} = Av$$

Its SI base unit is m^3/sec.

BERNOULLI'S PRINCIPLE:

Bernoulli's Principle states that;

"The velocity of a fluid is high, the pressure is low and the velocity is low, the pressure is high".

BERNOULLI'S EQUATION:

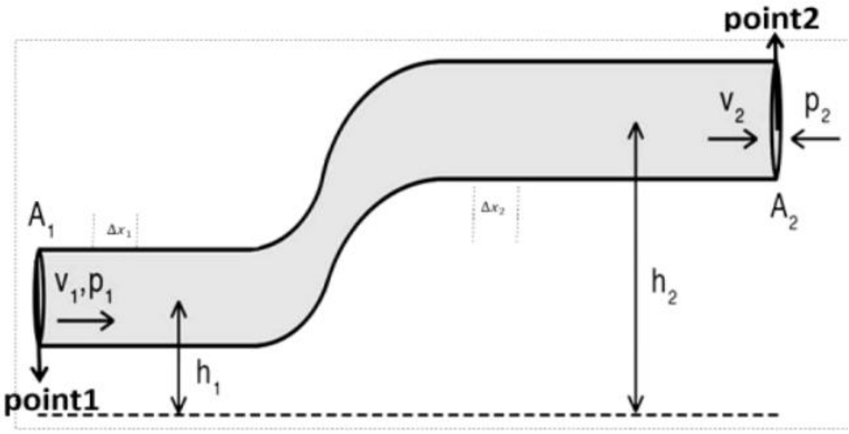
Bernoulli's equation is based upon the law of conservation of energy, for the ideal fluid , the total energy of fluid remains constant throughout the flow.

Statement:

"The sum of pressure, kinetic energy per unit volume and potential energy per unit volume of an ideal fluid throughout its steady flow remains constant".

ASSUMPTIONS:

The flow must be steady and streamline.
The fluid is incompressible.
Density should remain constant.
There are no viscous forces in the fluid.
The friction is negligible.



DERIVATION:

Consider a steady flow of incompressible and non-viscous fluid through a pipe, which has non-uniform cross sectional area at different height as shown in figure.

WORK DONE AT POINT 1:
At point '1' the height of the pipe is 'h_1' and the cross-sectional area 'A_1'. The velocity of fluid is 'v_1' and the pressure 'P_1'. Thus the work done on the fluid at distance 'Δx_1' in time 'Δt' by applied force 'F_1' is given as.

$$W = Fd\,cos\theta$$

$$W_1 = F_1 \Delta x_1 \,cos0^o$$

$$W_1 = F_1 \Delta x_1$$

Where $F_1 = P_1 A_1$

$$W_1 = P_1\, A_1 \Delta x_1 - - - - - (1)$$

WORK DONE AT POINT 2:
At point '2' the height of the pipe is 'h_2' and the cross-sectional area 'A_2'. The velocity of the fluid is 'v_2' and the pressure 'P_2'. Thus the work done on the fluid at distance 'Δx_2' in time 'Δt' by applied force 'F_2' is given as.

$$W_2 = -\,P_2\, A_2 \Delta x_2 - - - - - (2)$$

The total work done is.

$$W = W_1 + W_2$$

From equation 1 and 2.

$$W = P_1\, A_1\, \Delta x_1 - P_2\, A_2\, \Delta x_2$$

Where $\Delta x = v\ \Delta t$

$$W = P_1\, A_1\, v_1\, \Delta t - P_2\, A_2\, v_2\, \Delta t$$

From the equation of continuity

$$A_1\, v_1 = \;A_2\, v_2 = A\, v$$

$$W = P_1 \ A\,v - P_2\,A\,v\,\Delta t$$

$$W = (P_1 \ - P_2)\,A\,v\,\Delta t$$

But 'A v Δt = A Δx = V (Volume)

$$W = (P_1 \ - P_2)$$

Where V = m / ρ

$$W = (P_1 \ - P_2)\frac{m}{\rho} - - - - (3)$$

According to work energy theorm.

$$W = \ \Delta K.E + \Delta P.E$$

$$(P_1 \ - P_2)\frac{m}{\rho} = \left(\frac{1}{2}mv_2^2 \ - \ \frac{1}{2}mv_1^2\right) + (m\,g\,h_2 - m\,g\,h_1)$$

$$(P_1 \ - P_2)\frac{m}{\rho} = m\left(\frac{1}{2}v_2^2 \ - \ \frac{1}{2}v_1^2 + g\,h_2 - \ g\,h_1\right)$$

$$(P_1 \ - P_2) = \rho\left(\frac{1}{2}v_2^2 \ - \ \frac{1}{2}v_1^2 + g\,h_2 - \ g\,h_1\right)$$

