

## SPILLWAY & IRRIGATION PUMPS

## CHAPTER

## 10

**Spillway:**

The spillways are openings provided at the body of the dam to discharge safely the excess water or flood water when the water level rises above the normal pool level.

**Necessity of Spillways**

- (a) The height of the dam is always fixed according to the maximum reservoir capacity. The normal pool level indicates the maximum capacity of the reservoir. The water is never stored in the reservoir above this level. The dam may fail by over turning so, for the safety of the dam the spillways are essential.
- (b) The top of the dam is generally utilized by making road. The surplus water is not be allowed to over top the dam, so to stop the over topping by the surplus water, the spillways become extremely essential.
- (c) To protect the downstream base and floor of the dam from the effect of scouring and erosion, the spillways are provided so that the excess water flows smoothly.

**Location of Spillway**

*Generally, the spillways are provided at the following places*

- Spillways may be provided within the body of the dam.
- Spillways may sometimes be provided at one side or both sides of the dam.
- Sometimes by-pass spillway is provided which is completely separate from the dam.

**Determination of discharge capacity and number of spillways**

*The maximum discharge capacity and the number of spillways are determined by studying the following factors:*

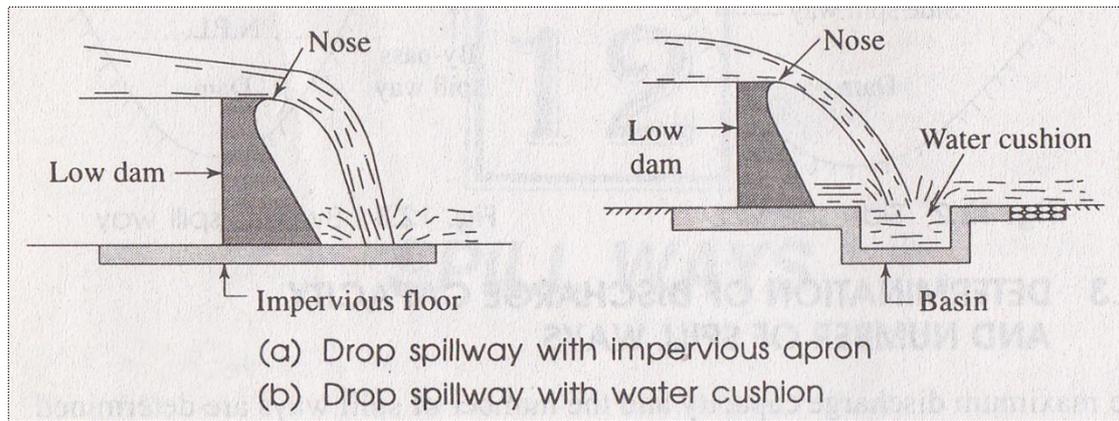
- (a) By studying the flood hydrograph of past ten years, the maximum flood discharge may be computed which is to be disposed off completely through the spillways.
- (b) The water level in the reservoir should never be allowed to rise above the maximum pool level and should remain in normal pool level. So, the volume of water collected between maximum pool level and minimum pool level computed, which indicates the discharge capacity of spillways.
- (c) The maximum flood discharge may also be computed from other investigation like, rainfall records, flood routing, empirical flood discharge formulae, etc.
- (d) From the above factors the highest flood discharge is ascertained to fix the discharge capacity of spillways.
- (e) The natural calamities are beyond the grip of human being. So, an allowance of about 25 % should be given to the computed highest flood discharge which is to be disposed off.
- (f) The size and number of spillways are designed according to the design discharge.

**Types of Spillways**

- (a) Drop Spillways
- (b) Ogee Spillway
- (c) Siphon Spillway
- (d) Chute or Trough Spillway
- (e) Shaft Spillway
- (f) Side Channel Spillway

