

BLACK DIAMOND SCHOOL OF ENGINEERING,  
JHARSUGUDA

**STUDY MATERIAL**



ON

**HYDRAULIC AND IRRIGATION ENGINEERING  
(TH-2)**

**FOURTH SEMESTER CIVIL ENGINEERING**

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**HYDRAULIC AND IRRIGATION  
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BDSE JHARSUGUDA

## Chapter-I

### HYDROSTATICS

Hydrostatic is that branch of science which relating to fluids at rest or to the pressures they exert or transmit **Hydrostatic Pressure**.

#### **Fluid:-**

**Fluid** is a substance that continuously deforms (flows) under an applied shear stress. Fluids are a subset of the phase of matter and include liquids, gases, plasmas and, to some extent, plastic solids. Fluids can be defined as substances which have zero shear modulus or in simpler terms a fluid is a substance which cannot resist any shear force applied to it.

- ❖ Fluid is a substance which is capable of flowing
- ❖ Conform the shape of the containing vessel
- ❖ Deform continuously under application of small shear force

#### **PROPERTIES OF FLUID:-**

##### **Density:-**

The density of a fluid, is generally designated by the Greek symbol  $\rho$  (*rho*), is defined as the mass of the fluid over a unit volume of the fluid at standard temperature and pressure. It is expressed in the SI system as kg/m<sup>3</sup>.

$$\rho = \lim \frac{\Delta m}{\Delta V} = \frac{dm}{dV}$$

If the fluid is assumed to be uniformly dense the formula may be simplified as:

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

Example: - setting of fine particles at the bottom of the container.

##### **Specific Weight:-**

The specific weight of a fluid is designated by the Greek symbol  $\gamma$  (*gamma*), and is generally defined as the weight per unit volume of the fluid at standard temperature and pressure. In SI systems the units is N/m<sup>3</sup>.

$$\lambda = \rho * g$$

$g$  = local acceleration of gravity and  $\rho$  = density

*Note:* It is customary to use:

$$g = 32.174 \text{ ft/s}^2 = 9.81 \text{ m/s}^2$$

$$\rho = 1000 \text{ kg/m}^3$$

### **Relative Density (Specific Gravity):-**

The relative density of any fluid is defined as the ratio of the density of that fluid to the density of the standard fluid. For liquids we take water as a standard fluid with density  $\rho=1000 \text{ kg/m}^3$ . For gases we take air or  $\text{O}_2$  as a standard fluid with density,  $\rho=1.293 \text{ kg/m}^3$ .

### **Specific volume:-**

Specific volume is defined as the volume per unit mass. It is just reciprocal of mass density. It is expressed in  $\text{m}^3/\text{kg}$ .

### **Viscosity:-**

Viscosity (represented by  $\mu$ , Greek letter mu) is a material property, unique to fluids, that measures the fluid's resistance to flow. Though a property of the fluid, its effect is understood only when the fluid is in motion. When different elements move with different velocities, each element tries to drag its neighboring elements along with it. Thus, shear stress occurs between fluid elements of different velocities.

Viscosity is the property of liquid which destroyed the relative motion between the layers of fluid.

- ❖ It is the internal friction which causes resistance to flow.
- ❖ Viscosity is the property which control the rate of flow of liquid

Viscosity is due to two factors-

- a) Cohesion between the liquid molecules.
- b) Transfer of momentum between the molecules.

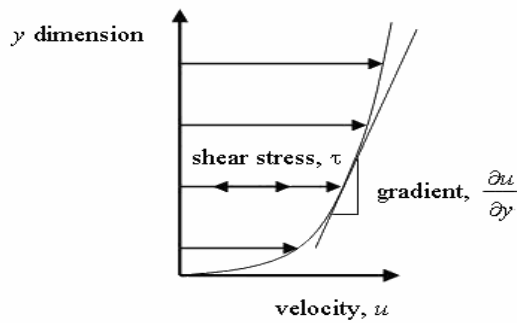


Fig. 1.1

The relationship between the shear stress and the velocity field was that the shear stresses are directly proportional to the velocity gradient. The constant of proportionality is called the coefficient of dynamic viscosity.

$$\tau = \mu \frac{\partial u}{\partial y}$$

### UNIT OF VISCOSITY

- ❖ In mks system unit of viscosity is kgf-sec/m<sup>2</sup>
- ❖ In cgs system unit of viscosity is dyne-sec/cm<sup>2</sup>
- ❖ In S.I system unit of viscosity is Newton-sec/m<sup>2</sup>

### Kinematic viscosity:-

Another coefficient, known as the kinematic viscosity ( $\nu$ , Greek nu) is defined as the ratio of dynamic viscosity and density.

I.et,  $\nu = \mu/\rho = \text{viscosity/density}$

In mks & S.I system unit of kinematic viscosity is meter<sup>2</sup>/sec

In cgs system unit of kinematic viscosity is stoke.

### SURFACE TENSION:-

Surface tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrane under tension. The magnitude of this force per unit length of the free surface will have the same value as the surface energy per unit area. It is denoted by Greek letter sigma( $\sigma$ ). In MKS units, it is expressed as kgf/m while in SI unit is N/m.

It is also defined as force per unit length, or of energy per unit area. The two are equivalent—but when referring to energy per unit of area, people use the term surface energy—which is a more general term in the sense that it applies also to solids and not just liquids.

### Capillarity:-

Capillarity is defined as a phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. The rise of liquid surface is known as capillary rise while the fall of the liquid surface is known as capillary depression. It is expressed in terms of cm or mm of liquid. Its value depends upon the specific weight of the liquid, diameter of the tube and surface tension of the liquid.

### 1.2 Pressure and its measurement:-

#### INTENSITY OF PRESSURE:-

Intensity of pressure is defined as normal force exerted by fluid at any point per unit area. It is also called specific pressure or hydrostatic pressure

$$P = df/da$$

- ❖ If intensity of pressure is uniform over an area “A” then pressure force exerted by fluid equal to

$$\text{Mathematically } F = PA$$

- ❖ If intensity of pressure is not uniform or vary point to point then pressure force exerted by fluid equal to integration of  $P \cdot A$

$$\text{Mathematically } F = \int PA$$

- ❖ Unit of pressure

- $1\text{N/m}^2 = 1 \text{ Pascal}$
- $1\text{KN/m}^2 = 1 \text{ kilo Pascal}$
- $\text{Kilo Pascal} = 1\text{kpa} = 10^3 \text{ Pascal}$
- $1 \text{ bar} = 10^5 \text{ Pascal} = 10^5 \text{ N/m}^2$

#### Pascal's law:-

It states that the pressure or intensity of pressure at a point in a static fluid is equal in all direction.

#### Atmospheric Pressure:-

The atmospheric air exerts a normal pressure upon all surface with which it is in contact and it is called atmospheric pressure. It is also called parametric pressure.

Atmospheric pressure at the sea level is called standard atmospheric pressure.

S.A.P =  $101.3 \text{ KN/m}^2 = 101.3 \text{ kpa} = 10.3\text{m of H}_2\text{O}$

= 760 mm of Hg

=10.3 (milli bar)

### Gauge pressure:-

It is the pressure which measure with help of pressure measuring device in which atmospheric pressure taken as datum.

The atmospheric pressure on scale is marked as zero.

### Absolute pressure:-

Any pressure measure above absolute zero pressure is called absolute pressure.

### Vacuum pressure:-

Vacuum pressure is defined as the pressure below the atmospheric pressure.

### RELATIONSHIP BETWEEN ABSOLUTE PRESSURE, GAUGE PRESSURE, VACUUM PRESSURE:-

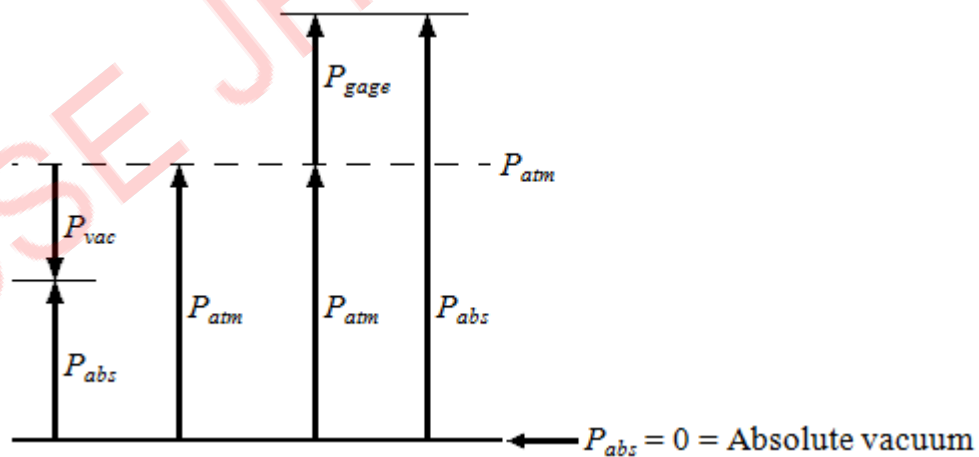


Fig. 1.2

❖ Equations

$P_{\text{gage}} = P_{\text{abs}} - P_{\text{atm}}$	gauge pressure
$P_{\text{vac}} = P_{\text{atm}} - P_{\text{abs}}$	vacuum pressure
$P_{\text{abs}} = P_{\text{atm}} + P_{\text{gage}}$	absolute pressure

❖ Nomenclature

$P_{\text{abs}}$	absolute pressure
$P_{\text{gage}}$	gage pressure
$P_{\text{vac}}$	vacuum pressure
$P_{\text{atm}}$	atmospheric pressure

**Pressure Head:-**

**pressure head** is the internal energy of a fluid due to the pressure exerted on its container. It may also be called **static pressure head** or simply **static head** (but not **static head pressure**). It is mathematically expressed as:

$$\psi = \frac{P}{\gamma} = \frac{P}{\rho g}$$

where

- $\psi$  is pressure head (Length, typically in units of m);
- $P$  is fluid pressure (force per unit area, often as Pa units); and
- $\gamma$  is the specific weight (force per unit volume, typically N/m<sup>3</sup> units)
- $\rho$  is the density of the fluid (mass per unit volume, typically kg/m<sup>3</sup>)
- $g$  is acceleration due to gravity (rate of change of velocity, given in m/s<sup>2</sup>)

If intensity of pressure express in terms of height of liquid column, which causes pressure is also called pressure head.

Mathematically,  $h = P/\gamma$

**Pressure Gauges :-**

The pressure of a fluid is measured by the following devices:-

1. manometers
2. mechanical gauges

**Manometers:-**Manometers are defined as the devices used for measuring the pressure at a point in a fluid by balancing the column of fluid by the same or another column of the fluid. They are classified as:

- a) Simple manometers
- b) Differential manometer



**Mechanical gauges:**-mechanical gauges are defined as the devices used for measuring the pressure by balancing the fluid column by the spring or dead weight. The commonly used mechanical gauges are:-

- a) Diaphragm pressure gauge
- b) Bourdon tube pressure gauge
- c) Dead weight pressure gauge
- d) Bellows pressure gauge

### **1.3 PRESSURE EXERTED ON IMMERSED SURFACE:-**

#### **Hydrostatic forces on surfaces:-**

Hydrostatic means the study of pressure exerted by a liquid at rest. The direction of such pressure is always perpendicular to the surface to which it acts.

#### **Forces on Submerged Surfaces in Static Fluids**

These are the following features of static fluids:-

- Hydrostatic vertical pressure distribution
- Pressures at any equal depths in a continuous fluid are equal
- Pressure at a point acts equally in all directions (Pascal's law).
- Forces from a fluid on a boundary acts at right angles to that boundary.

#### **Fluid pressure on a surface:-**

Pressure is defined as force per unit area. If a pressure  $p$  acts on a small area  $\delta A$  Then the force exerted on that area will be

$$F = p\delta A$$

**TOTAL PRESSURE:-**

Total pressure is defined as the force exerted by a static fluid on a surface when the fluid comes in contact with the surface.

Mathematically **total pressure**,

$$P = p_1 a_1 + p_2 a_2 + p_3 a_3 \dots\dots\dots$$

Where,

- $p_1, p_2, p_3$  = Intensities of pressure on different strips of the surface, and
- $a_1, a_2, a_3$  = Areas of corresponding strips.

The position of an immersed surface may be,

- Horizontal
- Vertical
- Inclined

**Total Pressure On A Horizontal Immersed Surface**

Consider a plane horizontal surface immersed in a liquid as shown in figure 1.

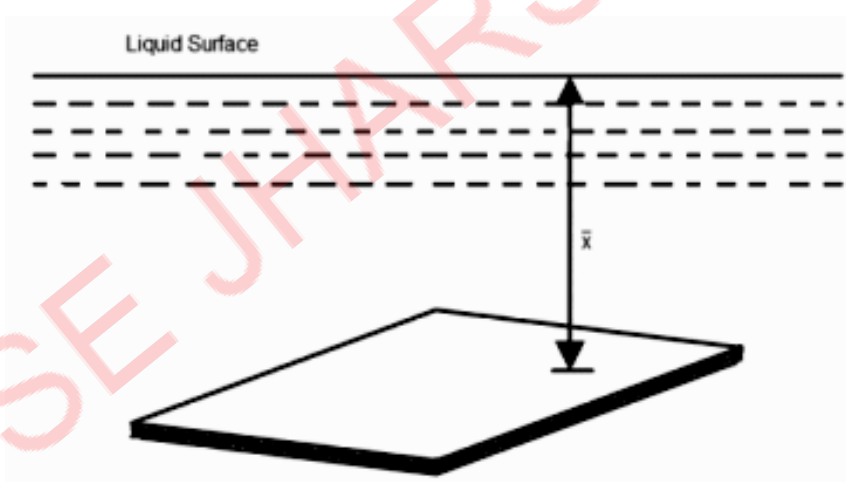


Fig. 1.3

- $\omega$  = Specific weight of the liquid
- $A$  = Area of the immersed surface in  $\text{in}^2$
- $\chi$  = Depth of the horizontal surface from the liquid level in meters

We know that the **Total pressure** on the surface,

**P** = Weight of the liquid above the immersed surface

= Specific weight of liquid \* Volume of liquid

= Specific weight of liquid \* Area of surface \* Depth of liquid

$$= \omega A \chi kN$$

### Total Pressure On A Vertically Immersed Surface

Consider a plane vertical surface immersed in a liquid shown in figure 2.

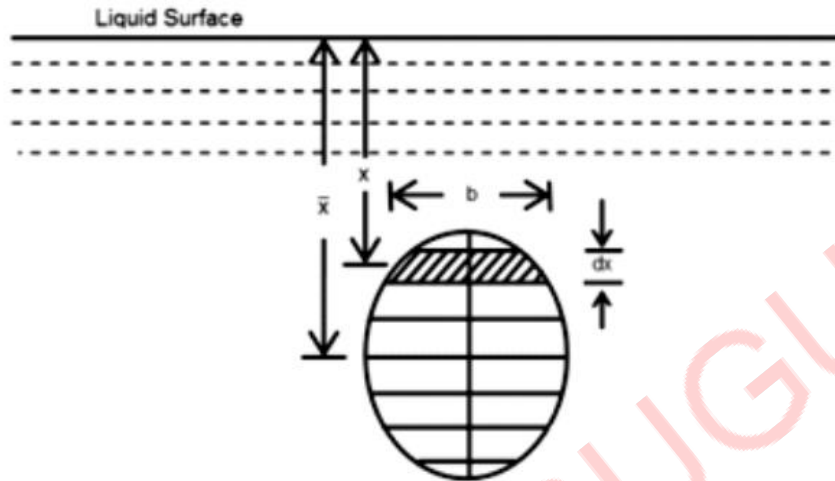


Fig. 1.4

Let the whole immersed surface is divided into a number of small parallel stripes as shown in figure.

Here,

- $\omega$  = Specific weight of the liquid
- $A$  = Total area of the immersed surface
- $\chi$  = Depth of the center of gravity of the immersed surface from the liquid surface

Now, consider a strip of thickness  $dx$ , width  $b$  and at a depth  $x$  from the free surface of the liquid.

