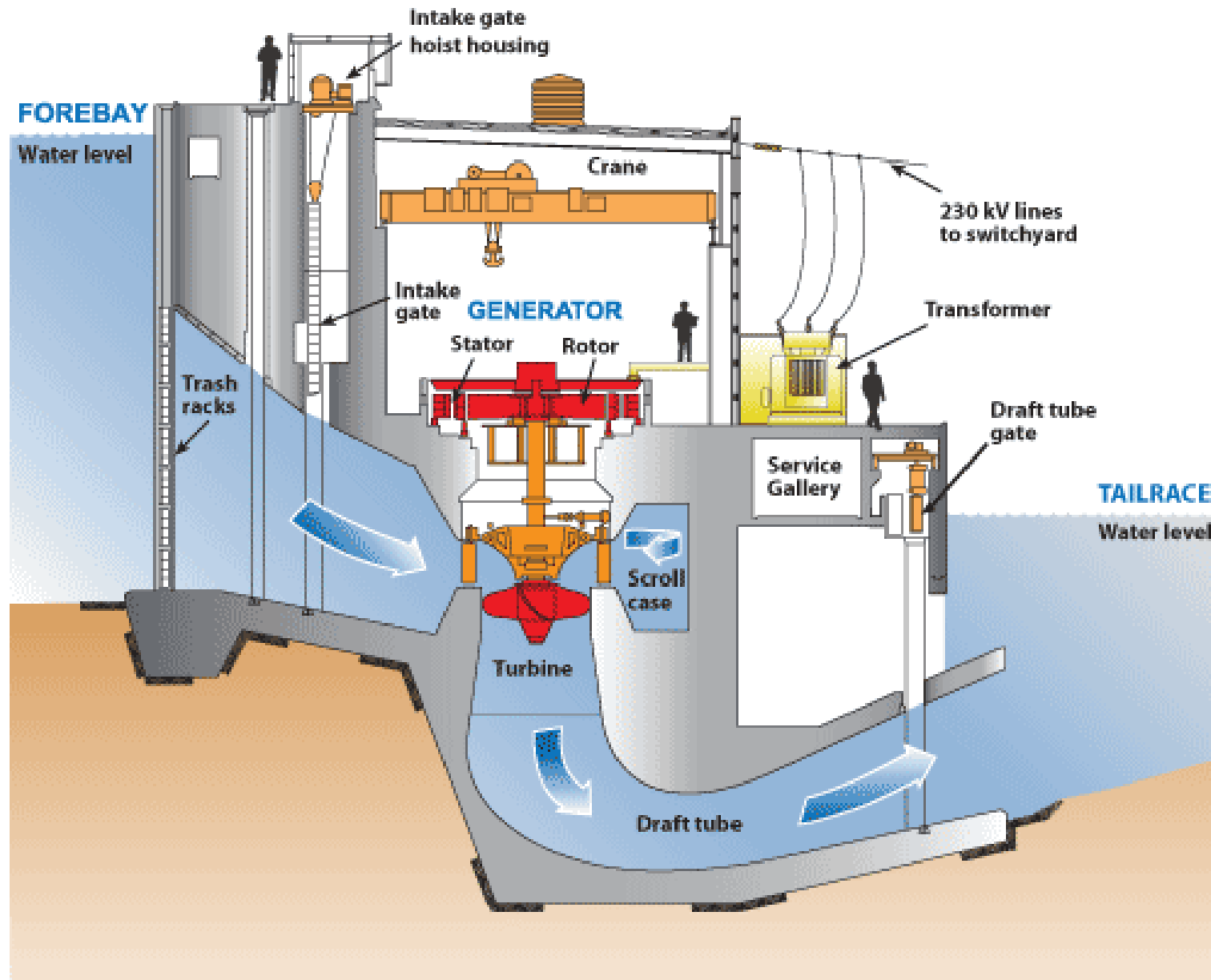


# Reaction Turbines – Axial Flow

## *Propeller and Kaplan Turbines*



# Propeller Turbine

The propeller turbine is an axial flow turbine having a small *number of blades, usually 3 to 8*. The runner is generally kept horizontal i.e., the shaft is vertical. The blades of a propeller turbine *resemble the propellers of a ship. The blades are fixed in the position.*