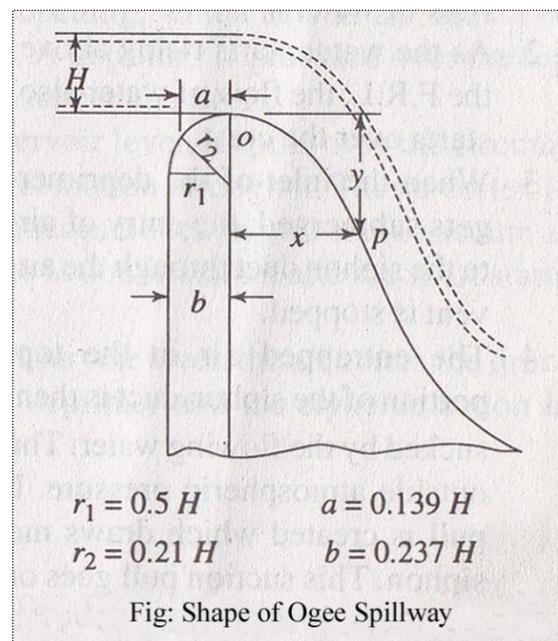
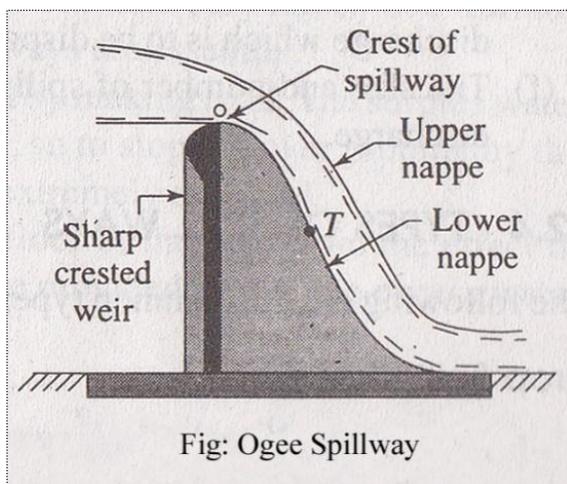
**(a) Drop Spillway**

In drop spillway, the over flowing water falls freely and almost vertically on the downstream side of the hydraulic structure. This type of spillway is suitable for weirs or low dams. The crest of the spillway is provided with nose so that the water jet may not strike the downstream base of the structure. To protect the structure from the effect of scouring horizontal impervious apron should be provided on the downstream side. Sometimes a basin is constructed on the downstream side to form a small artificial pool which is known as water cushion. This cushion serves the purpose of energy dissipater.



### (b) Ogee Spillways

The ogee spillway is a modified form of drop spillway. Here, the downstream profile of the spillway is made to coincide with the shape of the lower nappe of the free falling waterjet from a sharp crested weir. In this case, the shape of the lower nappe is similar to a projectile and hence downstream surface of the ogee spillway will follow the parabolic path where “O” is the origin of the parabola. The downstream face of the spillway forms a concave curve from a point “T” and meets with the downstream floor. This point “T” is known as point of tangency. Thus the spillway takes the shape of the letter “S” (i.e. elongated form). Hence, this spillway is termed as ogee spillway.



The shape of the lower nappe is not same for all the head of water above the crest of the weir. It differs with the head of water. But for the design of the ogee spillway the maximum head is considered. If the spillway runs with the maximum head, then the overflowing water just follows the curved profile of the spillway and there is no gap between the water and the spillway surface and the discharge is maximum.

When the actual head becomes more than the designed head, the lower nappe does not follow the ogee profile and gets separated from the spillway surface. Thus a negative pressure develops at the point of separation. Due to the negative pressure, air bubbles are formed within the flowing water. These air bubbles are responsible for the frictional force (i.e. abrasion) which causes much damage to the spillway surface.

Again, if the head of water is less than the designed head, the waterjet adheres to the body of the spillway and creates positive pressure which reduces the discharge through the spillway.

The shape of the ogee spillway has been developed by U.S Army Corps Engineers which is known as “Water-way experimental station spillway shape”. The equation given by them is,  $X^n = K \times H^{n-1} \times Y$ , where,  $x$  and  $y$  are the coordinates of a point  $P$  on the ogee profile taking  $O$  as origin.  $K$  and  $n$  are the constants according to the slope of the upstream face of the spillway (figure below).

The value of  $K$  and  $n$  are given as follow:

Shape of u/s face of spillway	$K$	$n$
Vertical	2.0	1.85
1:3 (H:V)	1.936	1.836
1:1½ (H:V)	1.939	1.810
1:1 (H:V)	1.873	1.776

Thus for different values of  $y$ , the values of  $x$  are determined considering the slope of u/s face. The value of  $r_1$ ,  $r_2$ ,  $a$  and  $b$  are also calculated. The results are tabulated for the constructional guidance.

**Problem-1**

Design and sketch the shape of an Ogee type spillway for the following data using the empirical equation developed by US Army Corps Engineers,

Upstream Head,  $H = 20$  m

Shape of the upstream face = 1: 1½ (H:V)