The intensity of pressure on the strip =  $\omega \chi$

and the area of strip =  $b \cdot dx$

∴ Pressure on the strip = Intensity of pressure \* Area =  $\omega \chi \cdot b \cdot dx$

Now, Total pressure on the surface,

$$P = \int \omega x \cdot b \cdot dx .$$

$$= \omega \int x \cdot b \cdot dx$$

But,  $w \int x.bdx = \text{Moment of the surface area about the liquid level} = A\bar{x}$

$$\therefore P = wA\bar{x}$$

#### 1.4 FLOTATION AND BUOYANCY:-

##### Archimedes Principle:-

Archimedes' principle indicates that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces. Archimedes' principle is a law of physics fundamental to fluid mechanics. Archimedes of Syracuse formulated this principle, which bears his name.

##### Buoyancy:-

When a body is immersed in a fluid an upward force is exerted by the fluid on the body. This upward force is equal to weight of the fluid displaced by the body and is called the force of buoyancy or simple buoyancy.

##### Centre of pressure:-

The center of pressure is the point where the total sum of a pressure field acts on a body, causing a force to act through that point. The total force vector acting at the center of pressure is the value of the integrated pressure field. The resultant force and center of pressure location produce equivalent force and moment on the body as the original pressure field. Pressure fields occur in both static and dynamic fluid mechanics. Specification of the center of pressure, the reference point from which the center of pressure is referenced, and the associated force vector allows the moment generated about any point to be computed by a translation from the reference point to the desired new point. It is common for the center of pressure to be located on the body, but in fluid flows it is possible for the pressure field to exert a moment on the body of such magnitude that the center of pressure is located outside the body.

##### Center of buoyancy:-

It is defined as the point through which the force of buoyancy is supposed to act. As the force of buoyancy is a vertical force and is equal to the weight of the fluid displaced by the body, the center of buoyancy will be the center of gravity of the fluid displaced.

##### METACENTER:-

The metacentric height (GM) is a measurement of the initial static stability of a floating body. It is calculated as the distance between the centre of gravity of a ship and its metacentre. A larger metacentric height implies greater initial stability against overturning. Metacentric height also has implication on the natural period of rolling of a hull, with very large metacentric heights being associated with shorter periods of roll which are uncomfortable for passengers. Hence, a sufficiently high but not excessively high metacentric height is considered ideal for passenger ships.

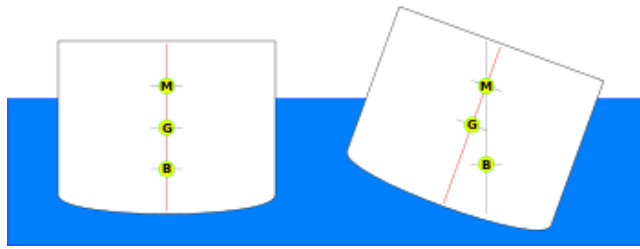


Fig. 1.5

The metacentre can be calculated using the formulae:

$$KM = KB + BM$$

$$BM = \frac{I}{V}$$

#### Metacentric height:-

The distance between the meta-center of a floating body and a center of gravity of the body is called metacentric height.

$$MG = BM - BG$$

$$MG = \frac{I}{V} - BG$$

#### Stability of a submerged body:-

Stable condition:-

- ❖ For stable condition  $w = f_b$  and the point "B" above the CG of the body.

Unstable equilibrium;-

- ❖ For unstable equilibrium  $w = f_b$  and the point B is below the CG of the body.

Neutral equilibrium:-

- ❖ If the force of buoyancy is act as CG of the body.

Stability of a floating body:-

- ❖ For stable condition  $w = f_b$  and the meta centre "m" is about the CG of the body.
- ❖ For unstable equilibrium  $w = f_b$  and the metacentre "m" is below CG of the body.
- ❖ In neutral equilibrium  $w = f_b$  and metacentre "m" is acting at CG of the body.

## Chapter-II

### KINEMATICS OF FLUID FLOW

#### 2.1 Basic equation of fluid flow and their application:-

##### Energy of a Liquid in Motion:-

The energy, in general, may be defined as the capacity to do work. Though the energy exists in many forms, yet the following are important from the subject point of view:

1. Potential energy,
2. Kinetic energy, and
3. Pressure energy.

##### Potential Energy of a Liquid Particle in Motion:-

It is energy possessed by a liquid particle by virtue of its position. If a liquid particle is  $Z$  m above the horizontal datum (arbitrarily chosen), the potential energy of the particle will be  $Z$  metre-kilogram (briefly written as mkg) per kg of the liquid. The potential head of the liquid, at that point, will be  $Z$  metres of the liquid.

##### Kinetic Energy of a Liquid Particle in Motion:-

It is the energy, possessed by a liquid particle, by virtue of its motion or velocity. If a liquid particle is flowing with a mean velocity of  $v$  metres per second; then the kinetic energy of the particle will be  $V^2/2g$  mkg per kg of the liquid. Velocity head of the liquid, at that velocity, will be  $V^2/2g$  metres of the liquid.

##### Pressure Energy of a Liquid Particle in Motion:-

It is the energy, possessed by a liquid particle, by virtue of its existing pressure. If a liquid particle is under a pressure of  $p$  kN/M<sup>2</sup> (i.e., kPa), then the pressure energy of the particle will be  $\frac{p}{w}$  mkg per kg of the liquid, where  $w$  is the specific weight of the liquid. Pressure head of the liquid under that pressure will be  $\frac{p}{w}$  metres of the liquid.

##### Total Energy of a Liquid Particle in Motion:-

The total energy of a liquid, in motion, is the sum of its potential energy, kinetic energy and pressure energy. Mathematically total energy,

$$E = Z + V^2/2g + \frac{P}{w} \text{ m of Liquid.}$$

##### Total Head of a Liquid Particle in Motion:-

The total head of a liquid particle, in motion, is the sum of its potential head, kinetic head and pressure head. Mathematically, total head,

$$H = Z + V^2/2g + \frac{P}{w} \text{ m of liquid.}$$

##### Example

Water is flowing through a tapered pipe having end diameters of 150 mm and 50 mm respectively. Find the discharge at the larger end and velocity head at the smaller end, if

the velocity of water at the larger end is 2 m/s. Solution. Given:  $d_1 = 150\text{mm} = 0.15\text{ m}$ ;  $d_2 = 50\text{ mm} = 0.05\text{ m}$  and  $V_1 = 2.5\text{ m/s}$ . Discharge at the larger end We know that the cross-sectional area of the pipe at the larger end,

$$a_1 = \frac{\pi}{4} \times (0.15)^2 = 17.67 \times 10^{-3} \text{m}^2$$

and discharge at the larger end,

$$Q_1 = a_1 \cdot v_1 = (17.67 \times 10^{-3}) \times 2.5 = 44.2 \times 10^{-3} \text{ m}^3/\text{s}$$

$$= 44.2 \text{ litres/s} \quad \text{Ans.}$$

Velocity head at the smaller end

We also know that the cross-sectional area of the pipe at the smaller end,

$$A_2 = \frac{\pi}{4} \times (0.05)^2 = 1.964 \times 10^{-3} \text{m}^2$$

Since the discharge through the pipe is continuous, therefore

$$a_1 \cdot v_1 = a_2 \cdot v_2$$

$$\text{or } v_2 = \frac{a_1 \cdot v_1}{a_2} = \frac{(17.67 \times 10^{-3}) \times 2.5}{1.964 \times 10^{-3}} = 22.5 \text{ m/s}$$

$\therefore$  Velocity head at the smaller end

$$V_2^2/2g = (22.5)^2/2 \times 9.81 = 25.8 \text{ m} \quad \text{Ans}$$

### Bernoulli's Equation:-

It states, "For a perfect incompressible liquid, flowing in a continuous stream, the total energy; of a particle remains the same, while the particle moves from one point to another." This statement is based on the assumption that there are no "losses due to friction in the pipe. Mathematically,

$$Z + V^2/2g + \frac{P}{w} = \text{Constant}$$

where

$Z$  = Potential energy,

$V^2/2g$  = Kinetic energy, and

$\frac{P}{w}$  = Pressure energy.

Proof

Consider a perfect incompressible liquid, flowing through a non-uniform pipe as shown in Fig-

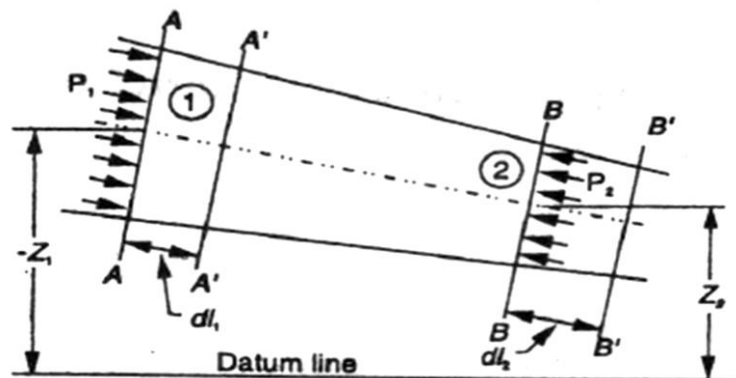


Fig. 2.1

Let us consider two sections AA and BB of the pipe. Now let us assume that the pipe is running full and there is a continuity of flow between the two sections.

Let

$Z_1$  = Height of AA above the datum,

$P_1$  = Pressure at AA,

$V_1$  = Velocity of liquid at AA,

$A_1$  = Cross-sectional area of the pipe at AA, and

$Z_2, P_2, V_2, A_2$  = Corresponding values at BB.

Let the liquid between the two sections AA and BB move to A' and B' through very small lengths  $dl_1$  and  $dl_2$  as shown in Fig. This movement of the liquid between AA and BB is equivalent to the movement of the liquid between AA and A' and BB and B', the remaining liquid between A' and BB being unhorizontally. Let  $W$  be the weight of the liquid between AA and A'. Since the flow is continuous, therefore

$$W = w a_1 dl_1 = w a_2 dl_2$$

$$\text{or } a_1 \times dl_1 = \frac{W}{w} \quad \dots \text{.i)}$$

$$\text{Similarly } a_2 dl_2 = \frac{W}{w}$$

$$\therefore a_1 \cdot dL_1 = a_2 \cdot dL_2 \quad \dots \text{.ii)}$$

We know that work done by pressure at AA, in moving the liquid to A'

$$\text{Force} \times \text{Distance} = P_1 \cdot a_1 \cdot dL_1$$

Similarly, work done by pressure at BB, in moving the liquid to B'

$$= P_2 a_2 dl_2$$

∴ minus sign is taken as the direction of  $P_2$  is opposite to that of  $P_1$ )

∴ Total work done by the pressure

$$= P_1 a_1 dl_1 - P_2 a_2 dl_2$$

$$= P_1 a_1 dl_1 - P_2 a_1 dl_1$$

$$\dots (a_1 dl_1 = a_2 dl_2)$$

$$= a_1 \cdot dl_1 (P_1 - P_2) = \frac{W}{w} (P_1 - P_2) \dots (a_1 \cdot dl_1 = \frac{W}{w})$$

$$\text{Loss of potential energy} = W (Z_1 - Z_2)$$

$$\text{and again in kinetic energy} = W[(V_2^2/2g) - (V_1^2/2g)] = \frac{W}{2g} (v_2^2 - v_1^2)$$

We know that loss of potential energy + Work done by pressure

= Gain in kinetic energy

$$\therefore W (Z_1 - Z_2) + \frac{W}{w} (P_1 - P_2) = \frac{W}{2g} (v_2^2 - v_1^2)$$

$$(Z_1 - Z_2) + (p_1/w) - (p_2/w) = v_2^2/2g - v_1^2/2g$$

$$\text{Or } Z_1 + v_1^2/2g + (p_1/w) = Z_2 + v_2^2/2g + (p_2/w)$$

which proves the Bernoulli's equation.

### Euler's Equation For Motion

The Euler's equation for steady flow of an ideal fluid along a streamline is based on the



Newton's' Second Law of Motion. The integration of the equation gives Bernoulli's equation in the form of energy per unit weight of the flowing fluid. It is based on the following assumptions:

1. The fluid is non-viscous (i.e., the frictional losses are zero).
2. The fluid is homogeneous and incompressible (i.e., mass density of the fluid is constant).
3. The flow is continuous, steady and along the streamline.
4. The velocity of flow is uniform over the section.
5. No energy or force (except gravity and pressure forces) is involved in the flow.

Consider a steady flow of an ideal fluid along a streamline. Now consider a small element

AB of the flowing fluid as shown in Fig.

Let

$dA$  = Cross-sectional area of the fluid element,

$ds$  = Length of the fluid element,

$dW$  = Weight of the fluid element,

$p$  = Pressure on the element at A,

$p + dp$  = Pressure on the element at B, and

$v$  = Velocity of the fluid element.

We know that the external forces tending to accelerate the fluid element in the direction of the streamline

$$= p \cdot dA - (p + dp) dA \\ = -dp \cdot dA$$

we also know that the weight of the fluid element,

$$dW = \rho g \cdot dA \cdot ds$$

From the geometry of the figure, we find that the component of the weight of the fluid element

in the direction of flow

$$= - \rho g \cdot dA \cdot ds \cos \theta$$

$$= - \rho g \cdot dA \cdot ds \left( \frac{dz}{ds} \right)$$

$$= - \rho g \cdot dA \cdot dz$$

$$\therefore \text{mass of the fluid element} = \rho \cdot dA \cdot ds$$

We see that the acceleration of the fluid element

$$\frac{dv}{dt} = \frac{dv}{ds} \times \frac{ds}{dt} = v \cdot \frac{dv}{ds}$$

Now, as per Newton's' Second Law of Motion, we know that

Force = Mass x Acceleration

$$(- dp \cdot dA) - (\rho g \cdot dA \cdot dz) = \rho \cdot dA \cdot ds \times \frac{dv}{ds}$$

$$\frac{dp}{\rho} + g \cdot dz = v \cdot dv$$

...(dividing both side by -

$$\rho dA)$$

$$\text{Or } \frac{dp}{\rho} + g \cdot dz + v \cdot dv = 0$$

This is the required Euler's' equation for motion and is in the form of a differential equation. Integrating the above equation,

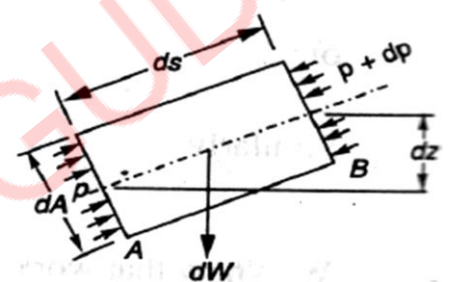


Fig. 2.2

$$\frac{p}{\rho} + g_z + v^2/2 = \text{constant}$$

$$P + wZ + Wv^2/2g = \text{constant}$$

$$\frac{p}{w} + Z + v^2/2g = \text{constant} \quad (\text{Dividing by } w)$$

or in other words,  $\frac{p_1}{w} + Z_1 + (v_1^2/2g) = \frac{p_2}{w} + Z_2 + (v_2^2/2g)$   
which proves the Bernoulli's' equation.

### Limitations of Bernoulli's' Equation:-

The Bernoulli's' theorem or Bernoulli's' equation has been derived on certain assumptions, which are rarely possible. Thus the Bernoulli's' theorem has the following limitations:

1. The Bernoulli's' equation has been derived under the assumption that the velocity of every liquid particle, across any cross-section of a pipe, is uniform. But, in actual practice, it is not so. The velocity of liquid particle in the centre of a pipe is maximum and gradually decreases towards the walls of the pipe due to the pipe friction. Thus, while using the Bernoulli's' equation, only the mean velocity of the liquid should be taken into account.
2. The Bernoulli's' equation has been derived under the assumption that no external force, except the gravity force, is acting on the liquid. But, in actual practice, it is not so. There are always some external forces (such as pipe friction etc.) acting on the liquid, which effect the flow of the liquid. Thus, while using the Bernoulli's' equation, all such external forces should be neglected. But, if some energy is supplied to, or, extracted from the flow, the same should also be taken into account.
3. The Bernoulli's' equation has been derived, under the assumption that there is no loss of energy of the liquid particle while flowing. But, in actual practice, -it is rarely so. In a turbulent flow, some kinetic energy is converted into heat energy. And in a viscous flow, some energy is lost due to shear forces. Thus, while using Bernoulli's' equation, all such losses should be neglected.
4. If the liquid is flowing in a curved path, the energy due to centrifugal force should also be taken into account.