Similar to Francis turbine, it also operates in an entirely closed conduit from inlet to tail race. The guide mechanism of a propeller turbine is similar to that in a Francis turbine. The expressions for the work done, efficiency and power are the same as that in a Francis turbine. Working proportions are also obtained in the same manner. However, *the following deviations from the Francis turbine should be carefully notes:*

(I) In the case of a propeller turbine, the ratio  $n$  is taken as  $D_1/D$ . (and not  $B_1/D$ ), where  $D_1$ , is the diameter of the boss (or hub) on which the blades are mounted and  $D$  is the outside diameter of the runner. The value of  $n$  ranges from 0.35 to 0.60. The value of  $\psi$ , is about 0.70. The equation for discharge is written as

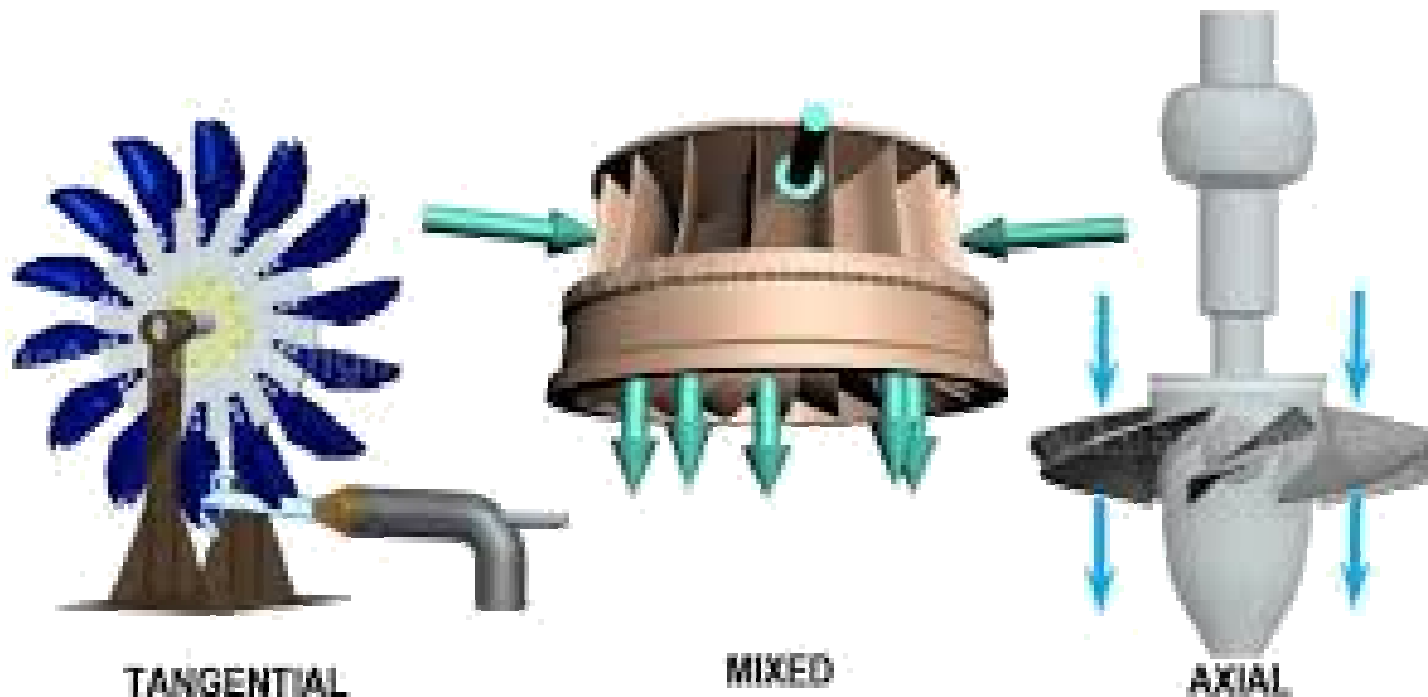
$$\begin{aligned} Q &= \frac{\pi}{4} (D^2 - D_1^2) V_f \\ &= \frac{\pi}{4} (D^2 - D_1^2) \psi \sqrt{2gh} \\ &= \frac{\pi}{4} D^2 (1 - n^2) \psi \sqrt{2gh} \end{aligned}$$