Values of  $K$  and  $n$  are 1.939 and 1.81 respectively

**Solution:**

$$r_1 = 0.5H = 0.5 \times 20 = 10 \text{ m}$$

$$r_2 = 0.21H = 0.21 \times 20 = 4.2 \approx 4.5 \text{ m}$$

$$a = 0.139H = 0.139 \times 20 = 2.78 \approx 3 \text{ m}$$

$$b = 0.237H = 0.237 \times 20 = 4.74 \approx 5 \text{ m}$$

X (m)	Y (m)
5	0.84
10	2.94
15	6.13
20	10.31
25	15.44

We know,  $X^n = K \times H^{n-1} \times Y$

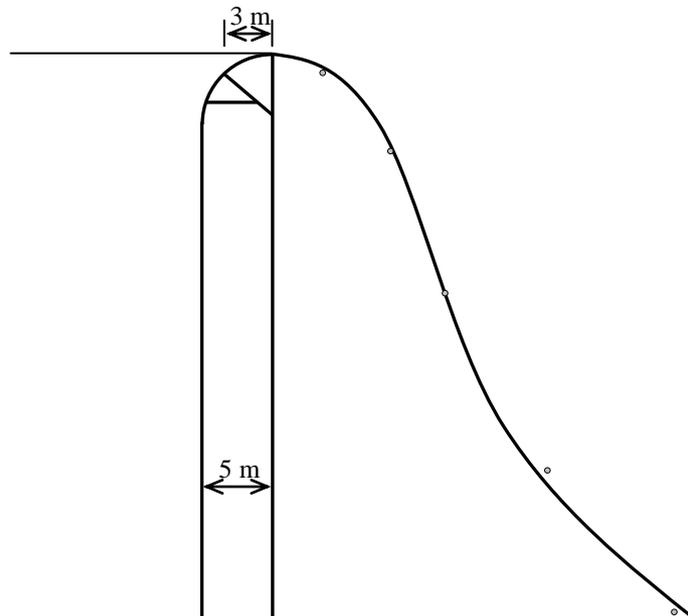
$$\Rightarrow X^{1.81} = Y \times 1.939 \times (20)^{1.81-1}$$

$$\Rightarrow X^{1.81} = Y \times 21.95$$

$$\therefore Y = 0.159 \text{ m}$$

From the different values of  $X$ , the values of  $Y$  are found which is given below in a tabulated form:

Finally the shape of Ogee type of spillway



## **Irrigation Pumps**

- Irrigation pumps are used to raise water from its source to the field
- Pumps are also important for irrigation by sprinkling. Selection of a suitable water lifting device for a particular situation depends on:
  - ✓ The characteristics of the source of water and the lifting device.
  - ✓ The amount of water to be lifted.
  - ✓ The depth to the pumping water level.
  - ✓ Type and amount of power available and
  - ✓ The economic status of the farmer.

## **Indigenous/ traditional water lift:**

The swing basket, water wheel, counterpoise-bucket lift, Hand Pump, Rower Pump, Twin Treadle Pump etc.

## **Fig: Traditional Irrigation method**

## **Types of Pumps:**

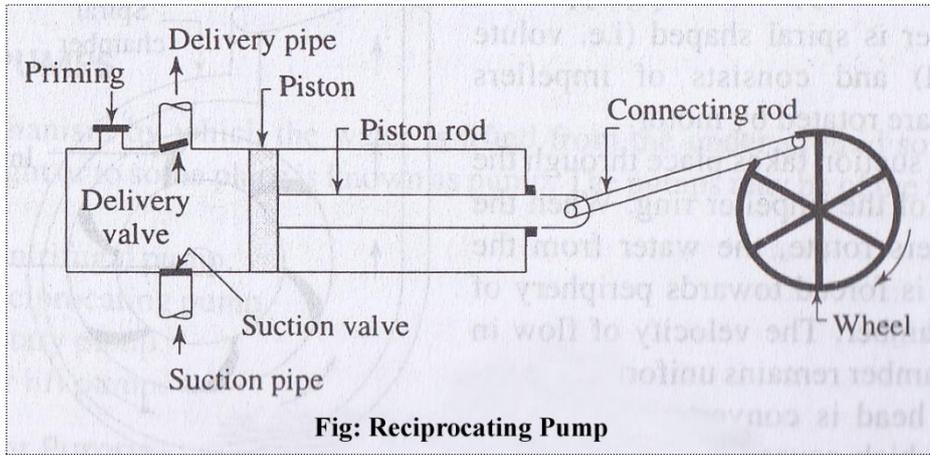
- (a) Reciprocating Pump/Piston Pump/Displacement Pump
- (b) Centrifugal Pump
- (c) Turbine Pump
- (d) Submersible Turbine Pump
- (e) Rotary Pump
- (f) Air lift Pump

## **Reciprocating Pump/ Piston Pump/Displacement Pump**

*The components are:*

- Cylinder/piston
- Suction Pipe
- Delivery Pipe
- Suction/inlet valve
- Delivery/discharge valve

This type of pump consists of a closed cylinder in which a piston moves to and fro by a connecting rod. The connecting rod is again hinged with a wheel which is rotated by a motor. During the suction stroke, the suction valve is opened and delivery valve remains closed and water enters the cylinder. During the delivery stroke, the delivery valve is opened and suction valve remains closed and water is forced through the delivery pipe. An inlet is provided for the priming which is necessary for starting the pump.