### Example

The diameter of a pipe changes from 200 mm at a section 5 metres-above datum = to 50 mm at a section 3 metres above datum. The pressure of water at first section is 500 kPa. If the velocity of flow at the first section is 1 m/s, determine the intensity of pressure at the second section.

Solution. 'G' ~ en:  $d_1 = 200 \text{ mm} = 0.2 \text{ m}$ ;  $Z_1 = 5 \text{ m}$ ;  $d_2 = 50 \text{ mm} = 0.05 \text{ m}$   $z_2 = 3 \text{ m}$ ;  $p = 500/$

kPa = 500 kN/M<sup>2</sup> and  $V_1 = 1 \text{ m/s}$ .

Let

$V_2 =$  Velocity of flow at section 2, and

$P_2 =$  Pressure at section 2. We know that area of the pipe at section 1

$$a_1 = \frac{\pi}{4} \times 0.2^2 = 31.42 \times 10^{-3} \text{ m}^2$$

$$\text{and area of pipe at section 2 } a_2 = \frac{\pi}{4} \times 0.05^2 = 1.964 \times 10^{-3} \text{ m}^2$$

Since the discharge through the pipe is continuous, therefore  $a_1 V_1 = a_2 V_2$

$$V_2 = \frac{a_1 v_1}{a_2} = [(31.42 \times 10^{-3}) \times 1] / 1.964 \times 10^{-3} = 16 \text{ m/s}$$

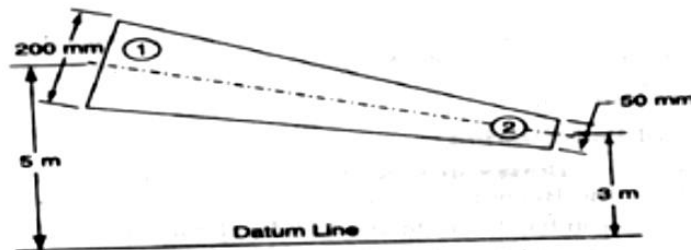


Fig. 2.3

Applying Bernoulli's equation for both the ends of the pipe,

$$Z_1 + v_1^2/2g + (p_1/w) = Z_2 + v_2^2/2g + (p_2/w)$$

$$5 + (1)^2/(2 \times 9.81) + 500/9.81 = 3 + (16)^2/(2 \times 9.81) + \frac{p_2}{9.81}$$

$$P_2 = 40 \times 9.81 = 392.4 \text{ kN/M}^2 = 392.4 \text{ kPa} \quad \text{Ans}$$

### practical Applications of Bernoulli's Equation

The Bernoulli's theorem or Bernoulli's equation is the basic equation which has the widest applications in Hydraulics and Applied Hydraulics. Since this equation is applied for the derivation

of many formulae, therefore its clear understanding is very essential. Though the Bernoulli's equation has a number of practical applications, yet in this chapter we shall discuss its applications on the following 'hydraulic devices':

1. Venturi meter.
2. Orifice meter.
3. Pitot tube.

### Venturimeter

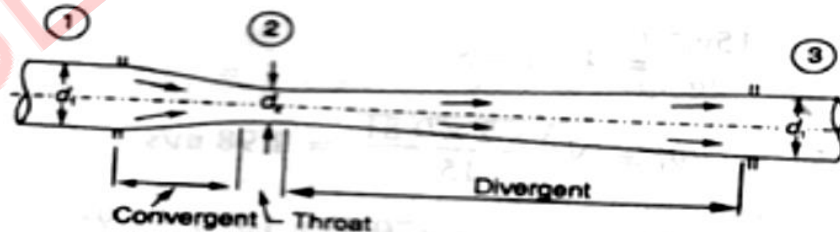


Fig. 2.4

A venturimeter is an apparatus for finding out the discharge of a liquid flowing in a pipe. A venturimeter, in its simplest form, consists of the following three parts:

- (a) Convergent cone.
- (b) Throat.
- (c) Divergent cone.
- (a) **Convergent cone**

It is a short pipe which converges from a diameter  $d_1$  (diameter of the pipe in which the venturi meter is fitted) to a smaller diameter  $d_2$ : The convergent cone is also known as inlet of the venturi meter. The slope of the converging sides is between 1 in 4 or 1 in 5 as shown in Fig.

**(b) Throat**

It is a small portion of circular pipe in which the diameter  $d_2$  is kept constant as shown in Fig.

**(c) Divergent cone**

It is a pipe, which diverges from a diameter  $d_2$  to a large diameter  $d_1$ . The divergent cone is also known as outlet of the venturi meter. The length of the divergent cone is about 3 to 4 times than that of the convergent cone as shown in Fig.

A little consideration will show that the liquid, while flowing through the venturi meter, is accelerated between the sections 1 and 2 (i.e., while flowing through the convergent cone). As a result of the acceleration, the velocity of liquid at section 2 (i.e., at the throat) becomes higher than that at section 1. This increase in velocity results in considerably decreasing the pressure at section 2. If the pressure head at the throat falls below the separation head (which is 2.5 metres of water), then there will be a tendency of separation of the liquid flow. In order to avoid the tendency of separation at throat, there is always a fixed ratio of the diameter of throat and the pipe (i.e.,  $d_2/d_1$ ). This ratio varies from  $1/4$  to  $3/4$ , but the most suitable value is  $1/3$  to  $1/2$ .

The liquid, while flowing through the venturi meter, is decelerated (i.e., retarded) between the sections 2 and 3 (i.e., while flowing through the divergent cone). As a result of this retardation, the velocity of liquid decreases which, consequently, increases the pressure. If the pressure is rapidly recovered, then there is every possibility for the stream of liquid to break away from the walls of the metre due to boundary layer effects. In order to avoid the tendency of breaking away the stream of liquid, the divergent cone is made sufficiently longer. Another reason for making the divergent cone longer is to minimize the frictional losses. Due to these reasons, the divergent cone is 3 to 4 times longer than convergent cone as shown in Fig.

**Discharge through a Venturi meter**

Consider a venturi meter through which some liquid is flowing as shown in Fig.

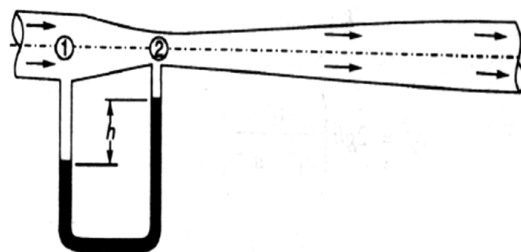


Fig. 2.5

Let

$P_1$  = Pressure at section 1,

$V_1$  = Velocity of water at section 1,

$Z_1$  = Datum head at section 1,

$a_1$  = Area of the venturi meter at section 1, and

$p_2, v_2, z_2, a_2$  = Corresponding values at section 2.

Applying Bernoulli's' equation at sections 1 and 2. i.e

$$Z_1 + v_1^2/2g + (p_1/w) = Z_2 + v_2^2/2g + (p_2/w) \quad \dots\dots(1)$$

Let us pass our datum line through the axis of the venturimeter as shown in Fig.

Now  $Z_1=0$  and  $Z_2=0$

$$\therefore v_1^2/2g + (p_1/w) = v_2^2/2g + (p_2/w)$$

$$\text{Or } (p_1/w) - (p_2/w) = v_2^2/2g - v_1^2/2g \quad \dots\dots(2)$$

Since the discharge at sections 1 and 2 is continuous, therefore

$$V_1 = a_2 v_2 / a_1 \quad (a_1 v_1 = a_2 v_2)$$

$$V_1^2 = a_2^2 v_2^2 / a_1^2 \quad \dots\dots(3)$$

Substituting the above value of  $v_1^2$  in equation (2),

$$\begin{aligned} \frac{p_1}{w} - \frac{p_2}{w} &= v_2^2/2g - (a_2^2/a_1^2) \times v_2^2/2g \\ &= v_2^2/2g (1 - a_2^2/a_1^2) = v_2^2/2g [(a_1^2 - a_2^2)/a_1^2] \end{aligned}$$

We know that  $\frac{p_1}{w} - \frac{p_2}{w}$  is the difference between the pressure heads at sections 1 and 2 when the pipe is horizontal, this difference represents the venturimeter head and is denoted by  $h$ .

$$\text{Or } h = v_2^2/2g [(a_1^2 - a_2^2)/a_1^2]$$

$$\text{Or } v_2^2 = 2gh [a_1^2 / (a_1^2 - a_2^2)]$$

$$\therefore v_2 = \sqrt{2gh} [a_1 / \sqrt{a_1^2 - a_2^2}]$$

We know that the discharge through a venturimeter,

$$Q = \text{Coefficient of venturimeter} \times a_2 v_2$$

$$= C \cdot a_2 v_2 = [C a_1 a_2 / \sqrt{a_1^2 - a_2^2}] \times \sqrt{2gh}$$

### Example

A venturimeter with a 150 mm diameter at inlet and 100 mm at throat is laid with its axis horizontal and is used for measuring the flow of oil specific gravity 0.9. The oil-mercury differential manometer shows a gauge difference of 200 mm. Assume coefficient of the meter as 0.9 Calculate the discharge in litres per minute.

Solution. Given:  $d_1 = 150 \text{ mm} = 0.15 \text{ m}$ ;  $d_2 = 100 \text{ mm} = 0.1 \text{ m}$ ; Specific gravity of oil = 0.9

$h = 200 \text{ mm} = 0.2 \text{ m}$  of mercury and  $C = 0.98$ .

We know that the area at inlet,

$$a_1 = \frac{\pi}{4} \times 0.15^2 = 17.67 \times 10^{-3} \text{ m}^2$$

and the area at throat,

$$a_2 = \frac{\pi}{4} \times 0.1^2 = 7.854 \times 10^{-3} \text{ m}^2$$

We also know that the difference of pressure head,  
 $H = 0.2(13.6 - 0.9/0.9) = 2.82 \text{ m}$  of oil  
 and the discharge through the venturimeter,

$$Q = [C a_1 a_2 / \sqrt{a_1^2 - a_2^2}] \times \sqrt{2gh}$$

$$= 63.9 \times 10^{-3} \text{ m}^3/\text{s} = 63.9 \text{ lit/s} \quad \text{Ans.}$$

### Orifice Metre

An orifice metre is used to measure the discharge in a pipe. An orifice metre, in its simplest

form, consists of a plate having a sharp edged circular hole known as an orifice. This plate is fixed inside a pipe as shown in Fig. c. A mercury manometer is inserted to know the difference

of pressures between the pipe and the throat (i.e., orifice).

Let

$h$  = Reading of the mercury manometer,

$P_1$  = Pressure at inlet,

$V_1$  = Velocity of liquid at inlet,

$a_1$  = Area of pipe at inlet, and

$P_2, v_2, a_2$  = Corresponding values at the throat.

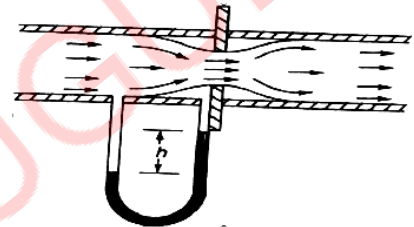


Fig. 2.6

Now applying Bernoulli's equation for inlet of the pipe and the throat,

$$Z_1 + v_1^2/2g + (p_1/w) = Z_2 + v_2^2/2g + (p_2/w) \quad \dots\dots\dots(i)$$

$$(p_1/w) - (p_2/w) = v_2^2/2g - v_1^2/2g$$

$$\text{Or } h = v_2^2/2g - v_1^2/2g = 1/2g(v_2^2 - v_1^2) \quad \dots\dots\dots(ii)$$

Since the discharge is continuous, therefore  $a_1 \cdot v_1 = a_2 v_2$

$$V_1 = a_2/a_1 \times v_2 \quad \text{or } v_1^2 = a_2^2/a_1^2 \times v_2^2$$

Substituting the above value of  $v_1^2$  in equation (ii)

$$h = 1/2g(v_2^2 - a_2^2/a_1^2 \times v_2^2) = v_2^2/2g \times (1 - a_2^2/a_1^2) = v_2^2/2g[(a_1^2 - a_2^2)/a_1^2]$$

$$\therefore v_2^2 = 2gh[a_1^2/(a_1^2 - a_2^2)] \quad \text{or } v_2 = \sqrt{2gh[a_1^2/(a_1^2 - a_2^2)]}$$

We know that the discharge,

$$Q = \text{Coefficient of orifice metre} \times a_2 \cdot v_2$$

$$= [C \sqrt{a_1 a_2} / \sqrt{a_1^2 - a_2^2}] \times \sqrt{2gh}$$

**Example.** An orifice metre consisting of 100 mm diameter orifice in a 250 mm diameter pipe has coefficient equal to 0.65. The pipe delivers oil (sp. gr. 0.8). The pressure difference on the two sides of the orifice plate is measured by a mercury oil differential in a manometer. If the differential gauge reads 80 mm of mercury, calculate the rate of flow in litres.

Solution. Given:  $d_2 = 100 \text{ mm} = 0.1 \text{ m}$ ;  $d_1 = 250 \text{ mm} = 0.25 \text{ m}$ ;  $C = 0.65$ ; Specific gravity of oil = 0.8 and  $h = 0.8 \text{ m}$  of mercury.

We know that the area of pipe,

$$a_1 = \frac{\pi}{4} \times 0.25^2 = 49.09 \times 10^{-3} \text{ m}^2$$

and area of throat

$$a_2 = \frac{\pi}{4} \times 0.1^2 = 7.854 \times 10^{-3} \text{ m}^2$$

We also know that the pressure difference,

$$h = 0.8[(13.6 - 0.8)/0.8] = 12.8 \text{ m of oil}$$

and rate of flow,

$$Q = [C \sqrt{a_1 a_2} / \sqrt{a_1^2 - a_2^2}] \times \sqrt{2gh}$$

$$= 82 \times 10^{-3} \text{ m}^3/\text{s} = 82 \text{ lit/s} \quad \text{Ans}$$

### Pitot Tube.

A Pitot tube is an instrument to determine the velocity of flow at the required point in a pipe or a stream. In its simplest form, a pitot tube consists of a glass tube bent at a through  $90^\circ$  as shown in Fig.

The lower end of the tube faces the direction of the flow as shown in Fig. The liquid rises up in the tube due to the pressure exerted by the flowing liquid. By measuring the rise of liquid in the tube, we can find out the velocity of the liquid flow.

Let  $h$  = Height of the liquid in the pitot tube above the surface,

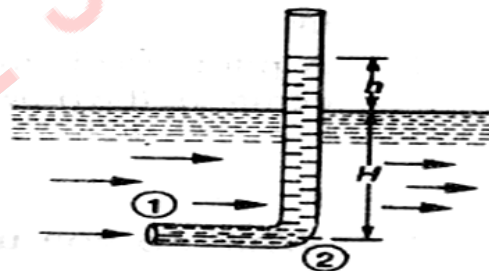


Fig. 2.7

$H$  = Depth of tube in the liquid, and

$v$  = Velocity of the liquid.

Applying Bernoulli's equation for the sections 1 and 2,

$$H + v^2/2g = H + h$$

$$\dots (z_1 = z_2)$$

$$h = v^2/2g$$

$$\therefore v = \sqrt{2gh}$$

**Example .**

A pitot tube was inserted in a pipe to measure the velocity of water in it. If (water rises the tube is 200 mm, find the velocity of water.

Solution. Given:  $h = 200 \text{ mm} = 0.2 \text{ m}$ .