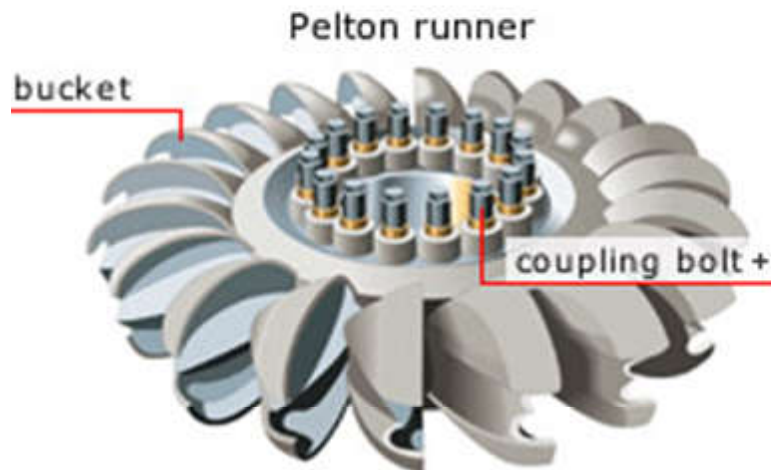
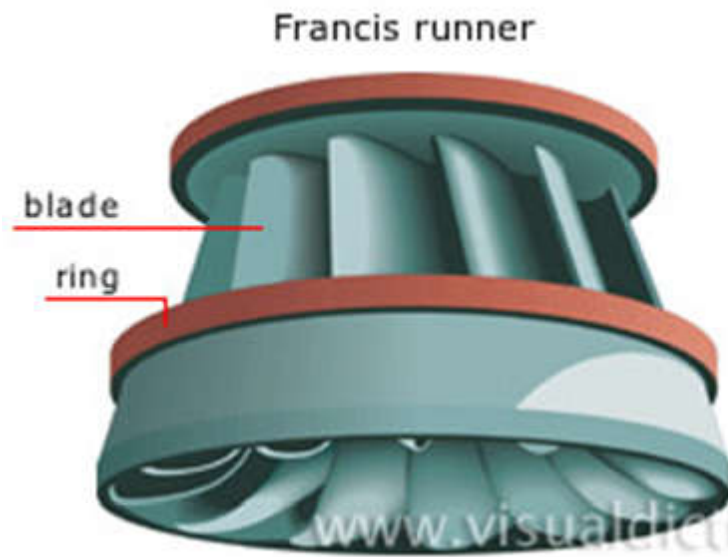
- (2) The *peripheral velocity  $u$*  of the *runner vanes depends upon the radius of the point under consideration.* Consequently, *the blade angles vary from the rim to the boss and the vanes-are warped.* *This is necessary to have shock-free entry and exit.*
- (3) The velocity triangle can be constructed at any radius. The expression for work done is the same as in the Francis turbine.

$$\text{Work done} = M(V_w u)$$

where  $u$  is the *rim velocity at that radius.*

- (4) *The velocity of flow remains constant throughout.*





If the flow enters the runner radially Fig.a, the turbine is called a **Francis radial-flow turbine**. If the flow enters the runner at some angle between radial and axial (Fig.b), the turbine is called a **Francis mixed-flow turbine**. If the runner has no band, and flow enters the runner partially turned, it is called a **propeller mixed-flow turbine** or simply a **mixed-flow turbine** (Fig.c).