**Fig: Reciprocating Pump**

**Advantages of Reciprocating pump:**

- ✓ It is suitable for large pumping units.
- ✓ It gives constant discharge.

**Disadvantages of Reciprocating pump:**

- ✓ It requires large space for installation.
- ✓ It is unsuitable for pumping water containing high sediment.

**Lift:**

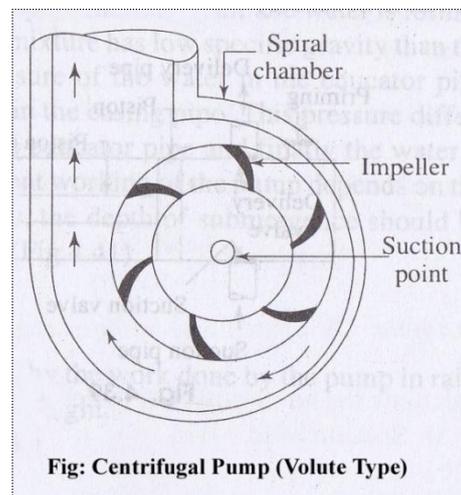
$h = \text{up to } 1 \text{ amp} = 10.33 \text{ m}$   
 $= 6.5 \sim 7 \text{ m}$  (practically, due to friction and other losses)

**Centrifugal Pump**

**(a) *Volute Type***

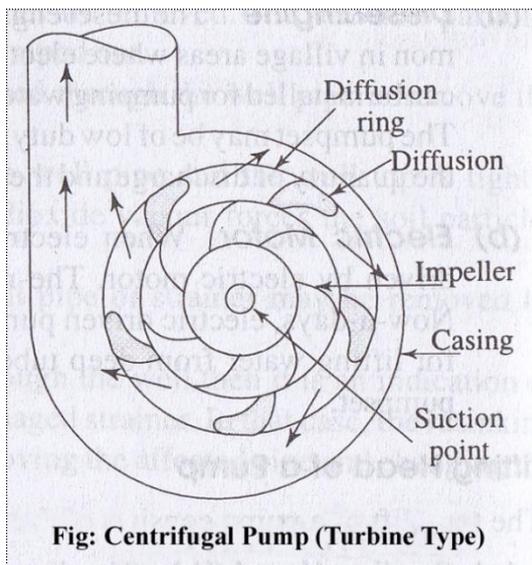
In this type, the chamber is spiral shaped (i.e. volute shaped) and consists of impellers which are rotated by motor.

The suction takes place through the center of the impeller ring. When the impellers rotate, the water from the center is forced towards periphery of the chamber. The velocity of flow in the chamber remains uniform. The velocity head is converted to pressure head which causes the water to flow through the delivery pipe.



**Fig: Centrifugal Pump (Volute Type)**

**(b) *Turbine Type***



**Fig: Centrifugal Pump (Turbine Type)**

In this type, a diffusion ring is provided between the impellers and the casing. The ring carries fixed diffusers or guide vanes. There are openings between the diffusers through which the water forces out towards the periphery. In this case also the velocity head is converted to pressure head which causes the water to flow through the delivery pipe.

### Advantages of centrifugal pump:

- ✓ It requires minimum space for installation as it is compact in design.
- ✓ It can be installed for high speed driving mechanism.
- ✓ The working is simple and there is no valve in the pump, hence it is reliable and durable.

### Disadvantages of centrifugal pump:

- ✓ The pump will not work, if the chamber is not full of water. So, the priming should always be done before starting the pump.
- ✓ The pump will not work if there is any leakage in the suction side.

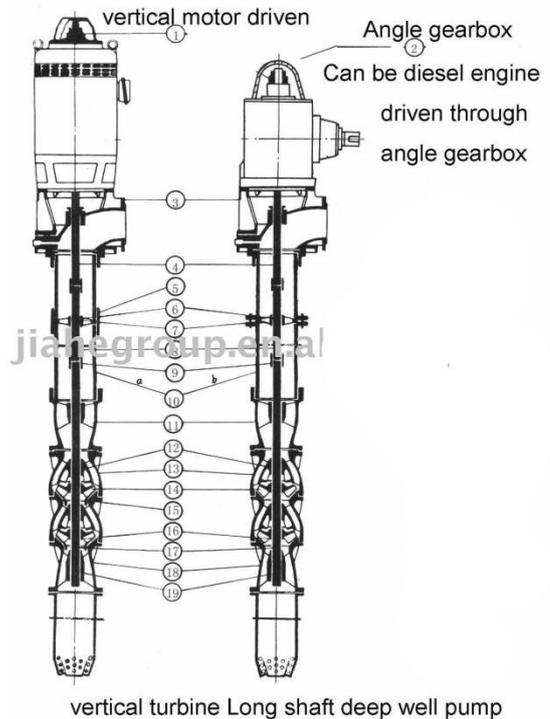
### Turbine Pump

The impeller is surrounded by stationary guide vanes that reduce the velocity of water and convert velocity head to pressure head. The casting surrounding the guide vanes is usually circular and concentric with the impeller.