We know that the velocity of water in the pipe,

$$v = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 0.2} = 1.98 \text{ m/s Ans.}$$

**Rate of Discharge**

The quantity of a liquid, flowing per second through a section of a pipe or a channel, is known as the rate of discharge or simply discharge. It is generally denoted by  $Q$ . Now consider a liquid flowing through a pipe.

Let,  $a =$  Cross-sectional area of the pipe, and  
 $v =$  Average velocity of the liquid,  
 $\therefore$  Discharge,  $Q = \text{Area} \times \text{Average velocity} = a.v$

**Notes:** 1. If the area is in  $\text{m}^2$  and velocity in  $\text{m/s}$ , then the discharge,

$$Q = \text{m}^2 \times \text{m/s} = \text{m}^3/\text{s} = \text{cumecs}$$

2. remember that  $1\text{m}^3 = 1000 \text{ litres}$ .

**Equation of Continuity of a Liquid Flow**

If an incompressible liquid is continuously flowing through a pipe or a channel (whose cross-sectional area may or may not be constant) the quantity of liquid passing per second is the same at all sections. This is known as the equation of continuity of a liquid flow. It is the first and fundamental equation of flow.

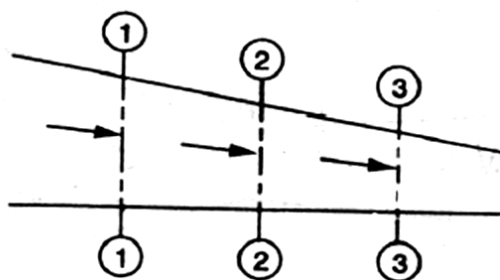


Fig. 2.8

**CONTINUITY OF A LIQUID FLOW**

Consider a tapering pipe through which some liquid is flowing as shown in Fig

Let,  $a_1 =$  Cross-sectional area of the pipe at section 1-1, and

$v_1 =$  Velocity of the liquid at section 1-1,



Similarly ,  $a_2, v_2 =$  Corresponding values at section 2-2,  
and  $a_3, v_3 =$  Corresponding values at section 3-3.

We know that the total quantity of liquid passing through section 1-1,

$$Q_1 = a_1.v_1 \quad \dots\dots\dots(i)$$

Similarly, total quantity of liquid passing through section 2-2,

$$Q_2 = a_2.v_2 \quad \dots\dots\dots(ii)$$

and total quantity of the liquid passing through section 3-3,

$$Q_3 = a_3.v_3 \quad \dots\dots\dots(iii)$$

From the law of conservation of matter, we know that the total quantity of liquid passing through the sections 1-1, 2-2 and 3-3 is the same. Therefore

$$Q_1 = Q_2 = Q_3 = \dots\dots \text{ or } a_1.v_1 = a_2.v_2 = a_3.v_3 \dots\dots \text{ and so on.}$$

**Example :** Water is flowing through a pipe of 100 mm diameter with an average velocity 10 m/s. Determine the rate of discharge of the water in litres/s. Also determine the velocity of water

At the other end of the pipe, if the diameter of the pipe is gradually changed to 200 mm.

**Solution.** Given:  $d_1 = 100 \text{ mm} = 0.1 \text{ m}$ ;  $V_1 = 10 \text{ m/s}$  and  $d_2 = 200 \text{ mm} = 0.2 \text{ m}$ .

*Rate of discharge*

We know that the cross-sectional area of the pipe at point 1,

$$a_1 = \left(\frac{\pi}{4}\right) \times (0.1)^2 = 7.854 \times 10^{-3} \text{ m}^2$$

$$\begin{aligned} \text{and rate of discharge, } Q &= a_1.v_1 = (7.854 \times 10^{-3}) \times 10 = 78.54 \times 10^{-3} \text{ m}^3/\text{s} \\ &= 78.54 \text{ litres/s} \quad \text{Ans.} \end{aligned}$$

*Velocity of water at the other end of the pipe*

We also know that cross-sectional area of the pipe at point 2,

$$a_2 = \left(\frac{\pi}{4}\right) \times (0.2)^2 = 31.42 \times 10^{-3} \text{ m}^2$$

$$\text{and velocity of water at point 2, } v_2 = \frac{Q}{a_2} = ((78.54 \times 10^{-3}) / (31.42 \times 10^{-3})) = 2.5 \text{ m/s} \quad \text{Ans.}$$

## 2.2 Flow over Notches:-

A notch is a device used for measuring the rate of flow of a liquid through a small channel or a tank. It may be defined as an opening in the side of a tank or a small channel in such a way that the liquid surface in the tank or channel is below the top edge of the opening.

A weir is a concrete or masonry structure, placed in an open channel over which the flow occurs. It is generally in the form of vertical wall, with a sharp edge at the top, running all the way across the open channel. The notch is of small size while the weir is of a bigger size. The notch is generally made of metallic plate while weir is made of concrete or masonry structure.

1. Nappe or Vein. The sheet of water flowing through a notch or over a weir is called Nappe or Vein.
2. Crest or Sill. The bottom edge of a notch or a top of a weir over which the water flows, is known as the sill or crest.

### Classification Of Notches And Weirs:-

The notches are classified as :

I. According to the shape of the opening:

- (a) Rectangular notch,
- (b) Triangular notch,
- (c) Trapezoidal notch, and
- (d) Stepped notch.

2. According to the effect of the sides on the nappe:

- (a) Notch with end contraction.
- (b) Notch without end contraction or suppressed notch,

Weirs are classified according to the shape of the opening, the shape of the crest, the effect of the sides on the nappe and nature of discharge. The following are important classifications.

### Discharge Over A Rectangular Notch Or Weir

The expression for discharge over a rectangular notch or weir is the same.

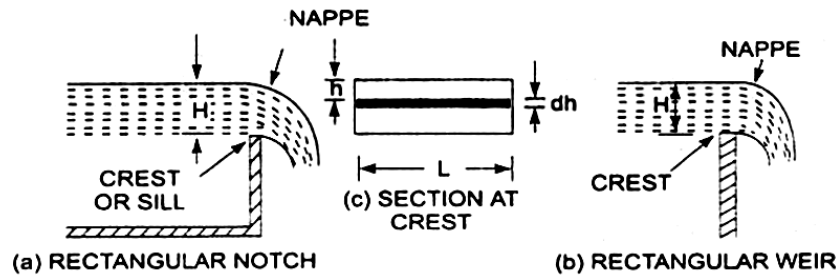


Fig. 2.9

#### Rectangular notch and weir:-

Consider a rectangular notch or weir provided in a channel carrying water as shown in Fig. Let  $H$  = Head of water over the crest,  $L$  = Length of the notch or weir

The total discharge,  $Q = \frac{2}{3} \times C_d \times L \times \sqrt{2g[H]}^{3/2}$

#### Problem - -

Find the discharge of water flowing over a rectangular notch 0/2 In length when the constant head over the notch is 300 mm. Take  $C_d = 0.60$ .

Solution. Given:

Length of the notch,  $L = 2.0\text{m}$

Head over notch,  $H = 300\text{ mm} = 0.30\text{ m}$

$C_d = 0.60$

Discharge  $Q = \frac{2}{3} \times C_d \times L \times \sqrt{2g[H]}^{3/2}$

$$= \frac{2}{3} \times 0.6 \times 2.0 \times \sqrt{2 \times 9.81} \times [0.30]^{3/2} = 1.5\text{ m}^3/\text{s}$$

$$= 3.5435 \times 0.1643 = 0.582\text{ m}^3/\text{s}. \text{ Ans,}$$

#### Problem 2

Determine the height of a rectangular weir of length 6 m to be built across a Rectangular channel. The maximum depth of water on the upstream side of the weir is 1.8m and discharge is 2000 litres/s. Take  $C_d = 0.6$  and neglect end contractions.

Solution. Given:

Length of weir,  $L = 6\text{m}$

Depth of water,  $H_1 = 1.8\text{m}$

Discharge,  $Q = 2000\text{ lit/s} = 2\text{ m}^3/\text{s}$

$C_d = 0.6$

Let  $H$  is the height of water above the crest of weir and  $H_2$  =height of weir

The discharge over the weir is given by the equation .

$$Q = \frac{2}{3} \times C_d \times L \times \sqrt{2g[H]}_{3/2}$$

$$= \frac{2}{3} \times 0.6 \times 6 \times \sqrt{2} \times 9.81 \times [H]_{3/2}$$

$$= 10.623 H^{3/2}$$

$$= H^{3/2} = \frac{2.0}{10.623}$$

$$H = \left( \frac{2.0}{10.623} \right)^{2/3} = 0.328 \text{ m}$$

Height of weir,  $H_2 = H_1 - H$

= Depth of water on upstream side -  $H$

=  $1.8 - 0.328 = 1.472 \text{ m}$ . Ans.

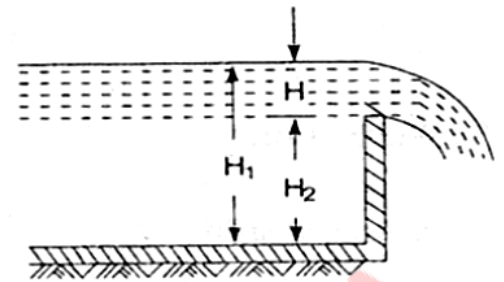


Fig. 2.10

### Discharge Over A Triangular Notch Or Weir:-

The expression for the discharge over a triangular notch or weir is the same. It is derived as : Let  $H$  = head of water above the V- notch

$\theta$  = angle of notch

$$\text{Total discharge, } Q = \frac{8}{15} \times C_d \times \frac{\tan \theta}{2} \times \sqrt{2g} \times H^{5/2}$$

For a right angle V Notch ,if  $C_d=0.6$

$$\theta = 90^\circ, \tan \frac{\theta}{2} = 1$$

$$\text{Discharge, } Q = \frac{8}{15} \times 0.6 \times 1 \times \sqrt{2} \times 9.81 \times H^{5/2}$$

$$= 1.417 \times H^{5/2}$$

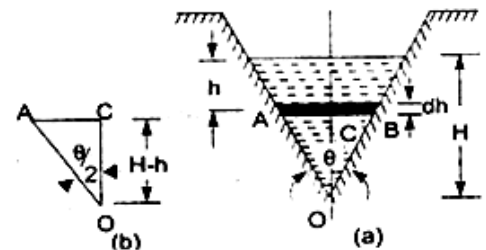


Fig. 2.11

### Problem -1

Find the discharge over a triangular notch of angle  $60^\circ$  when the head over the V-notch is 0.3 m. Assume  $C_d = 0.6$ .

Solution. Given an Angle of V-notch,  $\theta = 60^\circ$

Head over notch,  $H=0.3 \text{ m}$

$$C_d = 0.6$$

Discharge,  $Q$  over a V-notch is given by equation

$$Q = \frac{8}{15} \times C_d \times \frac{\tan \theta}{2} \times \sqrt{2g} \times H^{5/2}$$

$$\frac{8}{15} \times C_d \times \frac{0.6 \tan 60}{2} \times \sqrt{2 \times 9.81} \times (0.3)^{5/2}$$

$$= 0.8182 \times 0.0493 = 0.040 \text{ m}^3/\text{s. Ans,}$$

**Problem -2**

Water flows over a rectangular weir 1 m wide at a depth of 150 mm and afterwards passes through a triangular right-angled weir. Taking  $C_d$  for the rectangular and triangular weir as 0.62 and 0.59 respectively, find the depth over the triangular weir.

Solution. Given:

For rectangular weir. Length =  $L = 1 \text{ m}$

Depth of water,  $H = 150 \text{ mm} = 0.15 \text{ m}$

$$C_d = 0.62$$

For triangular weir.

$$\theta = 90^\circ$$

$$C_d = 0.59$$

Let depth over triangular weir =  $H_1$

The discharge over the rectangular weir is given by equation

$$Q = \frac{2}{3} \times C_d \times L \times \sqrt{2g[H]}^{3/2}$$

$$= \frac{2}{3} \times 0.62 \times 1.0 \times \sqrt{2 \times 9.81} \times (0.15)^{3/2}$$

$$= 0.10635 \text{ m}^3/\text{s}$$

The same discharge passes through the triangular right-angled weir. But discharge.  $Q$  is given by the equation

$$Q = \frac{8}{15} \times C_d \times \frac{\tan \theta}{2} \times \sqrt{2g} \times H^{5/2}$$

$$0.10635 = \frac{8}{15} \times 0.59 \times \frac{\tan 90}{2} \times \sqrt{2g} \times H_1^{5/2}$$

$$= \frac{8}{15} \times 0.59 \times 1 \times 4.429 \times H_1^{5/2}$$

$$= 1.3936 H_1^{5/2}$$

$$H_1^{5/2} = \frac{0.10635}{1.3936} = 0.07631$$

$$H_1 = (0.07631)^{0.4} = 0.3572 \text{ m, Ans}$$

$$\therefore \{ \theta = 90^\circ \text{ and } H = H_1 \}$$

**Discharge Over A Trapezoidal Notch Or Weir:-**

A trapezoidal notch or weir is a combination of a rectangular and triangular notch or weir. Thus the total discharge will be equal to the sum of discharge through a rectangular weir or notch and discharge through a triangular notch or weir.

Let  $H$  = Height of water over the notch

$L$  = Length of the crest of the notch

$C_{d1}$  = Co-efficient of discharge for rectangular portion ABCD of Fig.

$C_{d2}$  = Co-efficient of discharge for triangular portion [FAD and BCE]

The discharge through rectangular portion ABCD is given by

or 
$$Q_1 = \frac{2}{3} \times C_{d1} \times L \times \sqrt{2g} \times H^{3/2}$$

The discharge through two triangular notches FDA and BCE is equal to the discharge through a single triangular notch of angle  $\theta$  and it is given by equation

$$Q_2 = \frac{2}{3} \times C_{d2} \times \frac{\tan \theta}{2} \times \sqrt{2g} \times H^{5/2}$$

Discharge through trapezoidal notch or weir FDCEF =  $Q_1 + Q_2$

$$= \frac{2}{3} \times C_{d1} L \sqrt{2g} \times H^{3/2} + \frac{8}{15} C_{d2} \times \frac{\tan \theta}{2} \times \sqrt{2g} \times H^{5/2}$$

**Problem -1** Find the discharge through a trapezoidal notch which is 1 m wide at the top and 0.40 m at the bottom and is 30 cm in height. The head of water on the notch is 20 cm. Assume  $C_d$  for rectangular portion = 0.62 while for triangular portion = 0.60.

Solution. Given:

Top width  $AE = 1$  m  
 Base width,  $CD = L = 0.4$  m  
 Head of water,  $H = 0.20$  m  
 For rectangular portion,  $C_{d1} = 0.62$   
 From  $\triangle ABC$ , we have

$$\begin{aligned} \tan \theta &= \frac{AB}{BC} = \frac{AE - CD}{2H} \\ \frac{2}{1.0 - 0.4} &= \frac{0.6}{2 \times 0.2} \\ &= \frac{0.3}{0.3} = 1 \end{aligned}$$

Discharge through trapezoidal notch is given by equation

$$\begin{aligned} Q &= \frac{2}{3} C_{d1} \times L \times \sqrt{2g} \times H^{3/2} + \frac{8}{15} C_{d2} \times \frac{\tan \theta}{2} \times \sqrt{2g} \times H^{5/2} \\ &= \frac{2}{3} \times 0.62 \times 0.4 \times \sqrt{2 \times 9.81} \times (0.2)^{3/2} + \frac{8}{15} \times 0.60 \times 1 \times \frac{\sqrt{2 \times 9.81}}{2} \times (0.2)^{5/2} \\ &= 0.06549 + 0.02535 = 0.09084 \text{ m}^3/\text{s} = 90.84 \text{ litres/s. Ans} \end{aligned}$$

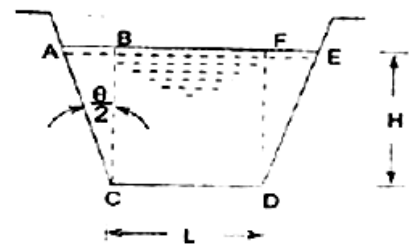


Fig. 2.12

### Discharge Over A Stepped Notch:-

A stepped notch is a combination of rectangular notches. The discharge through 'stepped notch' is equal to the sum of the discharges through the different rectangular notches.