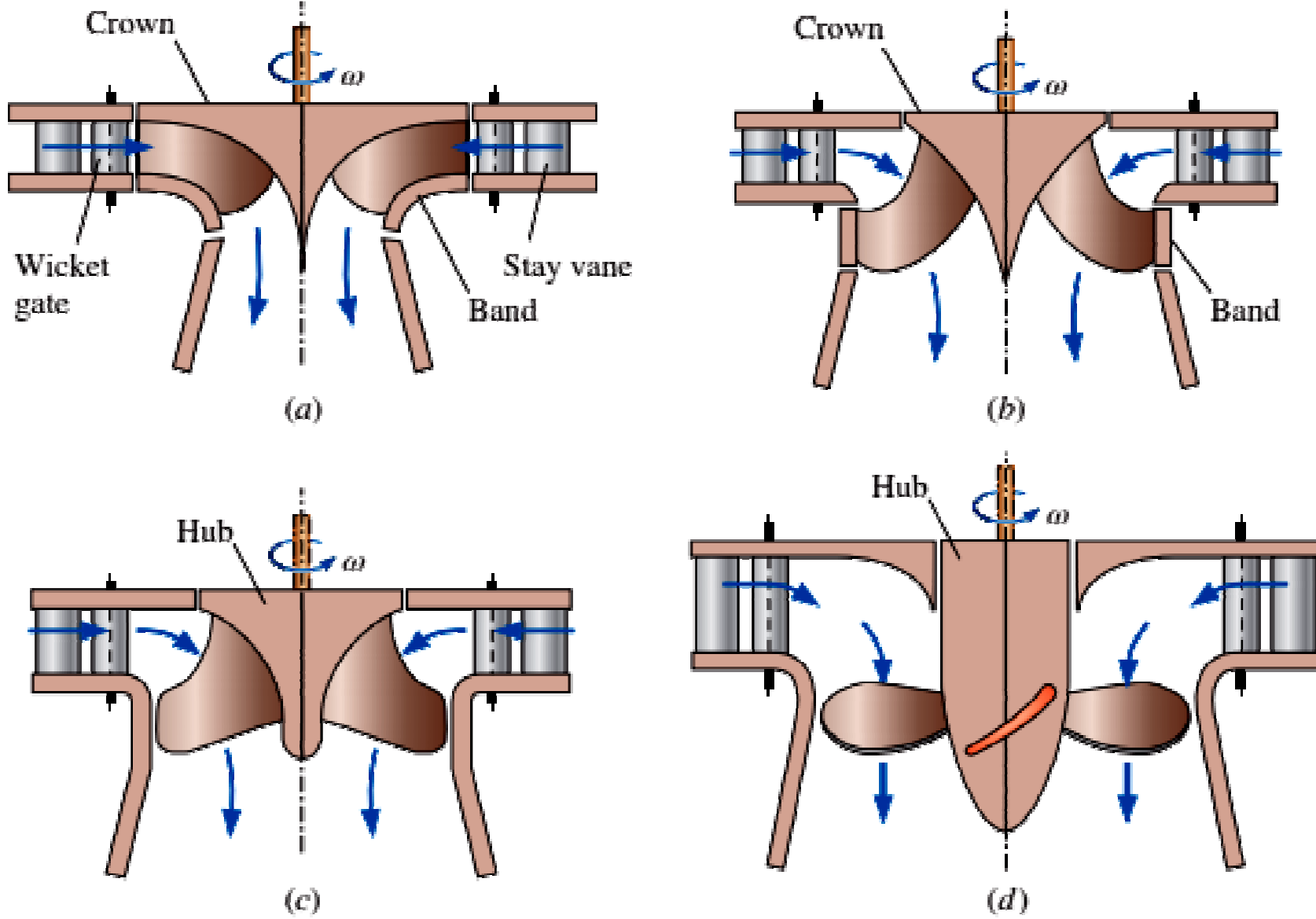


Fig: (a) Francis radial flow, (b) Francis mixed flow, (c) propeller mixed flow, and (d) propeller axial flow (Propeller and Kaplan).

If the flow is turned completely axially *before* entering the runner (Fig.d), the turbine is called an propeller **axial-flow turbine**.