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

By arranging

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

Or

$$P + \frac{1}{2}\,\rho v^2 + \rho\,g\,h = Constant$$

This is known as Bernoulli`s equation. Where;

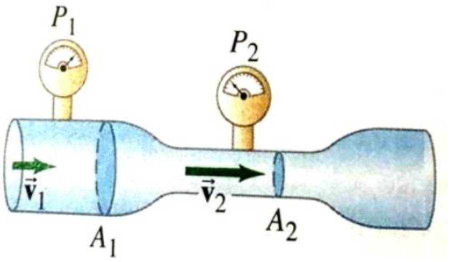
$\frac{1}{2}\,\rho v^2 + \rho\,g\,h$ **= Total pressure**

$\rho\,g\,h$ **= Static pressure**

$\frac{1}{2}\,\rho v^2$ **= Dynamic pressure**

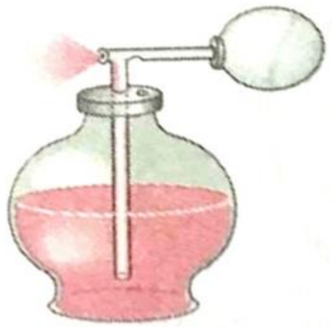
APPLICATIONS OF BERNOULLI'S PRINCIPLE:

Bernoulli's principle, also known as the Bernoulli`s effect, describes the relationship between fluid velocity and pressure in a flowing fluid



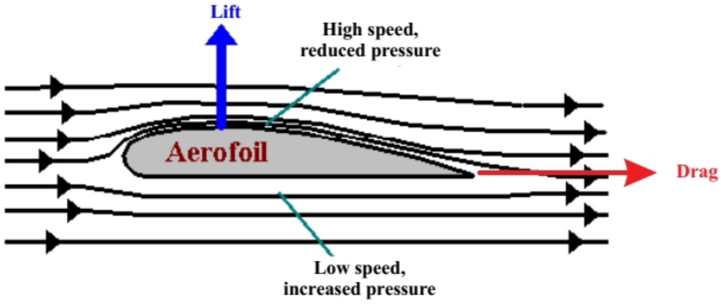
FILTER PUMP:

In a filter pump, Bernoulli's principle is applied to increase the pressure of the fluid passing through the pump. By reducing the cross- sectional area of the pump's outlet, the fluid's velocity increases according to the principle, leading to a decrease in pressure (as kinetic energy increases). This pressure drop helps draw fluid into the pump and through the filter medium, facilitating the filtration process.



VENTURI METER:

A Venturi meter is a device used to measure the flow rate of a fluid in a pipe. It consists of a gradually narrowing tube (Venturi tube) inserted in the pipe. As the fluid flows through the narrowing section, its velocity increases according to Bernoulli's principle, and the pressure decreases. By measuring the pressure difference between the narrowest section and the wider parts of the pipe, the flow rate can be determined.

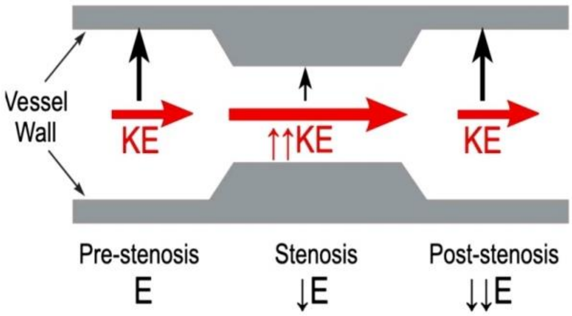


ATOMIZER:

Atomizers are devices used to convert liquids into fine sprays or mists. The application of Bernoulli's principle is crucial in this process. As the liquid passes through a small nozzle in the atomizer, its velocity increases, leading to a decrease in pressure according to the principle. This decrease in pressure facilitates the breakup of the liquid into tiny droplets or a fine spray.

FLOW OF AIR OVER AN AEROFOIL:

When air flows over an aerofoil (such as the wing of an aircraft), the shape of the aerofoil causes the air to travel faster over the top surface compared to the bottom surface. According to Bernoulli's principle, the air pressure decreases over the top surface due to the increased velocity, creating a pressure difference that results in lift, allowing the aircraft to stay airborne



BLOOD PHYSICS:

In the circulatory system, Bernoulli's principle is applicable to the flow of blood through blood vessels, particularly in areas of constriction or stenosis. When the diameter of a blood vessel narrows, the blood velocity increases, leading to a decrease in pressure, which can have clinical implications in conditions such as atherosclerosis or stenos is. It's essential to note that while Bernoulli's principle is an excellent theoretical tool for understanding fluid behavior in these applications, real-world fluids may have additional complexities, such as viscosity and compressibility, which need to be considered for precise calculations and analyses.