Consider a stepped notch as shown in Fig.

Let  $H_1$  = Height of water above the crest of notch (1).

$L_1$  = Length of notch 1,

$H_2, L_2$  and  $H_3, L_3$  are corresponding values for notches 2 and 3 respectively

$C_d$  = Co-efficient of discharge for all notches

Total discharge  $Q = Q_1 + Q_2 + Q_3$

$$Q = \frac{2}{3} \times C_d \times L_1 \times \sqrt{2g} [H_1^{3/2} - H_2^{3/2}] + \frac{2}{3} \times C_d \times L_2 \times \sqrt{2g} [H_2^{3/2} - H_3^{3/2}] + \frac{2}{3} \times C_d \times L_3 \times \sqrt{2g} \times H_3^{3/2}$$

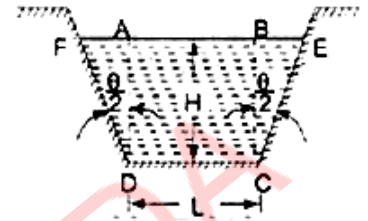


Fig. 2.12

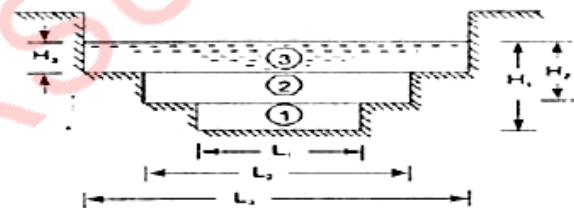


Fig. 2.13

### Problem

Fig. 1 shows a stepped notch. Find the discharge through the notch if  $C_d$  for all section = 0.62.

Solution. Given:

$L_1 = 40$  cm,  $L_2 = 80$  cm,

$L_3 = 120$  cm

$H_1 = 50 + 30 + 15 = 95$  cm,

$H_2 = 80$  cm,  $H_3 = 50$  cm,

$C_d = 0.62$

Total Discharge,  $Q = Q_1 + Q_2 + Q_3$

where

$$Q_1 = \frac{2}{3} \times C_d \times L_1 \times \sqrt{2g} [H_1^{3/2} - H_2^{3/2}]$$

$$= \frac{2}{3} \times 0.62 \times 40 \times \sqrt{2 \times 981} \times [95^{3/2} - 80^{3/2}]$$

$$= 154067 \text{ cm}^3/\text{s} = 154.067 \text{ lit/s}$$

$$Q_2 = \frac{2}{3} \times C_d \times L_2 \times \sqrt{2g} [H_2^{3/2} - H_3^{3/2}]$$

$$= \frac{2}{3} \times 0.62 \times 80 \times \sqrt{2 \times 981} \times [80^{3/2} - 50^{3/2}]$$

$$= 530141 \text{ cm}^3/\text{s}$$

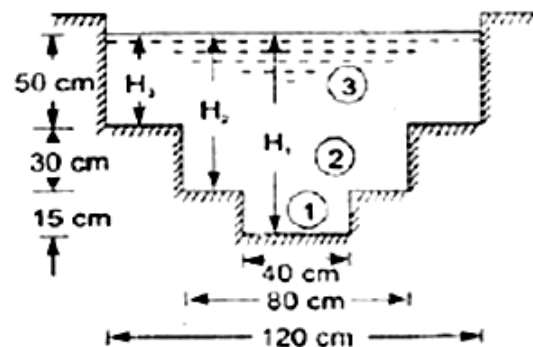


Fig. 2.14

$$=530.144 \text{ lit/s}$$

$$Q_3 = \frac{2}{3} C_d \times L \times \sqrt{2g} \times H^{3/2}$$

$$= \frac{2}{3} \times 0.62 \times 120 \times \sqrt{2 \times 981} \times 50^{3/2}$$

$$=776771 \text{ cm}^3/\text{s}$$

$$=776.771 \text{ lit/s}$$

$$\therefore Q = Q_1 + Q_2 + Q_3$$

$$=154.067 + 530.144 + 776.771$$

$$=1460.98 \text{ lit/s} \quad \text{Ans.}$$

### Velocity Of Approach

Velocity of approach is defined as the velocity with which the water approaches or reaches the weir or notch before it flows over it. Thus if  $V_a$  is the velocity of approach, then an additional head  $h_a$  equal

to  $V_a^2 / 2g$  due to velocity of approach, is acting on the water flowing over the notch. Then initial height of water over the notch becomes  $(H + h_a)$  and final height becomes equal to  $h_a$ , when all the formulae are

changed taking into consideration of velocity of approach.

The velocity of approach,  $V_a$  is determined by finding the discharge over the notch or weir neglecting velocity of approach. Then dividing the discharge by the cross-sectional area of the channel on the upstream side of the weir or notch, the velocity of approach is obtained. Mathematically,

$$V_a = \frac{Q}{\text{Area of Channel}}$$

This velocity of approach is used to find an additional head ( $h_a = V_a^2 / 2g$ ). Again the discharge is calculated and above process is repeated for more accurate discharge.

Discharge over a rectangular weir, with velocity of approach

$$= \frac{2}{3} \times C_d \times L \times \sqrt{2g} [(H_1 + h_a)^{3/2} - h_a^{3/2}]$$

### Problem:-

Water is flowing in a rectangular channel of 1 m wide and 0.75 m deep. Find the discharge over a rectangular weir of crest length 60 cm if the head of water over the crest of weir is



20 cm and water from channel flows over the weir. Take  $C_d = 0.62$ . Neglect end contractions. Take

velocity of approach into consideration.

Solution. Given:

Area of channel,  $A = \text{Width} \times \text{depth} = 1.0 \times 0.75 = 0.75 \text{ m}^2$

Length of weir,  $L = 60 \text{ cm} = 0.6 \text{ m}$

Head of water,  $H_1 = 20 \text{ cm} = 0.2 \text{ m}$

$C_d = 0.62$

Discharge over a rectangular weir without velocity of approach is given by

$$Q = \frac{2}{3} C_d \times L \times \sqrt{2g} \times H_1^{3/2}$$

$$= \frac{2}{3} \times 0.62 \times 0.6 \times \sqrt{2 \times 9.81} \times (0.2)^{3/2}$$

$$= 0.0982 \text{ m}^3/\text{s}$$

$$\text{velocity of approach } V_a = \frac{Q}{A} = \frac{0.0982}{0.75} = 0.1309 \frac{\text{m}}{\text{s}}$$

Additional head  $h_a = V_a^2 / 2g$

$$= (0.1309)^2 / 2 \times 9.81 = 0.0008733 \text{ m}$$

Then discharge with velocity of approach is given by equation

$$Q = \frac{2}{3} \times C_d \times L \times \sqrt{2g} [(H_1 + h_a)^{3/2} - h_a^{3/2}]$$

$$= \frac{2}{3} \times 0.62 \times 0.6 \times \sqrt{2 \times 9.81} [(0.2 + 0.00087)^{3/2} - (0.00087)^{3/2}]$$

$$= 1.098 [0.09002 - 0.00002566]$$

$$= 1.098 \times 0.09017$$

$$= 0.09881 \text{ m}^3/\text{s. Ans}$$

### Types of Weirs :-

Though there are numerous types of weirs, yet the following are important from the subject point of view :

1. Narrow-crested weirs,
2. Broad-crested weirs,
3. Sharp-crested weirs,
4. Ogee weirs, and
5. Submerged or drowned weirs.

### Discharge over a Narrow-crested Weir :-

The weirs are generally classified according to the width of their crests into two types. i.e.

narrow-crested weirs and broad crested weirs.

Let  $b$  = Width of the crest of the weir, and

$H$  = Height of water above the weir crest.

If  $2b$  is less than  $H$ , the weir is called a narrow-crested weir. But if  $2b$  is more than  $H$ , it is called a broad-crested weir.

A narrow-crested weir is hydraulically similar to an ordinary weir or to a rectangular weir. Thus, the same formula for discharge over a narrow-crested weir holds good, which we derived from an ordinary weir.

$$Q = \frac{2}{3} \times C_d \cdot L \sqrt{2g} \times H^{3/2}$$

Where,  $Q$  = Discharge over the weir,

$C_d$  = Coefficient of discharge,

$L$  = Length of the weir, and

$H$  = Height of water level above the crest of the weir.

**Example** A narrow-crested weir of 10 metres long is discharging water under a constant head of 400 mm. Find discharge over the weir in litres. Assume coefficient of discharge as 0.623.

**Solution.** Given:  $L = 10$  m;  $H = 400$  mm = 0.4 m and  $C_d = 0.623$ .

We know that the discharge over the weir,

$$\begin{aligned} Q &= \frac{2}{3} \times C_d \cdot L \sqrt{2g} \times H^{3/2} \\ &= \frac{2}{3} \times 0.623 \times 10 \sqrt{(2 \times 9.81)} \times (0.4)^{3/2} \\ &= 46.55 \text{ m}^3/\text{s} = 4655 \text{ lit/s} \end{aligned}$$

### Discharge over a Broad-crested Weir :-

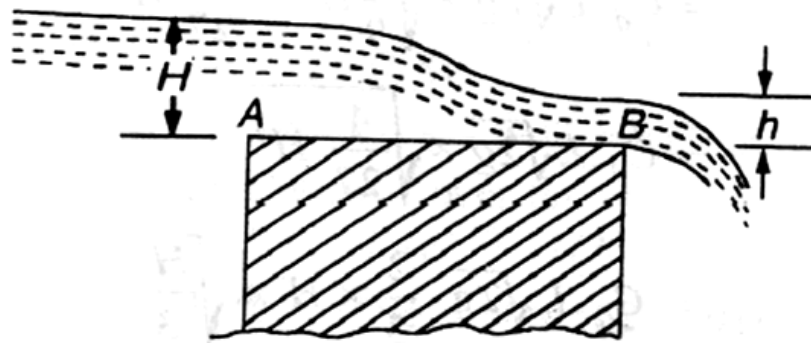


Fig. 2.15

#### Broad-crested weir

Consider a broad-crested weir as shown in Fig. Let A and B be the upstream and downstream ends of the weir.

Let  $H$  = Head of water on the upstream side of the weir (i.e., at A),  
 $h$  = Head of water on the downstream side of the weir (i.e., at B),  
 $v$  = Velocity of the water on the downstream side of the weir  
 (i.e., at B),  
 $C_d$  = Coefficient of discharge, and  
 $L$  = Length of the weir.

$$Q = 1.71 C_d \cdot L \times H^{3/2}$$

**Example** A broad-crested weir 20 m long is discharging water from a reservoir in to channel. What will be the discharge over the weir, if the head of water on the upstream and downstream sides is 1m and 0.5 m respectively? Take coefficient of discharge for the flow as 0.6 .

**Solution.** Given:  $L = 20$  m;  $H = 1$  m;  $h = 0.5$  m and  $C_d = 0.6$ .

We know that the discharge over the weir,

$$\begin{aligned} Q &= C_d \times L \cdot h \sqrt{2g(H - h)} \\ &= 0.6 \times 20 \times 0.5 \times \sqrt{2 \times 9.81(1 - 0.5)} \text{ m}^3/\text{s} \\ &= 6 \times 3.13 = 18.8 \text{ m}^3/\text{s} \quad \text{Ans.} \end{aligned}$$

#### Discharge over a Sharp-crested Weir :-

It is a special type of weir, having a sharp-crest as shown in Fig. The water flowing over the crest comes in contact with the crest-line and then springs up from the crest and falls as a trajectory as shown in Fig.

In a sharp-crested weir, the thickness of the weir is kept less than half of the height of water on the weir. i.e.,

$$b < (H/2)$$

where,  $b$  = Thickness of the weir,

and  $H$  = Height of water, above the crest of the weir.

The discharge equation, for a sharp crested weir, remains the same as that of a rectangular weir. i.e.,

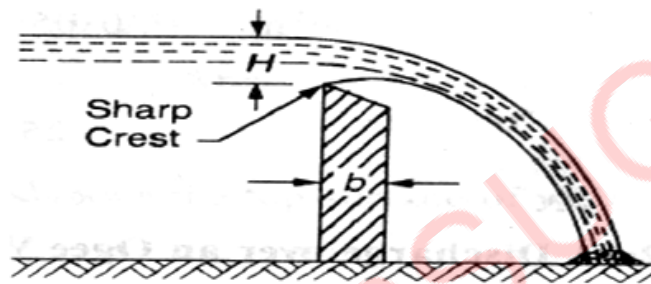


Fig. 2.16

**Sharp-crested weir :-**

$$Q = \frac{2}{3} \times C_d \cdot L \sqrt{2g} \times H^{3/2}$$

Where,  $C_d$  = Coefficient of discharge, and  
 $L$  = Length of sharp-crested weir

**Example** In a laboratory experiment, water flows over a sharp-crested weir 200 mm long under a constant head of 75mm. Find the discharge over the weir in litres/s, if  $C_d = 0.6$ .

**Solution.** Given:  $L = 200 \text{ mm} = 0.2 \text{ m}$ ;  $H = 75 \text{ mm} = 0.075 \text{ m}$  and  $C_d = 0.6$ .

We know that the discharge over the weir,

$$\begin{aligned} Q &= \frac{2}{3} \times C_d \cdot L \sqrt{2g} \times H^{3/2} \\ &= \frac{2}{3} \times 0.6 \times 0.2 \times \sqrt{2 \times 9.81} \times (0.075)^{3/2} \\ &= 0.0073 \text{ m}^3/\text{s} = 7.3 \text{ litres/s. Ans.} \end{aligned}$$

**Discharge over an Ogee Weir :-**

It is a special type of weir, generally, used as a spillway of a dam as shown in Fig.

, The crest of an ogee weir slightly rises up from the point A, (i.e., crest of the sharp-crested weir) and after reaching the maximum rise of  $0.115 H$  (where  $H$  is the height of a water above the point A) falls in a parabolic form as shown in Fig.

The discharge equation for an ogee weir remains the same as that of a rectangular weir. i.e.,

$$Q = \frac{2}{3} \times C_d \cdot L \sqrt{2g} \times H^{3/2}$$

Where  $C_d$  = Co-efficient of discharge and  
 $L$  = Length of an ogee weir

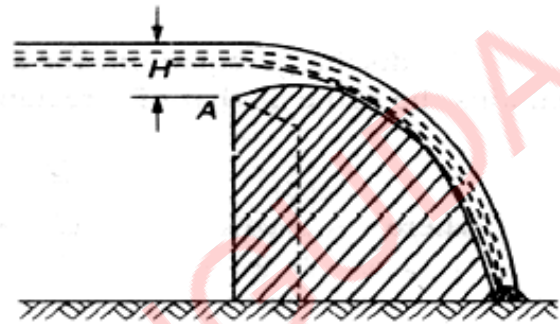


Fig. 2.17

### Example

An ogee weir 4 metres long has 500 mm head of water. Find the discharge over the weir, if  $C_d = 0.62$ .

Solution. Given:  $L = 4$  m;  $H = 500$  mm =  $0.5$  m and  $C_d = 0.62$ .

We know that the discharge over the weir,

$$Q = \frac{2}{3} \times C_d \cdot L \sqrt{2g} \times H^{3/2}$$

$$= \frac{2}{3} \times 0.62 \times 4 \sqrt{2 \times 9.81} \times (0.5)^{3/2} \text{ m}^3/\text{s}$$

$$= 7.323 \times 0.354 = 2.59 \text{ m}^3/\text{s} = 2590 \text{ litres/s} \quad \text{Ans}$$

### Discharge over a Submerged or Drowned Weir :-

When the water level on the downstream side of a weir is above the top surface of weir, it is known as a submerged or drowned weir as shown in Fig

The total discharge, over such a weir, is found out by splitting up the height of water, above the sill of the weir, into two portions as discussed below:

Let  $H_1$  = Height of water on the upstream side of the weir, and

$H_2$  = height of water on the downstream side  
of the weir.