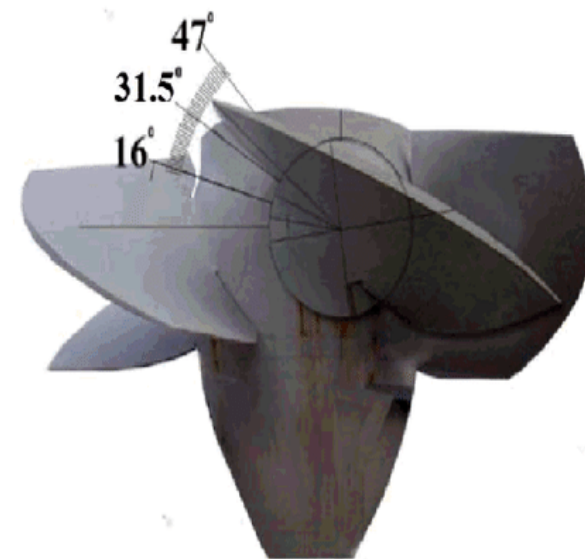
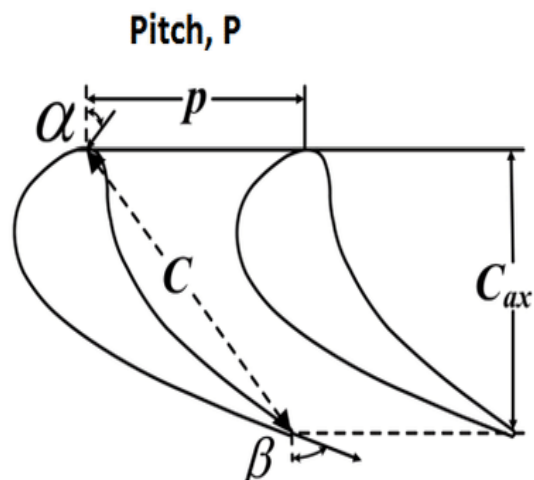