SHORT REASONING QUESTIONS

1 What is difference between streamline and turbulent flow?

Ans: **STREAMLINE**

1 Streamline flow in fluids is defined as the flow in which the fluids flow in parallel layers such that there is no disruption or intermixing of the layers and at a given point, the velocity of each fluid particle passing by remains constant with time.

2. The Reynolds number is less than 2000 in a laminar flow.

3. Shear stress in laminar flow depends only on the viscosity and is independent of the density.

TURBULENT FLOW:-

1 Turbulent flow is uneven, unstable and exceeds the fluid's critical velocity.

2. The layers of the fluid obstruct the motion of the other layer.

3. The Reynolds number is greater than 4000.

2 Would a drinking straw work in space where there is no gravity?

Ans No, you can't. Because there is no atmosphere (filled with air) and atmospheric pressure. ie; straw depends on the surrounding pressure of the atmosphere to push matter into our mouths, it follows that a straw could not work in space.

3 Why do airplanes take off into wind?

Ans: Airplanes take off into the wind because the oncoming wind increases the airflow over the wings, generating more lift. This allows the airplane to reach the required lift for takeoff more quickly and with less ground distance required.

4 Describe terminal velocity in liquids.

Ans Terminal velocity is defined as the highest velocity attained by an object falling through a liquid. It is observed when the sum of drag force and buoyancy is equal to the downward gravity force acting on the object. The acceleration of the object is zero as the net force acting on the object is zero.

5 Discuss the significance of Reynolds number.

Ans: The Reynolds number determines whether a fluid flow is steady or unsteady. (laminar and turbulent) If a flow is laminar, fluids will move along smooth streamlines. If the flow is turbulent, these streamlines break up and the fluid will move irregularly.

For the different flows of fluid.

if $R_e < 2300$, the flow of fluid is laminar.

If $2300 < R_e < 4000$, the flow is transient.

If $R_e > 4000$, the flow is turbulent.

6. State Bernoulli's principle.

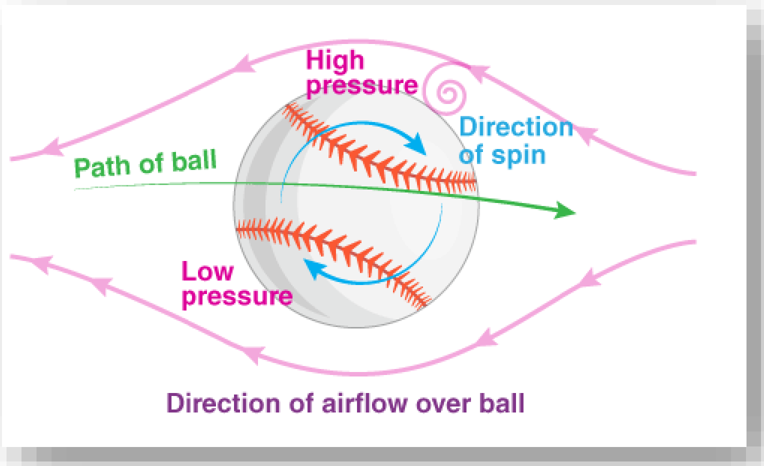
The total mechanical energy of the moving fluid comprising the gravitational potential energy of elevation, the energy associated with the fluid pressure and the kinetic energy of the fluid motion, remains constant.

7 Give two applications of Bernoulli 's principle.

Ans:

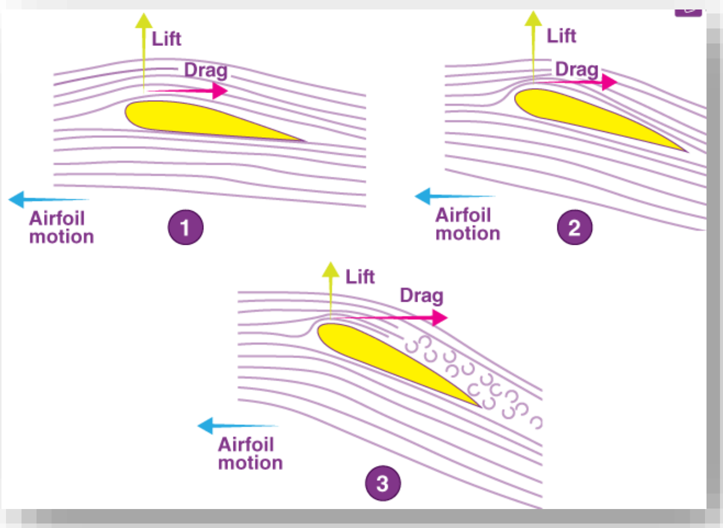
CURVE OF A BASEBALL

When the baseball takes a curved trajectory as it passes the plate, in most cases, the batter would not be able to judge the path of the ball and miss the ball. One of the crucial aspects of curveball can be explained using a formula typically used to describe fluid flow. Bernoulli's equation can be used to explain the basic aspect of the curve of a baseball (curveball). Usually, Bernoulli's equation points to pressure, height, and velocity ("air" is the fluid). At any particular point in the fluid (air), the K (constant) will be equal to the total sum of the other three values (height, pressure, and velocity).



AIRFOIL AND BERNOULLI'S PRINCIPLE

The air over the top of a typical airfoil encounter compressed flow lines and boosted air speed compared to the wing. This introduces a reduction in pressure on the top (as per the Bernoulli equation) and produces a lift force. Aerodynamicists use the Bernoulli concept to explain the pressure calculations made in wind tunnels. They show that when pressure calculations are done at multiple places around the airfoil and added together, it is similar to the observed lift.



8 'Fluid flow is turbulent rather than laminar', support this statement.

Ans: **Turbulent flow**, type of fluid (gas or liquid) flow in which the fluid undergoes irregular fluctuations, or mixing, in contrast to laminar flow, in which the fluid moves in smooth paths or layers. In turbulent flow the speed of the fluid at a point is continuously undergoing changes in both magnitude and direction. The flow of wind and rivers is generally turbulent in this sense, even if the currents are gentle. The air or water swirls and eddies while its overall bulk moves along a specific direction.

Detailed knowledge of the behavior of turbulent flow regimes is important in engineering because **most industrial flows**, especially those in nuclear engineering, **are turbulent.**

9 Discuss the importance of Stokes law

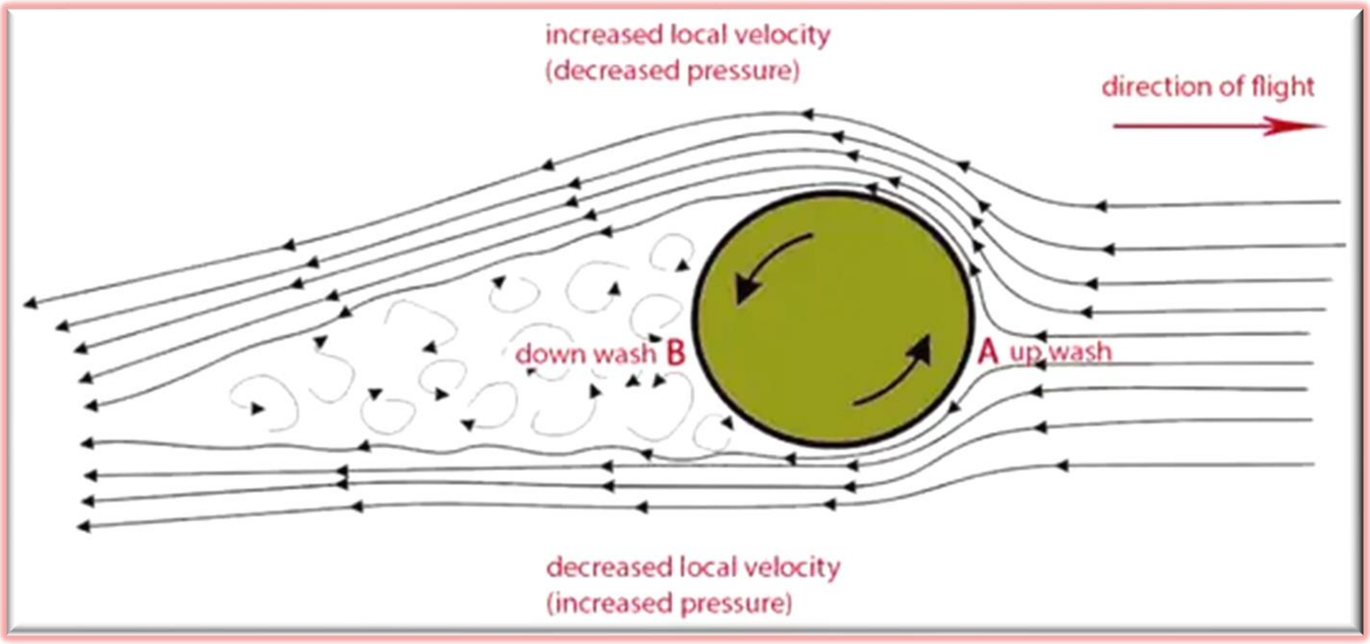
Ans: Stokes Law is important because it describes the relationship between the drag force experienced by an object and the object's velocity through a fluid. This linear relationship means that the drag force is proportional to the velocity.