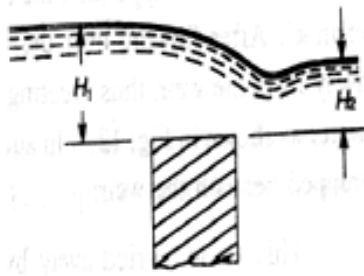


Fig. 2.18

The discharge over the upper portion may be considered as a free discharge under a head of water equal to  $(H_1 - H_2)$ . And the discharge over the lower portion may be considered as a submerged discharge under a head of  $H_2$ . Thus discharge over the free portion (i.e., upper portion),

$$Q_1 = \frac{2}{3} \times C_d \cdot L \sqrt{2g} \times (H_1 - H_2)^{3/2}$$

**Submerged weir :-**

and the discharge over the submerged (i.e., lower portion),

$$Q_2 = C_d \cdot L \cdot H_2 \cdot \sqrt{2g(H_1 - H_2)}$$

$$\therefore \text{Total discharge, } Q = Q_1 + Q_2$$

**Example** A submerged sharp crested weir 0.8 metre high stands clear across a channel having vertical sides and a width of 3 meters. The depth of water in the channel of approach is 1.2 meter. And 10 meters downstream from the weir, the depth of water is 1 meter. Determine the discharge over the weir in liters per second. Take  $C_d$  as 0.6.

**Solution.** Given:  $L = 3$  m and  $C_d = 0.6$ .

From the geometry of the weir, we find that the depth of water on the upstream side,

$$H_1 = 1.25 - 0.8 = 0.45 \text{ m and depth of water on the downstream side,}$$

$$H_2 = 1 - 0.8 = 0.2 \text{ m}$$

We know that the discharge over the free portion of the weir

$$Q_1 = \frac{2}{3} \times C_d \cdot L \sqrt{2g} \times (H_1 - H_2)^{3/2}$$

$$= \frac{2}{3} \times 0.6 \times 3 \times (\sqrt{2 \times 9.81})(0.45 - 0.20)^{3/2}$$

$$= 5.315 \times 0.125 = 0.664 \text{ m}^3/\text{s} = 664 \text{ liters/s} \quad \dots (i)$$

and discharge over the submerged portion of the weir,

$$Q_2 = C_d \cdot L \cdot H_2 \cdot \sqrt{2g(H_1 - H_2)}$$

$$= 0.6 \times 3 \times 0.2 \sqrt{2} \times 9.81(0.45 - 0.2) \text{ m}^3/\text{s}$$

$$= 0.36 \times 2.215 = 0.797 \text{ m}^3/\text{s} = 797 \text{ liters/s} \quad \dots \text{ (ii)}$$

$$\therefore \text{ Total discharge: } Q = Q_1 + Q_2 = 664 + 797 = 1461 \text{ liters/s} \quad \text{Ans.}$$

### 2.3 Flow over Weirs:-

An open channel is a passage through which the water flows under the force of gravity - atmospheric pressure. Or in other words, when the free surface of the flowing water is in contact, with the atmosphere as in the case of a canal, a sewer or an aqueduct, the flow is said to be through an open channel. A channel may be covered or open at the top. As a matter of fact, the flow of water in an open channel, is not due to any pressure as in the case of pipe flow. But it is due to the slope the bed of the channel. Thus during the construction of a channel, a uniform slope in its bed is provided to maintain the flow of water.

#### Chezy's' Formula for Discharge through an Open Channel :-

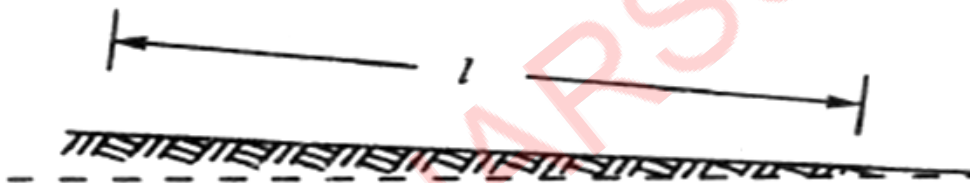


Fig. 2.19

#### Sloping bed of a channel :-

Consider an open channel of uniform cross-section and bed slope as shown in Fig.

Let

$I$  = Length of the channel,

$A$  = Area of flow,

$v$  = Velocity of water,

$p$  = Wetted perimeter of the cross-section,  $m$  =

$f$  = Frictional resistance per unit area at unit velocity, and

$i$  = Uniform slope in the bed.

$$m = \frac{A}{P}$$

hydraulic radius )

.....(known as hydraulic mean depth or

$$\therefore \text{Discharge } Q = A \times v = AC\sqrt{mi}$$

**Example.**

A rectangular channel is 1.5 metres deep and 6 metres wide. Find the discharge through channel, when it runs full. Take slope of the bed as 1 in 900 and Chezy's constant as 50.

Solution. Given:  $d = 1.5 \text{ m}$ ;  $b = 6 \text{ m}$ ;  $i = 1/900$  and  $C = 50$ .

We know that the area of the channel,

$$A = b.d = 6 \times 1.5 = 9 \text{ m}^2$$

$$\text{and wetted perimeter, } D = b + 2d = 6 + (2 \times 1.5) = 9 \text{ m}$$

$$\therefore \text{Hydraulic mean depth, } m = \frac{A}{P} = 1 \text{ m}$$

and the discharge through the channel,

$$Q = AC\sqrt{mi} = 9 \times 50 \sqrt{(1 \times 1/900)} = 15 \text{ m}^3/\text{s} \quad \text{Ans.}$$

**Manning Formula for Discharge :-**

Manning, after carrying out a series of experiments, deduced the following relation for the value of C in Chezy's formula for discharge:

$$C = \frac{1}{N} \times m^{1/6}$$

where N is the Kutter's constant

Now we see that the velocity,

$$v = C\sqrt{mi} = M \times m^{2/3} \times i^{1/2}$$

where

$M = 1/N$  and is known as Manning's constant.

Now the discharge,

$$Q = \text{Area} \times \text{Velocity} = A \times 1/N \times m^{2/3} \times i^{1/2}$$

$$= A \times M \times m^{2/3} \times i^{1/2}$$



**Example**

An earthen channel with a 3 m wide base and side slopes 1 : 1 carries water with a depth of 1 m. The bed slope is 1 in 1600. Estimate the discharge. Take value of N in Manning's formula as 0.04.

Solution.

Given:  $b = 3$  m; Side slopes = 1 : 1;  $d = 1$  m;  $i = 1/1600$  and  $N = 0.04$ .

We know that the area of flow,

$$A = \frac{1}{2} \times (3 + 5) \times 1 = 4 \text{ m}^2$$

and wetted perimeter,

$$P = 3 + 2 \times \sqrt{(1)^2 + (1)^2} = 5.83 \text{ m}$$

$$\therefore \text{hydraulic mean depth } m = A/P = 4/5.83 = 0.686 \text{ m}$$

We know that the discharge through the channel

$$Q = \text{Area} \times \text{Velocity} = A \times \frac{1}{N} \times m^{2/3} \times i^{1/2}$$

$$= 4 \times \frac{1}{0.04} \times 0.686^{2/3} \times (1/1600)^{1/2}$$

$$= 1.945 \text{ m}^3/\text{s} \text{ Ans}$$

**Channels of Most Economical Cross-sections :-**

A channel, which gives maximum discharge for a given cross-sectional area and bed slope is called a channel of most economical cross-section. Or in other words, it is a channel which involves least excavation for a designed amount of discharge. A channel of most economical cross-section is, sometimes: also defined as a channel which has a minimum wetted perimeter; so that there is a minimum resistance to flow and thus resulting in a maximum discharge. From the above definitions,

it is obvious that while deriving the condition for a channel of most economical cross-section, the cross-sectional area is assumed to be constant. The relation between depth and breadth of the section is found out to give the maximum discharge.

The conditions for maximum discharge for the following sections will be dealt with in the succeeding pages :

1. Rectangular section,
2. Trapezoidal section, and
3. Circular section.

### Condition for Maximum Discharge through a Channel of Rectangular Section :-

A rectangular section is, usually, not provided in channels except in rocky soils where the faces of rocks can stand vertically. Though a rectangular section is not of much practical importance, yet we shall discuss it for its theoretical importance only.

Consider a channel of rectangular section as shown in Fig.

Let

$b$  = Breadth of the channel, and

$d$  = Depth of the channel.

$$A = b \times d$$

$$\text{Discharge } Q = A \times v = AC \sqrt{m} i$$

$$m = A/P$$

$$= d/2$$

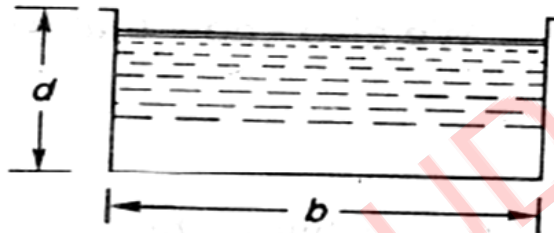


Fig. 2.20

Hence, for maximum discharge or maximum velocity, these two conditions (i.e.,  $b = 2d$  and  $m = d/2$ ) should be used for solving the problems of channels of rectangular cross-sections.

### Example

A rectangular channel has a cross-section of 8 square metres. Find its size and discharge through the most economical section, if bed slope is 1 in 1000. Take  $C = 55$ .

Solution. Given:  $A = 8 \text{ m}^2$

$$i = 1/1000 = 0.001 \text{ and } C = 55.$$

Size of the channel

Let

$b$  = Breadth of the channel, and

$d$  = Depth of the channel.

We know that for the most economical rectangular section,

$$b = 2d$$

$$\therefore \text{Area (A)} = 8 = b \times d = 2d \times d = 2d^2$$

$$= b = 2 \text{ m}$$

$$\text{And } b = 2d = 2 \times 2 = 4 \text{ m}$$

Discharge through the channel

We also know that for the most economical rectangular section, hydraulic mean depth,

$$m = d/2 = 2/2 = 1 \text{ m}$$

and the discharge through the channel,

$$Q = AC \sqrt{m} i = 8 \times 55 \sqrt{1} \times 0.001 \text{ m}^3/\text{s}$$

$$= 440 \times 0.0316 = 13.9 \text{ m}^3/\text{s}, \text{ Ans.}$$

### Condition for Maximum Discharge through a Channel of Trapezoidal Section :-

A trapezoidal section is always provided in the earthen channels. The side slopes, in a channel of trapezoidal cross-section are provided, so that the soil can stand safely. Generally, the side slope in a particular soil is decided after conducting experiments on that soil. In a soft soil, flatter side slopes should be provided whereas in a harder one, steeper side slopes may be provided. consider a channel of trapezoidal cross-section ABCD as shown in Fig.

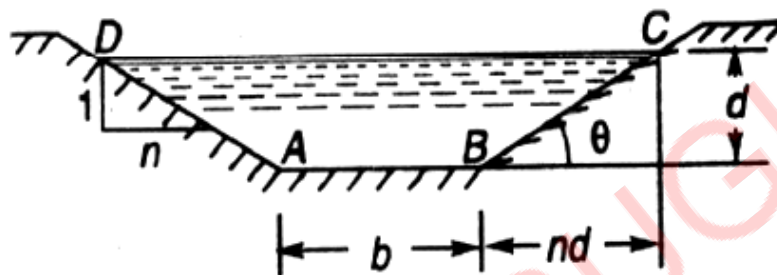


Fig. 2.21

Let

$b$  = Breadth of the channel at the bottom,

$d$  = Depth of the channel and

$\frac{1}{n}$

= side slope

(i.e., 1 vertical to  $n$  horizontal)

Hence, for maximum discharge or maximum velocity these two (i.e.,  $b + 2nd^2 = d\sqrt{n^2 + 1}$  and  $m = d/2$ ) should be used for solving problems on channels of trapezoidal cross-sections.

#### Example .

A most economical trapezoidal channel has an area of flow  $3.5 \text{ m}^2$  discharge in the channel, when running 1 metre deep. Take  $C = 60$  and bed slope 1 in 800.

**Solution.** Given:  $A = 3.5 \text{ m}^2$  ;  $d = 1 \text{ m}$ ;  $C = 60$  and  $i = 1/800$ .

We know that for the most economical trapezoidal channel the hydraulic mean depth

$$m = d/2 = 0.5 \text{ m}$$

and discharge in the channel,

$$Q = A.C.\sqrt{mi} = 5.25 \text{ m}^3/\text{s} \text{ Ans.}$$

#### Example .

A trapezoidal channel having side slopes of 1 : 1 and bed slope of 1 in 1200 is required to carry a discharge of 1800 m<sup>3</sup>/min. Find the dimensions of the channel for cross-section. Take Chezy's constant as 50.

**Solution.**

Given side slope (n)=1

(i.e. 1 vertical to n horizontal),

$i = 1/1200$ ,  $Q = 1800 \text{ m}^3/\text{min} = 30 \text{ m}^3/\text{sec}$

and  $C = 50$

Let  $b$  = breadth of the channel of its bottom and  $d$  = depth of the water flow.

We know that for minimum cross section the channel should be most economical and for economical trapezoidal section half of the top width is equal to the sloping side. i.e.

$$b + 2nd^{1/2} = d \sqrt{n^2 + 1}$$

or  $b = 0.828d$

$$\therefore \text{Area } A = d \times (b + nd) = 1.828d^2$$

We know that in the case of a most economical trapezoidal section the hydraulic mean depth  $m = d/2$

And discharge through the channel  $(Q) = A.C.\sqrt{mi} = 1.866d^{5/2}$

$$\therefore d^{5/2} = 30/1.866 = 16.08$$

Or  $d = 1.21 \text{ m}$

$$\therefore b = 0.828d = 0.828 \times 1.21 = 1 \text{ m ANS}$$

**Condition for Maximum Velocity through a Channel of Circular Section :-**

Consider a channel 'o' circular section, discharging water under the atmospheric pressure shown in Fig.

Let  $r$  = Radius of the channel,

$h$  = Depth of water in the channel, and

$2\theta$  = Total angle (in radians) subtended at the centre by the water

From the geometry of the figure, we find that the wetted perimeter of the channels,

$$P = 2r\theta \quad \dots(i)$$

and area of the section, through which the water is flowing,

$$A = r^2\theta - \frac{r^2 \sin 2\theta}{2} = r^2 \left( \theta - \frac{\sin 2\theta}{2} \right) \quad \dots(ii)$$

We know that the velocity of flow in an open channel,

$$Q = A.C.\sqrt{mi}$$

We know that the velocity of flow in an open channel ,  $v = C\sqrt{mi}$

**Problem: Find the maximum velocity of water in a circular channel of 500 mm radius, if the bed slope is 1 in 400. Take manning's constant as 50.**

**Solution:-**

Given  $d = 500\text{mm} = 0.5\text{m}$  or  $r = 0.5/2 = 0.25\text{m}$ ,  $i = 1/400$  and  $M = 50$

Let  $2\theta$  = total angle (in radian) subtended by the water surface at the centre of the channel.

Now we know that for maximum velocity , the angle subtended by the water surface at the centre of the channel.

$$2\theta = 257^{\circ}30' \text{ or } \theta = 128.75^{\circ} = 128.75 \times \frac{\pi}{180} = 2.247\text{rad}$$

$$\therefore \text{Area of flow, } A = r^2 \left( \theta - \frac{\sin 2\theta}{2} \right) = 171\text{m}^2$$

$$\text{And perimeter } P = 2r\theta = 1.124\text{m}$$

$$\therefore \text{hydraulic mean depth } m = A/P = 0.171/1.124 = 0.152\text{m}$$

$$\text{And velocity of water } v = M X m^{2/3} X i^{1/2} = 0.71\text{m/s} \quad \text{ANS}$$

## Chapter-III

### PUMPS

#### 3.1 Centrifugal Pumps:-

The hydraulic machines which convert the mechanical energy to hydraulic energy are called pumps. The hydraulic energy is in the form of pressure energy. If the mechanical energy is converted, into pressure energy by means of centrifugal force acting on the fluid, the hydraulic machine is called centrifugal pump.