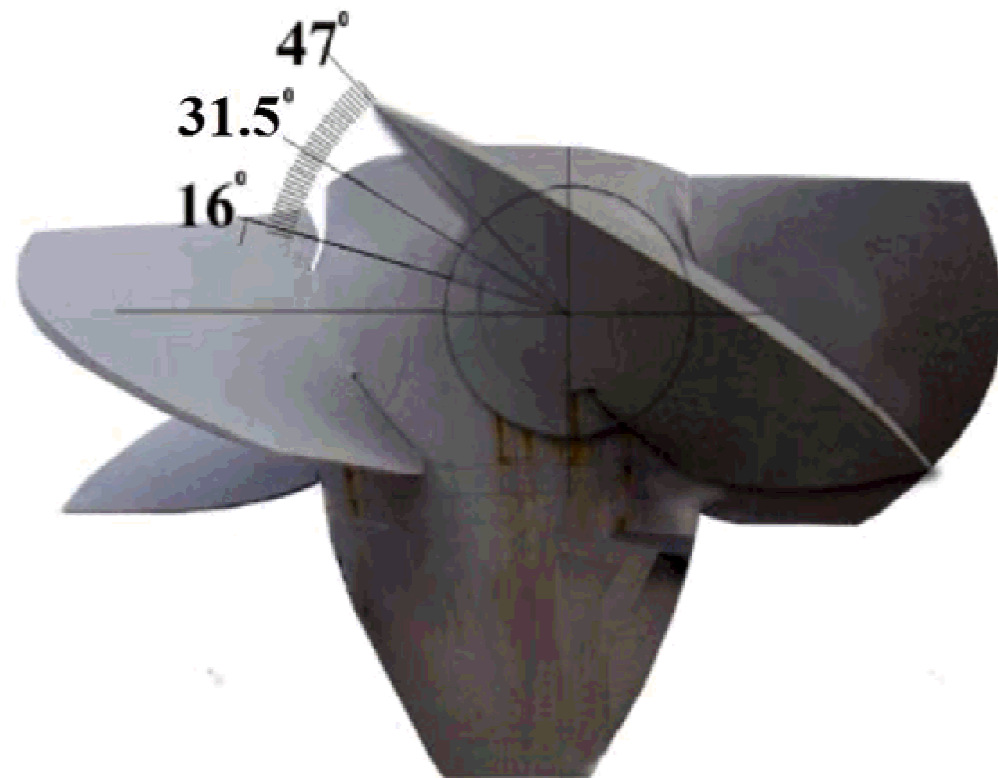
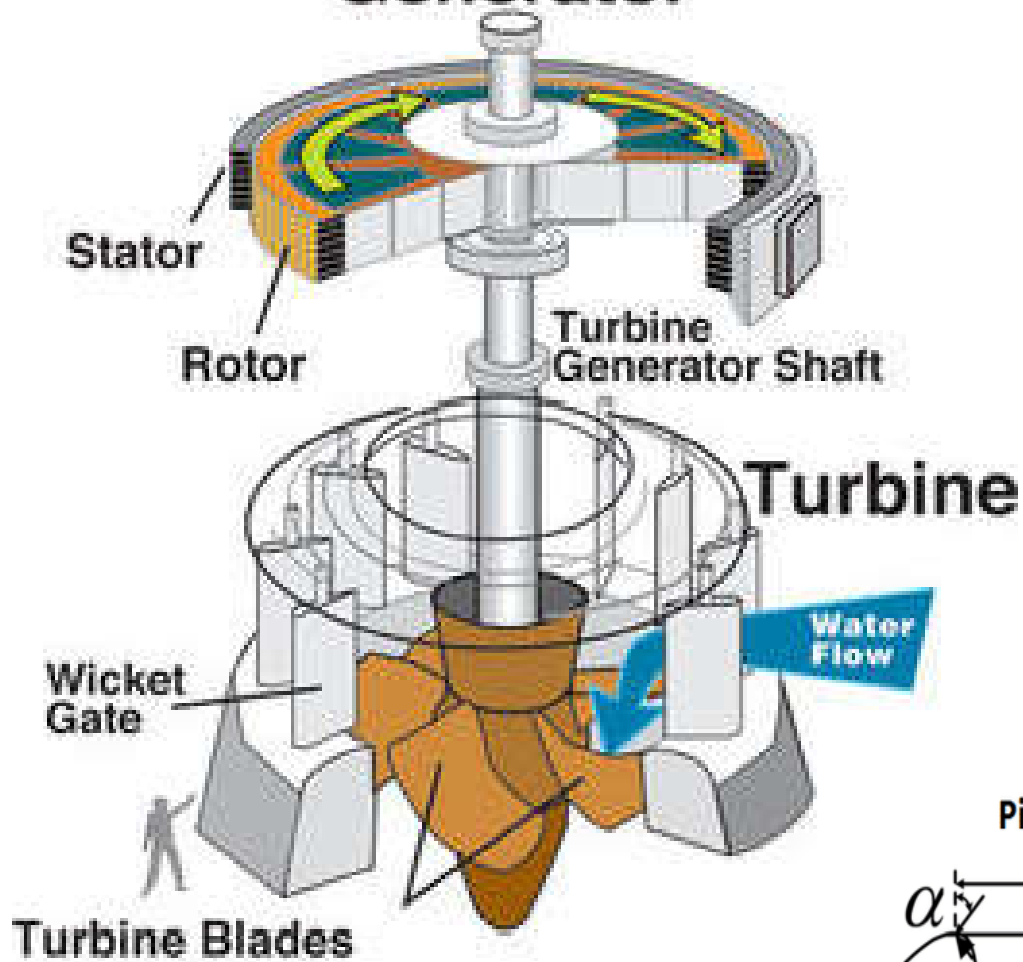
## Kaplan Turbine