A deep well turbine pump is a multi-stage pump that accommodates several impellers on a vertical shaft and stationary bowls pressing guide vanes.

The two bowl assemblies are nearly always located beneath the water surface.

The several bowls are connected in series to obtain the desired total head.



### Applicability:

Deep-well turbine pumps are used for irrigation when the water surface is below the practical lift of the centrifugal pump.

$$Q = 56 \text{ liter/sec, } h = \text{up to } 300 \text{ m below ground level}$$

### Advantages:

- Priming is not required
- Adapted to high lifts
- Adapted to seasonal fluctuations in water level in the well

### Disadvantages:

Operating parts are inaccessible and difficult to inspect

- Low efficiency is common
- Frequent shaft rupture
- Higher initial cost

### When pumping from ground water source

$$h = \text{Static head} + \text{drawdown} + h_f = \text{Total Pumping head}$$

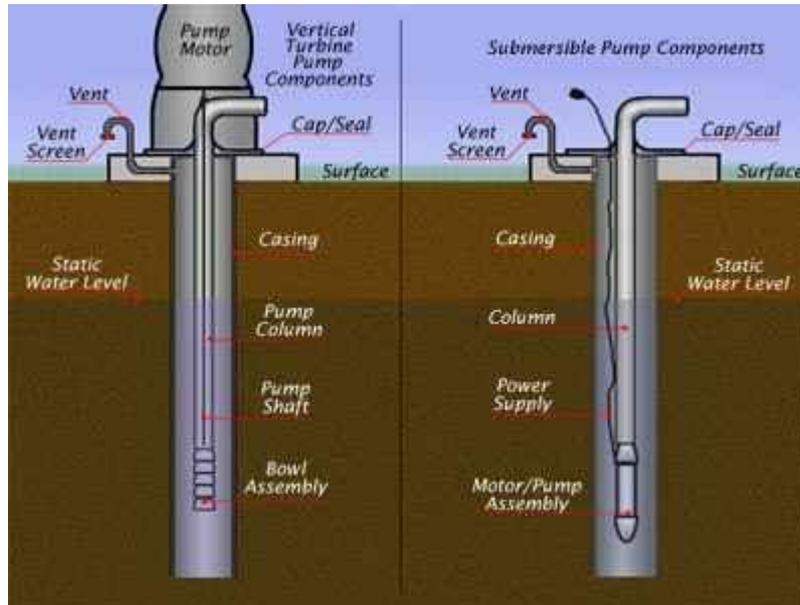
Where, static head = vertical distance from discharge water level to the static water level in the well

### Net Positive Suction Head (NPSH)

- NPSH is the total suction head, determined at the suction nozzle minus the vapor pressure of water at the pumping temperature, both expressed in meter
- The NPSH is a characteristic of the pump and is usually furnished with the pump characteristic curve

## Submersible Turbine Pump

- A submersible turbine pump is one in which the pump and the electric motor are placed below the water surface of a well. Delivery of water to the surface is through a riser pipe on which the assembly is suspended.
- The characteristics of the pump unit are similar to a conventional vertical turbine pump.
- They have been used in wells over 4000 meter deep. Units with more than 250 stages have been used.



### **Advantages:**

- It eliminates the long vertical shaft from the ground surface to the pump which reduces bearing friction and provides an unobstructed pipe for delivery of water to the surface.
- It can be used where the installation is flooded or where an above ground pump house would be inconvenient, unsightly or hazardous.

### **Disadvantages:**

- Operating parts are inaccessible and difficult to inspect.

## Rotary Pump

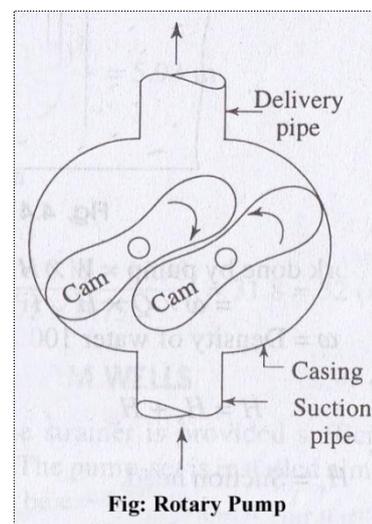
It consists of two cams which are pivoted in a casing. These cams rotate in opposite directions and thereby the suction takes place through the suction pipe. The rotation of the cam pushes the water in upward direction through the delivery pipe.

### **Advantages of Rotary Pump:**

- ✓ The flow of water is uniform.
- ✓ No priming is required.
- ✓ It requires no valves and its operation is simple.