The centrifugal pump works on the principle of forced vortex flow which means that when a certain mass of liquid is rotated by an external torque, the rise in pressure head of the rotating liquid takes place. The rise in pressure head at any point of the rotating liquid is proportional to the square of tangential velocity of the liquid at that point (i.e. , rise in pressure head =  $\frac{v^2}{2g}$  or  $\frac{\omega^2 r^2}{2g}$  ). Thus at the outlet of the impeller, where radius is more , the rise in pressure head will be more & the liquid will be more & the liquid will be discharged at the outlet with a high pressure head. Due to this high pressure head, the liquid can be lifted to a high level.

#### Main Parts Of A Centrifugal Pump:-

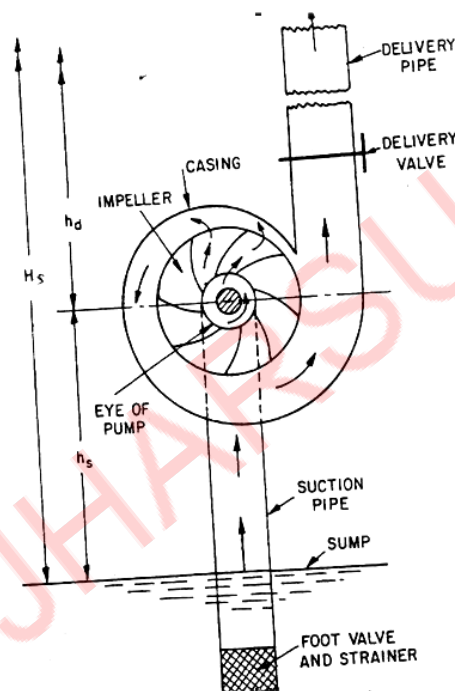
The followings are the main parts of a centrifugal pump:

1. Impeller
2. Casing
3. Suction pipe with a foot valve & a strainer
4. Delivery Pipe

All the main parts of the centrifugal pump are shown in Fig 19.1

1. **Impeller:** The rotating part of a centrifugal pump is called 'impeller'. It consists of a series of backward curved vanes. The impeller is mounted on a shaft which is connected to the shaft of an electric motor.
2. **Casing:** The casing of a centrifugal pump is similar to the casing of a reaction turbine. It is an air-tight passage surrounding the impeller & is designed in such a way that the kinetic energy of the water discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing & enters the delivery pipe. The following three types of the casings are commonly adopted:

- a. Volute **casing** as shown in Fig.19.1
  - b. Vortex casing as shown in Fig.19.2(a)
  - c. Casing with guide blades as shown in Fig.19.2(b)
- a) **Volute casing** as shown in Fig.3.1 the Volute casing, which is surrounding the impeller. It is of spiral type in which area of flow increases gradually. The increase in area of flow decrease velocity of flow. Decrease in velocity increases the pressure of water flowing through casing. it has been observed that in case of volute casing, the efficiency of pump increases.



Main parts of a centrifugal pump

Fig. 3.1

**b) Vortex casing.** if a circular chamber is introduced between the casing and impeller as shown in fig.3.1, the casing is known as vortex casing .by introducing the circular chamber, loss of energy due to formation of eddies is reduced to a considerable extent. thus efficiency of pump is more than the efficiency when only volute casing is provided.

**c) Casing with guide blades.** This casing is shown in fig.3.1 in which the impeller is surrounded by a series of guide blades mounted on a ring which is known as diffuser. the guide vanes are designed in which a way that the water from the impeller enters the guide vanes without stock. Also the area of guide vanes increases, thus reducing the velocity of

flow through guide vanes and consequently increasing the pressure of water. the water from guide vanes then passes through the surrounding casing which is in most of cases concentric with the impeller as shown in fig.3.1.

**3. suction pipe with foot-valve and a strainer:** A pipe whose one end is connected to the inlet of pump and other end dips into water in a sump is known as suction pipe. A foot valve which is a non-return valve or one –way type valve is fitted at lower end of suction pipe. Foot valve opens only in upward direction. A strainer is also fitted at lower end of suction pipe.

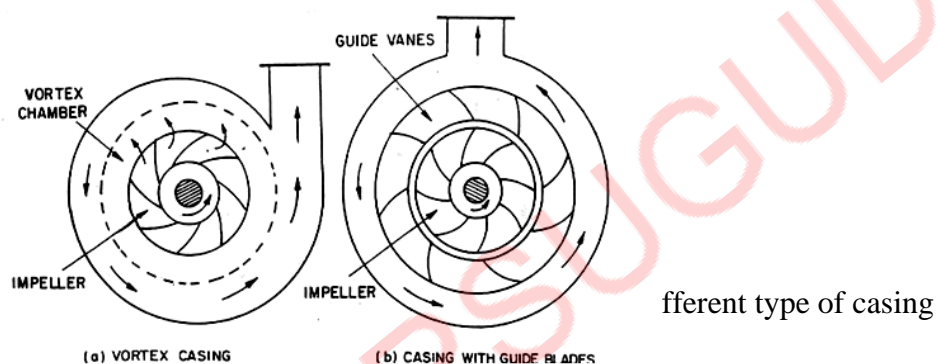


Fig: 3.2

**4. delivery pipe:** a pipe whose one end is connected to outlet of pump and other end delivers water at a required height is known as delivery pipe.

**Efficiencies of a centrifugal pump:** Efficiencies of a centrifugal pump: In case of a centrifugal pump, the power is transmitted from the shaft of the electric motor to the shaft of the pump & then to the impeller. From the impeller, the power is given to the water. Thus power is decreasing from the shaft of the pump to the impeller & then to the water. The following are the important efficiencies of a centrifugal pump:

- a. Manometric efficiencies  $\eta_{man}$
- b. Mechanical efficiencies  $\eta_m$
- c. Overall efficiencies  $\eta_o$

a) **Manometric Efficiencies  $\eta_{man}$ :** The ratio of the manometric head to the head imparted by the impeller to the water is known as manometric efficiency. It is written as



$\eta_{\max}$  = Manometric head/Head imparted by impeller to water

$$= \frac{H_m}{\frac{V_{w2}u_2}{g}} = \frac{gH_m}{V_{w2}u_2} \dots\dots\dots$$

The impeller at the impeller of the pump is more than the power given to the water at outlet of the pump. The ratio of the power given to water at outlet of the pump to the power available at the impeller, is known as manometric efficiency.

The power given to water at outlet of the pump =  $\frac{WH_m}{1000}$  kW

The power at the impeller =  $\frac{\text{Work done by impeller per second}}{1000}$  kW

$$\begin{aligned} & \frac{W}{g} \times \frac{V_{w2}u_2}{1000} \text{ kW} \\ &= \\ & \eta_{\max} = \frac{\frac{WH_m}{1000}}{\frac{W}{g} \times \frac{V_{w2}u_2}{1000}} = \frac{gH_m}{V_{w2} \times u_2} \end{aligned}$$

**b) Mechanical efficiencies:-**

The power at the shaft of the centrifugal pump is more than the power available at the impeller of the pump. The ratio of the power available at the impeller to the power at the shaft of the centrifugal pump is known as mechanical efficiency. It is written as

$\eta_m$  = Power at the impeller/Power at the shaft

The power at the impeller in kW = work done by impeller per second/10000

$$\begin{aligned} &= \frac{W}{g} \times \frac{V_{w2}u_2}{1000} \\ & \eta_m = \frac{\frac{W}{g} \left( \frac{V_{w2}u_2}{1000} \right)}{S.P.} \dots\dots\dots \end{aligned}$$

Where S.P. = Shaft Power

**c) Overall efficiencies  $\eta_o$**

It is defined as the ratio of power output of the pump to the power input to the pump .  
The power output of the pump in kW

$$= \frac{\text{Weight of water lifted} \cdot H_m}{1000} = \frac{WH_m}{1000}$$

Power input to the pump = Power supplied by the electric motor

= S.P. of the pump

$$= \eta_o = \frac{\left( \frac{WH_m}{1000} \right)}{S.P.} \dots\dots\dots$$

$$= \eta_{man} \times \eta_m \dots\dots\dots$$

**Problem 3.1:** The internal & external diameters of the impeller of a centrifugal pump are 200mm & 400mm respectively. The pump is running at 1200 r.p.m. The vane angles of the impeller at inlet & outlet are  $20^\circ$  &  $30^\circ$  respectively. The water enters the impeller radially & velocity of flow is constant. Determine the velocity of flow per metre sec.

**Solution:** Internal Dia. Of impeller,  $= D_1 = 200\text{mm} = 0.20\text{m}$

External Dia. Of impeller,  $= D_2 = 400\text{mm} = 0.40\text{m}$

Speed  $N = 1200\text{r.p.m}$

Vane angle at inlet,  $\theta = 20^\circ$

Vane angle at outlet,  $\phi = 30^\circ$

Water enters radially means,  $\alpha = 90^\circ$  and  $V_{w1} = 0$

Velocity of flow,  $= V_{f1} = V_{f2}$

Tangential velocity of impeller at inlet & outlet are,

$$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times .20 \times 1200}{60} = 12.56\text{m/s}$$

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times .40 \times 1200}{60} = 25.13\text{m/s}$$

From inlet velocity triangle,

$$\tan \phi = \frac{V_{f1}}{u_1} = \frac{V_{f2}}{12.56}$$

$$V_{f1} = 12.56 \tan \theta = 12.56 \times \tan 20 = 4.57 \text{ m/s}$$

$$V_{f2} = V_{f1} = 4.57 \text{ m/s}$$

**Problem 3.2:** A centrifugal pump delivers water against a net head of 14.5 metres & a design speed of 1000r.p.m. The values are back to an angle of  $30^\circ$  with the periphery. The impeller diameter is 300mm & outlet width 50mm. Determine the discharge of the pump if manometric efficiency is 95%.

**Solution:** Net head,  $H_m = 14.5\text{m}$

Speed,  $N = 1000\text{r.p.m}$

Vane angle at outlet,  $\phi = 30^\circ$

Impeller diameter means the diameter of the impeller at outlet

Diameter,  $D_2 = 300\text{mm} = 0.30\text{m}$

Outlet width,  $B_2 = 50\text{mm} = 0.05\text{m}$

Manometric efficiency,  $\eta_{man} = 95\% = 0.95$

Tangential velocity of impeller at outlet,  $u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times .30 \times 1000}{60} = 15.70 \text{ m/s}$

Now using equation

$$\eta_{\max} = \frac{gH_m}{V_{w2}u_2}$$

$$0.95 = \frac{9.81 \times 14.5}{V_{w2} \times 15.70}$$

$$V_{w2} = \frac{0.95 \times 14.5}{0.95 \times 15.70} = 9.54 \text{ m/s}$$

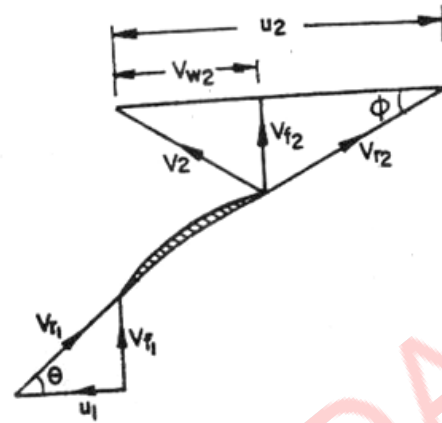


Fig. 3.3

Refer to fig(3.3). From outlet velocity triangle, we have

$$\tan \phi = \frac{V_{f2}}{(u_2 - V_{w2})}$$

$$\tan 30^\circ = \frac{V_{f2}}{(15.70 - 9.54)} = \frac{V_{f2}}{6.16}$$

$$V_{f2} = 6.16 \times \tan 30^\circ = 3.556 \text{ m/s}$$

$$\text{Discharge } Q = \pi \times D_2 \times B_2 \times V_{f2}$$

$$= \pi \times 0.30 \times 0.05 \times 3.556 \text{ m}^3 / \text{s} = 0.1675 \text{ m}^3 / \text{s}$$

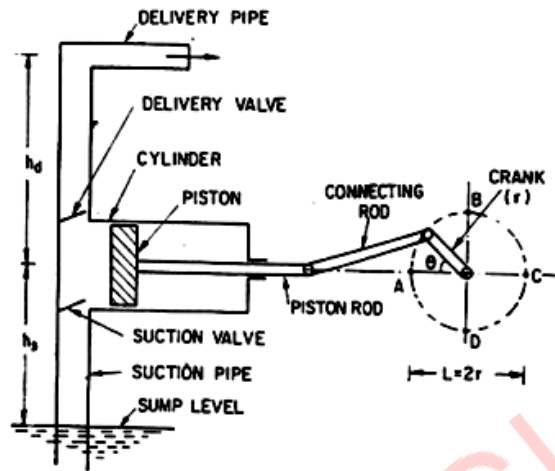
### 3.2 Reciprocating Pump:-

#### Introduction:-

We have defined the pumps as the hydraulic machines which convert the mechanical energy to hydraulic energy which is mainly in the form of pressure energy. If the mechanical energy is converted into hydraulic energy (or pressure energy) by sucking the liquid into a cylinder in which a piston is reciprocating (moving backwards and forwards), which exerts the thrust on the liquid & increases its hydraulic energy (pressure energy), the pump is known as reciprocating pump.

### Main parts of a reciprocating pump:-

The following are the main parts of a reciprocating pump as shown in fig (3.4)



Main parts of a reciprocating pump.

1. A cylinder with a piston, piston rod, connecting rod and a crank,
2. Suction pipe,
3. Delivery pipe,
4. Suction valve, and
5. Delivery valve.

Fig. 3.4

**Discharge through a Reciprocating Pump:** Consider a single acting reciprocating pump as shown in fig ( ).

Let  $D$  = dia. Of the cylinder

$A$  = C/s area of the piston or cylinder

$$= \frac{\pi}{4} D^2$$

$r$  = Radius of crank

$N$  = r.p.m of the crank

$L$  = Length of the stroke =  $2*r$

$h_s$  = height of the axis of the cylinder from water surface in sump

$h_d$  = Height of the delivery outlet above the cylinder axis (also called delivery head)

Volume of water delivered in one revolution or discharge of water in one revolution

$$= \text{Area} * \text{Length of stroke} = A*L$$

Number of revolution per second, =  $\frac{N}{60}$

Discharge of the pump per second,  $Q =$  Discharge in one direction  $\times$  No. of revolution per second

$$= A \times L \times \frac{N}{60} = \frac{ALN}{60} \dots\dots\dots$$

Wt. of water delivered per second,  $W = \rho g Q = \frac{\rho g ALN}{60} \dots\dots\dots$

**Work done by Reciprocating Pump :** Work done by the reciprocating pump per sec. is given by the reaction as

Work done per second = Weight of water lifted per second  $\times$  Total height through which water is lifted

$$= W \times (h_s + h_d)$$

Where  $(h_s + h_d) =$  Total height through which water is lifted

From equation () Weight,  $W$  is given by  $W = \frac{\rho g ALN}{60}$

Substituting the value of  $W$  in equation () we get

Work done per second =

$$\frac{\rho g ALN}{60} (h_s + h_d) \dots\dots\dots$$

Power required to drive the pump, in kW

$$P = \frac{\text{Work done per second}}{1000} =$$

$$\frac{\rho \times g \times ALN(h_s + h_d)}{60 \times 1000}$$

$$= \frac{\rho g ALN(h_s + h_d)}{60,000} \text{ kW} \dots\dots\dots$$

**Classification of reciprocating pumps:**

The reciprocating pumps may be classified as:

1. According to the water being in contact with one side or both sides of the piston, and
2. According to the number of cylinders provided

If the water is in contact with one side of the piston, the pump is known as single-acting.  
On the other hand,

If the water is in contact with both sides of the piston, the pump is called double –acting.  
Hence, classification according to the contact of water is:

- I. Single-acting pump
- II. Double –acting pump

According to the number of cylinder provided, the pumps are classified as:

- I. Single cylinder pump
- II. Double cylinder pump
- III. Triple cylinder pump

## Chapter-IV

### HYDROLOGY

#### Hydrological cycle

Hydrological cycle is also known as the “water cycle”; it is the normal water recycling system on Earth . Due to solar radiation, water evaporates, generally from the sea, lakes, etc. Water also evaporates from plant leaves through the mechanism of *transpiration*. As the steam rises in the atmosphere, it is being cooled, condensed, and returned to the land and the sea as precipitation. Precipitation falls on the earth as surface water and shapes the surface, creating thus streams of water that result in lakes and rivers. A part of the water precipitating penetrates the ground and moves downward through the incisions, forming aquifers. Finally, a part of the surface and underground water leads to sea. During this trip, water is converted in all phases: gas, liquid, and solid. As mentioned above, water always changes states between liquid, vapor and ice, with these processes happening in the blink of an eye and over millions of years.