The following are the importance of Stoke's Law:

1. **Millikan employs this concept in an oil-drop experiment to determine the electronic charge.**
2. **The person falling from a great parachute.**
3. **Cloud formation.**

10 Justify spin of the ball in Bernoulli's principle

Ans: **Bernoulli's effect** has another interesting consequence. Suppose a **ball** is **spinning** as it travels through the air. As the ball spins, the surface friction of the ball with the surrounding air drags a thin layer (referred to as the **boundary layer**) of air with it. It can be seen from the picture the boundary layer is on one side traveling in the **same direction** as the air stream that is flowing around the ball (the upper arrow). On the other side, the boundary layer is traveling in the **opposite direction** (the bottom arrow), on the side of the ball where the air stream and boundary layer are moving in the opposite direction (the bottom arrow) to each other, friction between the two **slows the air stream**. On the opposite side, these layers move in the same direction, and the **stream moves faster.**



SELF-ASSESSMENT QUESTIONS

Q1) What is viscosity and how does it relate to fluid friction?

Viscosity:

Viscosity is the measure of resistance of fluid to deformation or flow. It is due to the internal resistance between the layers of fluid.

Viscosity describes that how ‘thick’ or ‘sticky’ a fluid is.

For example, honey has a much higher viscosity than water

Fluid friction; (Viscous drag)

Fluid friction is the resistive force experienced by a body during the motion through the viscous fluid.

Fluid friction arises from the interaction between molecules of fluid and the surface of the body.

Relation between viscosity and fluid friction:

Fluid friction directly relates to the viscosity of the fluid. According to Stoke`s law, the viscous drag experienced by a small sphere moving through the viscous fluid is given as.

$$F = 6\pi\eta rv$$

Where “F” is the viscous drag (fluid friction) and “η” is the viscosity of fluid.

Q2) Describe the relationship between fluid velocity and fluid friction.

Fluid velocity:

The velocity with which the particles of fluid move at a given point within the fluid flow.

Fluid friction has a significant role in determining the fluid velocity by retarding the motion of fluid particles. Fluid friction resists the relative motion between the adjacent layers of fluid. This resistance retards the fluid velocity.

Q3) What factors affect the terminal velocity?

Terminal velocity:

The uniform velocity with which an object is moving through a viscous fluid is called terminal velocity.

By Stoke`s law, the terminal velocity of a small sphere through the viscous fluid is given as.

$$v_t = \frac{2}{9}\left(\frac{r^2 \rho g}{\eta}\right)$$

This expression shows that;

The terminal velocity is affected by the radius of the sphere, the density of the sphere, and the viscosity of the fluid.

Q4) State the equation of continuity in terms of fluid flow.

Equation of Continuity:

It is stated as.

The mass flow rate of an incompressible fluid at any instant and any point during the steady flow through a pipe remains the same.

Mathematically it is given as.

$$\frac{\Delta m_1}{\Delta t} = \frac{\Delta m_2}{\Delta t}$$

Also

$$A_1 v_1 = A_2 v_2$$

Where A_1 and A_2 are the cross-sectional areas of pipe and v_1 and v_2 are the velocities of fluid at respective cross sections of pipe.

Q5) How the equation of continuity does relate to the conservation of mass?

Equation of continuity based upon the law of conservation of mass.
According to the equation of continuity, the mass flow rate of an incompressible fluid during the steady flow remains the same. This implies that the mass of fluid remains conserved during the steady flow at any instant of time and at any point through the pipe. That is;

$$\frac{\Delta m_1}{\Delta t} = \frac{\Delta m_2}{\Delta t}$$

$$\frac{\Delta m}{\Delta t} = \text{Constant}$$

Q6) How does the velocity of a fluid change when it flows through a constricted pipe?

According to the principle of the equation of continuity, the product of the cross-sectional area of the constricted pipe and the velocity of the fluid is constant. That is.

$$A_1 v_1 = A_2 v_2$$

$$Av = \text{Constant}$$

$$v = \frac{\text{Constant}}{A}$$

$$v \propto \frac{1}{A}$$

It shows that the velocity of the fluid is inversely proportional to the cross-sectional area of the constricted pipe.