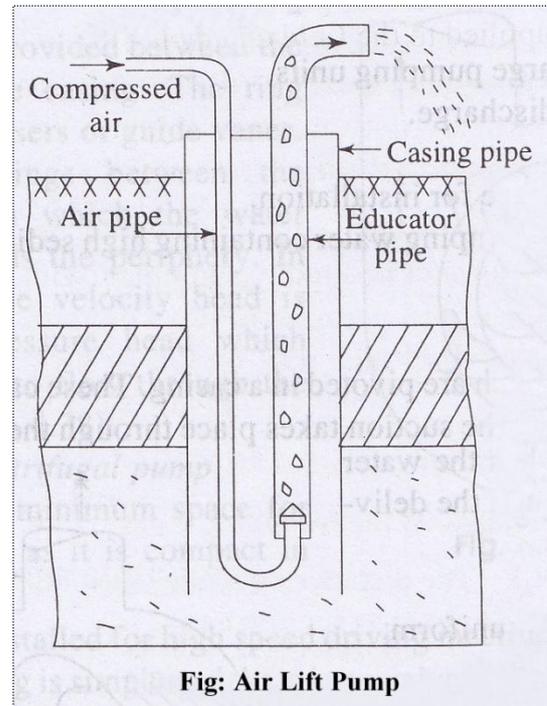
### **Disadvantages of Rotary Pump:**

- ✓ It requires replacement of cams frequently and hence it involves more maintenance cost.
- ✓ It cannot be used for pumping water containing high sediment.

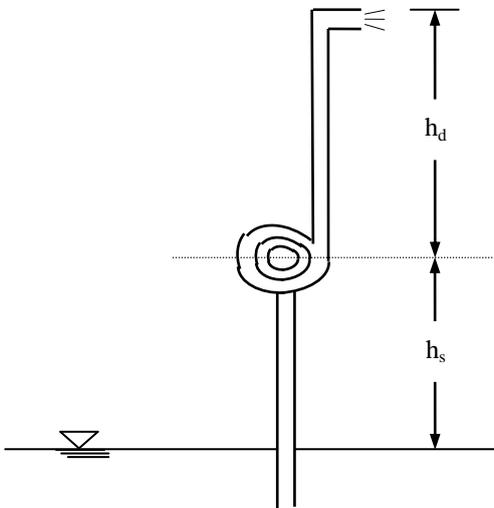


## Air Lift Pump

It consists of a casing pipe in which an educator pipe is introduced. An air pipe is also introduced into the casing pipe. The bottom end of the air pipe carries an air diffuser which is introduced into the educator pipe in upward direction. When compressed air is forced through the air pipe, a mixture of air and water is formed and rises in the form of bubbles. This mixture has low specific gravity than the water in the casing pipe. Thus the pressure of the water in the educator pipe becomes less than the pressure of water in the casing pipe. This pressure difference forces the water to rise through the educator pipe and finally the water is discharged through the outlet. The efficient working of the pump depends on the air pipe's submergence depth. Generally, the depth of submergence should be about two third of the length of air pipe.



## Pumping Head



$h_s$  = Static suction lift = vertical distance from the free suction water level to the centre line of the pump

$h_d$  = Static discharge head = vertical distance from the centre line of the pump to the discharge water level

$h_s + h_d$  = Total static head = vertical distance from the suction water to the discharge water level

$h = h_s + h_d + h_f$  = Total pumping head

Where,  $h_f$  = Total frictional head loss in the suction and delivery pipes

## Horse power of pump

The horse power of a pump is determined by work done by the pump in raising a particular quantity of water to some height.

Let,  $W$  = Quantity of water (kg)

$H$  = Total head (m)

Then, work done by pump =  $W \times H$

$$= w \times Q \times H \quad \text{----- (i)} \quad [W = w \times Q]$$

Where,  $w$  = Density of water ( $1000 \text{ kg/m}^3$ )

$Q$  = Discharge ( $\text{m}^3/\text{s}$ )

Again,  $H = H_s + H_d + H_f$

Where,  $H_s$  = Suction head (m)

$H_d$  = Delivery head (m)

$H_f$  = Head loss due to friction (m)

The head lost by friction is given by,

$$H_f = \frac{f \times l \times Q^2}{3d^5}$$

Where,  $f$  = Coefficient of friction

$l$  = Total length of pipe (suction and delivery)

$d$  = Diameter of pipe (m)

From equation (i)  $\Rightarrow$

$$\text{Water Horse Power (W.H.P)} = \frac{w \times Q \times H}{75}$$

Considering the coefficient of the pump as  $\eta$ , brake horse power

$$\text{Brake Horse Power (B.H.P)} = \frac{w \times Q \times H}{75\eta}$$

### Power requirements

WHP (Water Horse Power) is the theoretical horse power required for pumping. It is the head and capacity of the pump expressed in terms of horse power.