#### PRECIPITATION INTRODUCTION:

The term “precipitation” denotes all forms of water that reach the earth from the atmosphere. The usual forms are rainfall, snowfall, hail, frost and dew. The magnitude of precipitation varies with time and space.

For precipitation to form:

- (i) the atmosphere must have moisture,



- (ii) there must be sufficient nuclei present to aid condensation
- (iii) weather conditions must be good for condensation of water vapour to take place
- (iv) the products of condensation must reach the earth.

#### FORMS OF PRECIPITATION:

Some of the common forms of precipitation are rain, snow, drizzle, glaze, sleet and hail.

##### 1. rain

It is the principal form of precipitation in India. The term rainfall is used to describe precipitation in the form of water drops of sizes larger than 0.5mm. The maximum size of a raindrop is 6mm. Any drop larger in size than this tends to break up into drops of smaller sizes during its fall from the clouds. On the basis of its intensity rainfall is classified as follows:

Light rain: trace to 2.5 mm/hr

Moderate rain: 2.5mm/hr to 7.5mm/hr

Heavy rain: > 7.5mm/hr

##### 2. Snow

Snow is another important form of precipitation. Snow consists of ice crystals which usually combine to form flakes. When fresh, snow has an initial density varying from 0.06 to 0.15g/cm<sup>3</sup> and it is usual to assume an average density of 0.1 g /cm<sup>3</sup> . In India, snow occurs only in the Himalayan regions.

##### 3. Drizzle

A fine sprinkle of numerous water droplets of size less than 0.5mm and intensity less than 1mm/hr is known as drizzle. In this, the drops are so small that they appear to float in the air.

##### 4. Glaze

When rain or drizzle comes in contact with cold ground at 00C, the water drops freeze to form an ice coating called glaze or freezing rain.

##### 5. Sleet

It is frozen raindrops of transparent grains which form when rain falls through air at sub freezing temperature. In Britain, sleet denotes precipitation of snow and rain simultaneously.

##### 6. Hail

It is a showery precipitation in the forms of irregular pellets of lump of ice of size more than 8mm. Hails occur in violent thunderstorms in which vertical currents are very strong.

#### WEATHER SYSTEMS FOR PRECIPITATION:

For the formation of clouds and subsequent precipitation, it is necessary that the moist air masses cool to form condensation. This is normally accomplished by adiabatic cooling of moist air through a process of being lifted to higher altitude. Some of the terms and processes connected with weather systems associated with precipitation are given below.

##### 1. Front

A front is the interface between two distinct air masses. Under certain favorable conditions when a warm air mass and cold air mass meet, the warmer air mass is lifted over the colder one with the formation of front. The ascending warmer air cools adiabatically with the consequent formation of clouds and precipitation.

##### 2. Cyclone

A cyclone is a large low pressure region with circular wind motion. Two types of cyclones are recognized: tropical cyclones and extra tropical cyclones.

(a) Tropical cyclone: A tropical cyclone, also called cyclone in India, hurricane in USA and typhoon in south East Asia, is a wind system with an intensely strong depression with MSL pressures sometimes below 915 m bars. The normal areal extend of cyclone is about 100-200 km in diameter. The isobars are closely spaced and the winds are anticlockwise in the northern hemisphere. The center of the storm called the eye, which may extend to about 10-50 km in diameter, will be relatively quiet. However, right outside the eye, very strong winds/reaching to as much as 200 km per hr exist. The wind speed gradually decreases towards the outer edge. The pressure also increases outwards. The rainfall will normally be heavy in the entire area occupied by the cyclone.

(b) Extra tropical cyclone: These are cyclones formed in locations outside the tropical zone. Associated with a frontal system, they possess a strong counter clockwise wind circulation in the northern hemisphere. The magnitude of precipitation and wind velocities are relatively lower than those of a tropical cyclone. However, the duration of precipitation is usually longer and the areal extend is also larger.

(c) Cyclogenesis: These are regions of high pressure, usually of large areal extent. The weather is usually calm at the center. Anticyclones cause clockwise wind circulations in the northern hemisphere. Winds are of moderate speed, and at the outer, cloudy and precipitation conditions exist.

(d) Convective precipitation: In this type of precipitation, a packet of air which is warmer than the surrounding air due to localized heating rises because of its lesser density. Air from

cooler surroundings flows to take up its place, thus setting up a convective cell. The warm air continues to rise, undergoes cooling and results in precipitation. Depending upon the moisture, thermal and other conditions, light showers to thunderstorms can be expected in convective precipitation. Usually, the aerial extent of such rains is small, being limited to a diameter of about 10km.

(e) Orographic precipitation: The moist air masses may get lifted up to higher altitudes due to the presence of mountain barriers and consequently undergo cooling, condensation and precipitation. Such a precipitation is known as orographic precipitation. Thus, in mountain ranges, the windward slopes of heavy precipitation and the leeward slopes have light rainfall.

## MEASUREMENT OF PRECIPITATION

1)infall Precipitation is expressed in terms of the depth to which rainfall water would stand on an area if all the rain were collected on it. Thus, 1cm of rainfall over a catchment area of 1km represents a volume of water equal to 100 cu m . In the case of snowfall, an equivalent depth of water is used as the depth of precipitation. The precipitation is collected and measured in a rain gauge. Terms such pluviometer ombrometer and hyetometer also sometimes used to designate a rain gauge. A rain gauge essentially consists of a cylindrical vessel assembly kept in the open to collect rain. The rainfall catch of the rain gauge is affected by its exposure conditions. To enable the catch of rain gauge to accurately represent the area in the surrounding the rain gauge standard settings are adopted. For setting up a rain gauge the following considerations are important:

- The ground must be level and in the open and the instrument must present a horizontal catch surface.
- The gauge must be set as near the ground as possible to reduce wind effects but it must be sufficiently high to prevent splashing flooding etc.
- The instrument must be surrounded by an open fenced area of at least 5.5 m \* 5.5 m.
- No object should be nearer to the instrument than 30 m or twice the height of the obstruction.

Rain gauges can be broadly classified into two categories as

(i) Non recording gauges

(ii) Recording gauges.

A. Non recording gauges

The non recording gauge extensively used in India is the Symon's gauge. It essentially consists of a circular collection area of 12.7 cm (5.0 inch) diameter connected to a funnel. The rim of the collector is set in a horizontal plane at a height of 30.5 cm above the ground level. The funnel discharges the rainfall catch into a receiving vessel. The funnel and receiving vessel are housed in a metallic container. Fig below shows the details of the installation. Water contained in the receiving vessel is measured by a suitably graduated measuring glass, with accuracy up to 0.1mm. Recently, the Indian Meteorological Department (IMD) has changed over to the use of fiber glass reinforced polyester rain-gauges, which is an improvement over the Symon's gauge. These come in different combinations of collector is in two sizes having areas of 200 and 100 cm<sup>2</sup> respectively. Indian standard (IS: 5225- 1969) gives details of these new rain-gauges. For uniformity, the rainfall is measured everyday at 8.30a.m.(IST) and is recorded as the rainfall of that day. The receiving bottle normally does not hold more than 10cm of rain and as such, in the case of heavy rainfall, the measurements must be done more frequently and entered. However, the last reading must be taken at 8.30 a.m. and the sum of the previous readings in the past 24 hours entered as the total of that day. Proper care, maintenance and inspection of rain-gauges, especially during dry weather to keep the instrument free from dust and dirt, is very necessary. The details of installation of non-recording rain-gauges and measurement of rain are specified in Indian Standard (IS:4986-1968). This rain-gauge can also be used to measure snowfall. When snow is expected, the funnel and receiving bottle are removed and the snow is allowed to collect in the outer metal container. The snow is then melted and the depth of resulting water measured. Antifreeze agents are sometimes used to facilitate melting of snow. In areas where considerable snowfall is expected, special snow-gauges with shields (for minimizing the wind effect) and storage pipes (to collect snow over longer durations) are used.

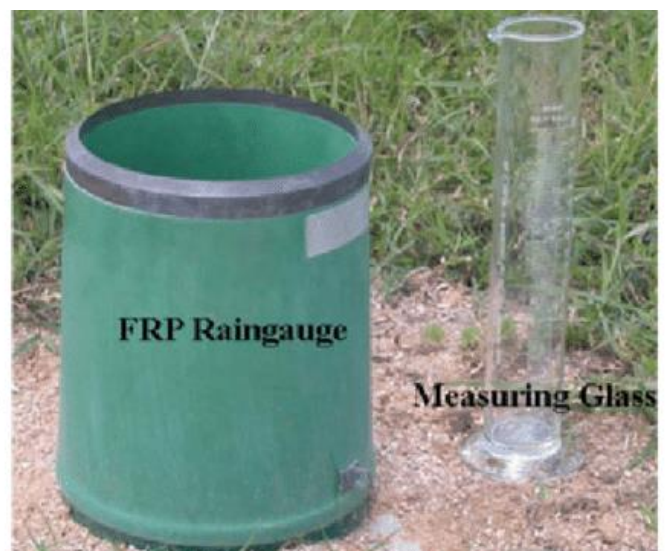
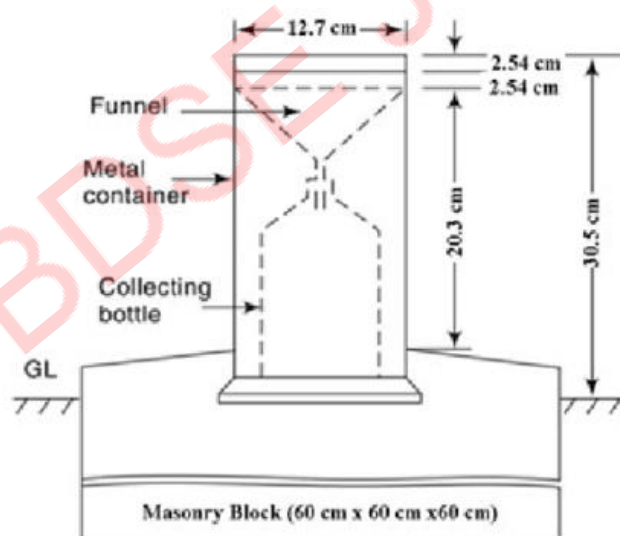


Fig- Symon's raingauge

B. Recording Gauges Recording gauges produce a continuous plot of rainfall against time and provide valuable data of intensity and duration of rainfall for hydrological analysis of storms. The following are some of the commonly used recording rain-gauges.

(a) Tipping-Bucket Type

This is a 30.5 cm size rain-gauge adopted for use by the US Weather Bureau. The catch from the funnel falls onto one of a pair of small buckets. These buckets are so balanced that when 0.25 mm of rainfall collects in one bucket, it tips and brings the other one in position. The water from the tipped bucket is collected in a storage can. The tipping actuates an electrically driven pen to trace a record on the clockwork-driven chart. The water collected in the storage can is measured at regular intervals to provide the total rainfall and also serve as a check. It may be noted that the record from the tipping bucket gives data on the intensity of rainfall. Further, the instrument is ideally suited for digitalizing of the output signal.

(b) Weighing-Bucket Type In this rain-gauge, the catch from the funnel empties into a bucket mounted on a weighing scale. The weight of the bucket and its contents are recorded on a clockwork-driven chart. The clockwork mechanism has the capacity to run for as long as one week. This instrument gives a plot of the accumulated rainfall against the elapsed time, i.e. the mass curve of rainfall. In some instruments of this type, the recording unit is so constructed that the pen reverses its direction at every preset value, say 7.5 cm (3inch) so that a continuous plot of storm is obtained.

(natural-Syphon Type -This type of recording rain-gauge is also known as float-type gauge. Here, the rainfall collected by a funnel-shaped collector is led into a float chamber causing a float to rise. As the float rises, a pen attached to the float through a lever system records the elevation of the float on a rotating drum driven by a clockwork mechanism. A siphon arrangement empties the float chamber when the float has reached a preset maximum level. This type of rain-gauge is adopted as the standard recording-type rain-gauge in India and in details is described in Indian Standard (IS: 5235-1969).

### HYETOGRAPH

- A hyetograph is a graphical representation of the relationship between the rainfall intensity and time.
- It is the plot of the rainfall intensity drawn on the ordinate axis against time on the abscissa axis.
- The hyetograph is a bar diagram.
- The area under the hyetograph gives the total rainfall occurred in that period.
- This chart is very useful in representing the characteristics of storm, and is particularly important in developing the design storm to predict extreme floods.

## RUNOFF

It means the draining/flowing off of precipitation from catchment area through a surface channel. Otherwise it represents the output from the catchment in a basin unit of time.

**BASIN:** – Area bounded by the highest contour called ridge line from where precipitated water is collected by surface and subsurface flows & drained out through the natural river.

The ridge line divides one basin from the other basin/catchment/watershed/drainage basin. Watershed discharge 'Q' can be related to the area 'A' as

$$Q = x \cdot A^y$$

Where x, y = parameters (Depending on this values Q = peak flow min. or mean flow.)

**STREAM:-** It is a natural flow channel in which water from a basin is collected and drained out to the water body.

**OVERLOAD FLOW & SURFACE RUNOFF-** After meeting all the losses, the excess rain water flows over the land surface in the form of a sheet of water to join the nearest stream and is called overland flow. The surface runoff is considered as overland flow so long as it does not join the nearest stream.

Lof = Length of overland flow

Ds = Stream density

## SURFACE RUNOFF

The flow where it travels all the time over the surface is overland flow and through the channels as open channel flow and reaches the catchment outlet is called surface runoff.

## SUBSURFACE RUNOFF

Otherwise known as interflow/ subsurface flow/ through flow/Storm seepage/ quick return flow. The part of precipitation which infiltrates into the ground and moves laterally/ horizontally in the soil and returns to the surface at some location away from the point of entry into the soil is called as interflow. Depending upon the time delay between the infiltration and outflow, Prompt (with least time lag)

## GROUND WATER FLOW

Another route for the infiltrated water is to undergo deep resolution and reach the ground water storage in the soil.

The part of runoff is called ground water runoff/ flow.

**STREAM FLOW** The total runoff consisting of surface flow, subsurface flow, ground water or base flow & the precipitation falling directly in the stream is the stream flow/ total runoff of a basin.

Effluent stream (When the ground water table is higher than the water level of stream, then the stream receives water from ground water reservoir)

Influent stream (When the position of ground water table is lower than the water level of stream, stream water from the stream contributes to the ground water storage. e.G. In early part of rainy season all rivers of India.

Based on the time delay between the precipitation and the runoff, runoff are of two types Direct Runoff & Base flow

#### DIRECT RUNOFF

Direct/storm runoff is that part of stream flow occurring promptly as precipitation starts & contributes for an acceptable period after the storm ceases. Contribution from subsurface flow is considered constant during the period.

#### BASE FLOW

It is that part of stream flow available mainly from ground water reservoir and delayed sub-surface flow appearing during dry period. Direct runoff and base flow are distinguished by mainly on time of arrival of flow to the catchment.

#### CONCEPT OF CATCHMENT AREA

The word catchment (aka watershed) in hydrology is spoken with respect to a river/stream. It denotes all that area that drains into the river/stream under consideration. Any precipitation that falls on the catchment region of a river will flow down the land to join the river to contribute to its volume either through surface runoff or through baseflow (underground water flow). A catchment's boundary is denoted by the ridge line