$$\text{WHP} = \frac{Qh}{76}$$

Where, Q = Discharge (liter/sec)  
h = Total pumping head (meter)

Efficiency is the ratio of the power output to power input

$$\text{Pump efficiency, } E_p = \frac{WHP}{SHP} \quad \text{Where, SHP} = \text{Shaft horse power}$$

Break Horse Power (BHP) is the actual horse power required to be supplied by the engine or electric motor for driving the pump

$$\text{BHP} = \frac{SHP}{E_d} = \frac{WHP}{E_p \times E_d} \quad \text{Where, } E_d = \text{Delivery efficiency}$$

$$\text{Horse Power input to electric motor} = \frac{WHP}{E_p \times E_d \times E_m}$$

$$\text{Kilowatt input to electric motor, KW} = \frac{BHP}{E_m} \times 0.746$$

### Problem-2

A centrifugal pump is required to lift water at the rate of 150 lit/sec. Calculate the brake horse power of the engine from the following data when the water is directly supplies to the field channel.

- Suction head = 6 m
- Coefficient of friction = 0.01
- Efficiency of pump = 75%
- Water is directly supplied to the field channel
- Diameter of pipe = 15 cm

### **Solution:**

Q = 100 lit/sec = (100/1000) m<sup>3</sup>/s = 0.1 m<sup>3</sup>/s  
 Delivery head, H<sub>d</sub> = 0 (As water is directly supplied to field)  
 Suction head, H<sub>s</sub> = 6 m  
 Coefficient of friction, f = 0.01  
 Diameter of pipe, d = 15 cm = 0.15 m

The length of the pipe where frictional effect may occur is taken equal to the suction head, so l = 6 m

$$H_f = \frac{f \times l \times Q^2}{3d^5} = \frac{0.01 \times 6 \times (0.15)^2}{3 \times (0.15)^5} = 5.93 \text{ m}$$

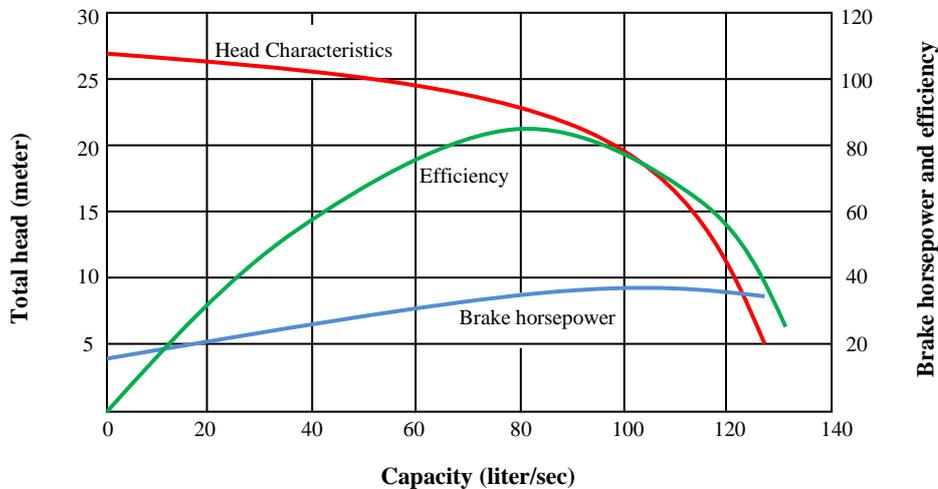
$$\begin{aligned} \text{So, total head, } H &= H_s + H_d + H_f \\ &= 6 + 0 + 5.93 \\ &= 11.93 \text{ m} \end{aligned}$$

Efficiency,  $\eta = 75\% = 0.75$

$$\text{Horse Power (H.P)} = \frac{w \times Q \times H}{75\eta} = \frac{1000 \times 0.15 \times 11.93}{75 \times 0.75} = 31.8 \approx 32$$

## Pump Characteristics

- The interrelations between speed, head, discharge and horse power of a pump are usually represented by curves which are designated as ‘Characteristics curves’
- Knowledge of pump characteristics enables one to select a pump which fits operating conditions and thus attain a relatively high efficiency with low operating cost.
- As the discharge increases, the head decreases. The resulting efficiency is observed to increase from zero where the discharge is zero to a maximum of 82% when the discharge is 86 liter/sec and the head 23 m (and then found to decrease to zero at zero head).



**Fig: Pump Characteristics Curve**

The BHP curve for a centrifugal pump usually increases over most of the range as the discharge increases, reaching a somewhat higher rate of discharge than that which produce maximum efficiency,

## Selection of Power Plant

The power plant must be capable of delivering the required power under varying conditions. The factors are:

- ✓ Brake Horse Power required
- ✓ Initial cost
- ✓ Availability and cost of energy or fuel
- ✓ Depreciation
- ✓ Dependability of unit
- ✓ Portability required
- ✓ Maintenance and convenience of operation
- ✓ Labor availability and quality

## Effect of Speed and Impeller Diameter on Pump Performance

### Effect of change of pump speed:

When the speed of a centrifugal pump is changed, the operation of the pump is changed as follows:

- The capacity varies directly as the speed.
- The head varies as the square of the speed.
- The brake horse power varies as the cube of the speed.

Expressed mathematically,

$$Q = Q_1 \times (n/n_1) \text{ ----- (i)}$$

$$H = H_1 \times (n/n_1)^2 \text{ ----- (ii)}$$

$$P = P_1 \times (n/n_1)^3 \text{ ----- (iii)}$$

From equation (i), (ii) & (iii)  $\Rightarrow$

$$n/n_1 = Q/Q_1 = (H/H_1)^{1/2} = (P/P_1)^{1/3}$$

Where,

n = New speed desired, rpm

Q = Capacity at the desired speed n, liter/sec

H = Head at the desired speed n for capacity Q, meter

P = BHP at the desired speed n at H and Q

n<sub>1</sub> = Speed at which the characteristics are known, rpm

Q<sub>1</sub> = Capacity at speed n<sub>1</sub>, liter/sec

H<sub>1</sub> = Head at speed n<sub>1</sub> and capacity Q<sub>1</sub>, meter

P<sub>1</sub> = BHP at speed n<sub>1</sub> at H<sub>1</sub> and Q<sub>1</sub>

**Effect of Change of Impeller Diameter**

Changing the impeller diameter has the similar effect on the pump performance as changing the speed.

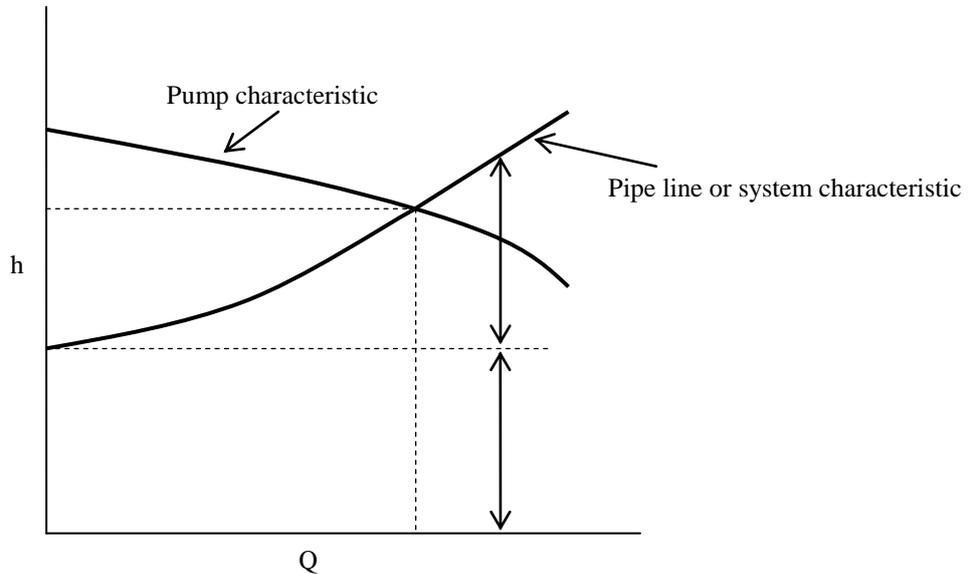
Thus,  $D/D_1 = Q/Q_1 = (H/H_1)^{1/2} = (P/P_1)^{1/2}$

Where,

D = Changed diameter of impeller, mm

D<sub>1</sub> = Original diameter of impeller, mm

**Pump and System Characteristics**



**Fig: Graphical method for finding the operating condition of a pump and pipeline**

- The head and flow rate developed by a pump depend on the pump characteristics and nature of the pipe system in which the pump is operating.
- The point of intersection of the pump characteristics curve (Q vs. h for the pump) and the system characteristic curve (Q vs. h or the pipe system in which the pump is operating) defines the flow rate and head that will be developed for the given situation.

If under this mode of operation the efficiency of the pump is not very high, an improvement in efficiency can be made by changing the speed of the pump or the impeller diameter or by selecting a different type of pump

**Pumping Cost**

Cost of pumping includes fixed cost and operating cost.

**(a) Fixed cost:**

Total annual cost = capital cost 'X' CRF + annual O & M cost

Where,

CRF = Capital Recovery Factor

$$= \frac{i(1+i)^n}{(1+i)^n - 1}$$

i = Discount rate,

n = Project life, years

**(b) Operating cost:**

Annual Operating cost = energy consumption rate X hours of operation X energy cost rate