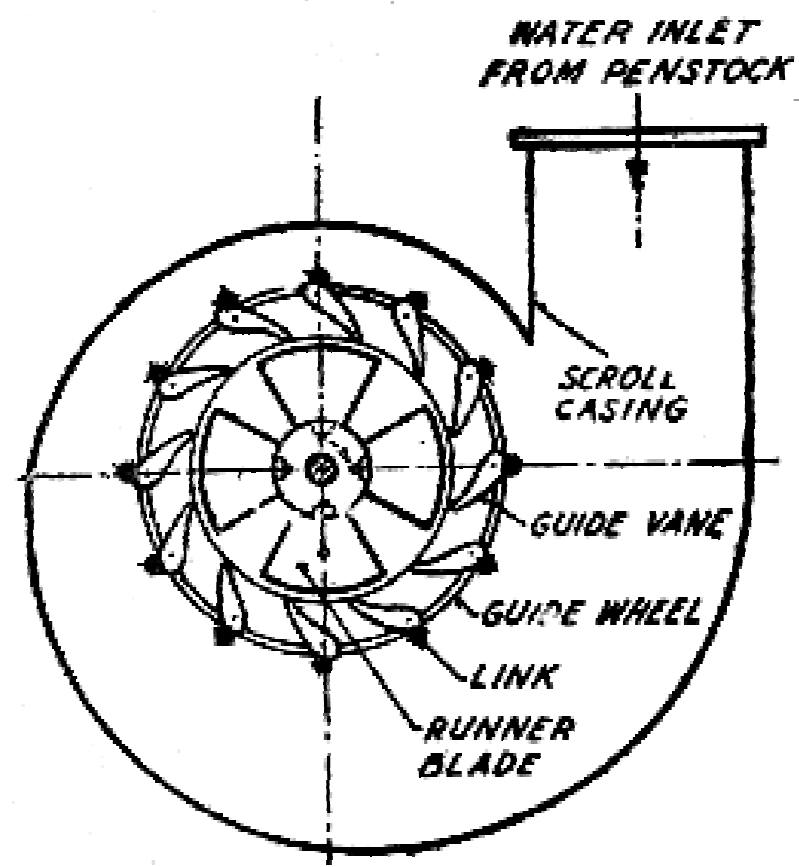
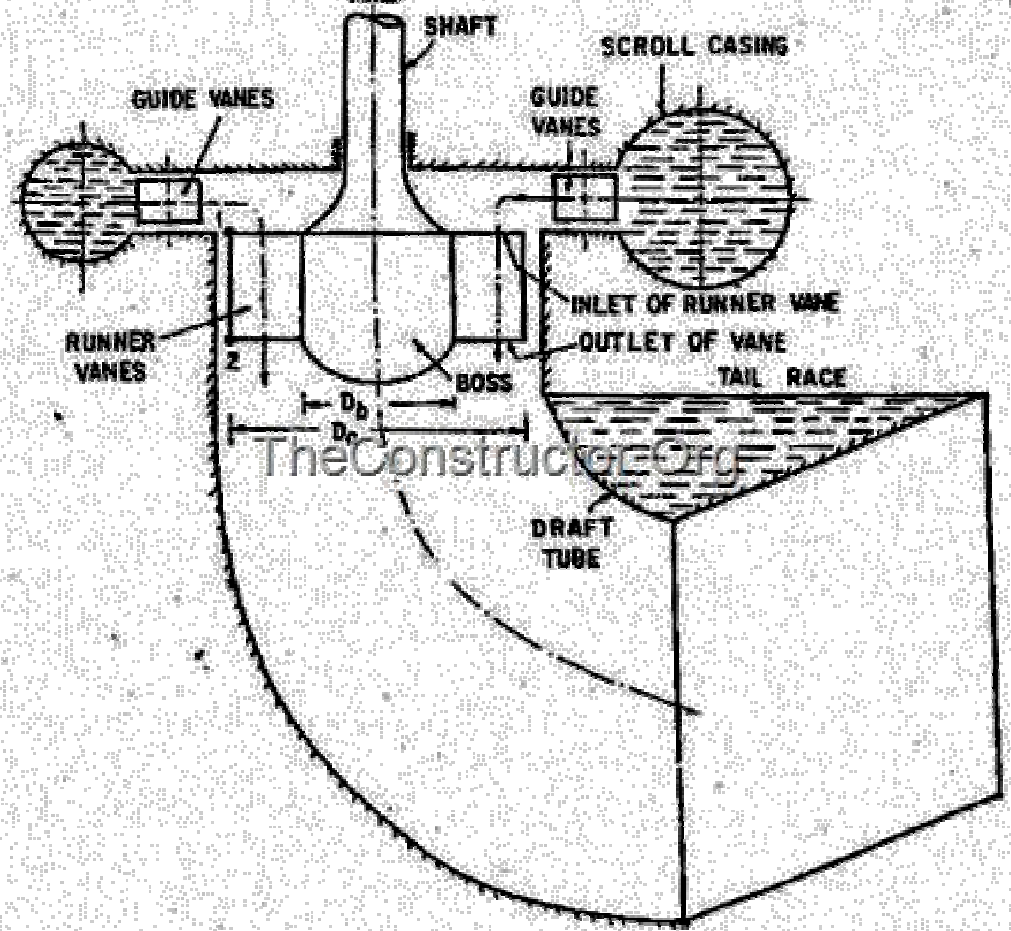
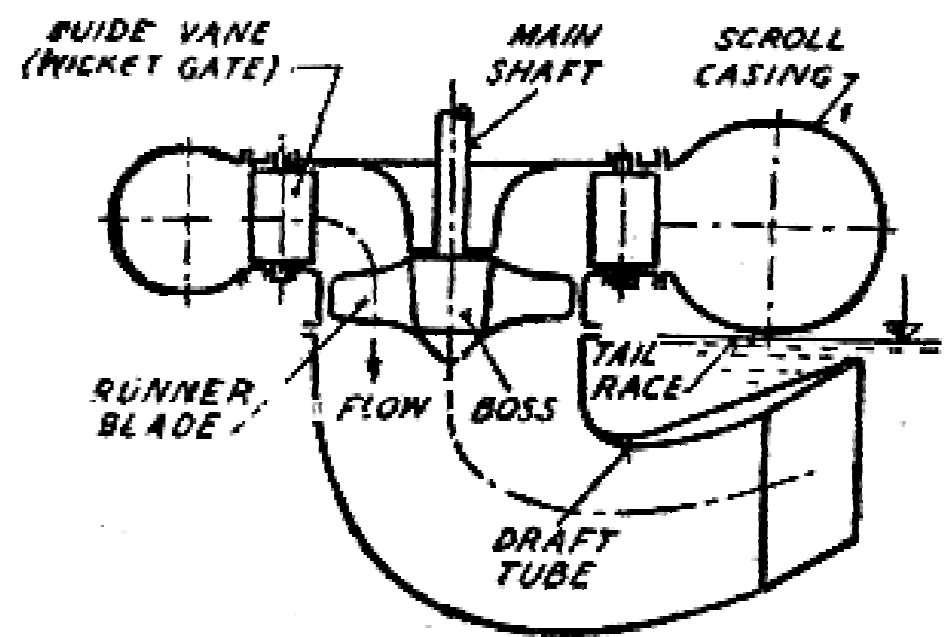
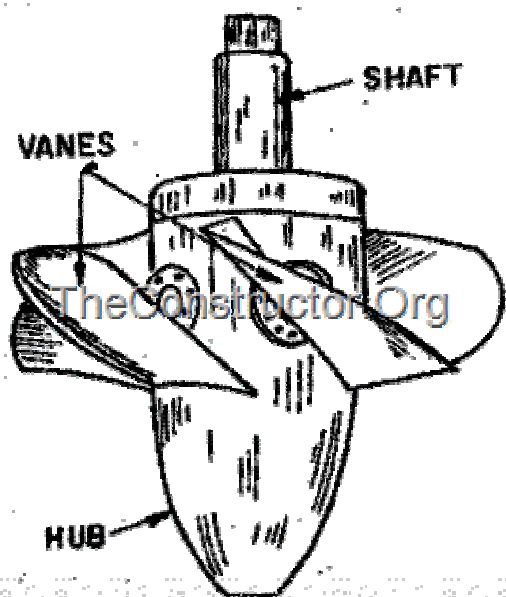
Kaplan turbine is just a propeller turbine in which the runner blades are made adjustable. Kaplan turbines are called double regulated because the *flow rate is controlled in two ways—by turning the wicket gates and by adjusting the pitch on the runner blades*. The propeller turbine can be employed economically when it has to work constantly under full load, otherwise Kaplan turbine will be preferred.

The propeller turbine has got a very low efficiency at part load. As the blade angles are fixed, at part load, water enters with shock and eddies are formed. This reduces the efficiency of the turbine. This defect of the propeller turbine is removed in Kaplan turbine. A Kaplan turbine is fitted with adjustable blades. The blade angles changes automatically by an oil pressure servo-motor as the load changes. Thus a high efficiency is maintained even at part-load. The servo-motor cylinder is usually accommodated in the hub.

The Kaplan turbine has purely axial flow. There are usually 4 to 6 blades having no outside rim. Because of adjustable vanes, the pitch of the turbine can be changed. That is the reason why a Kaplan turbine is also known as a variable-pitch propeller turbine. At full load conditions, the Kaplan turbine behaves like a propeller turbine.

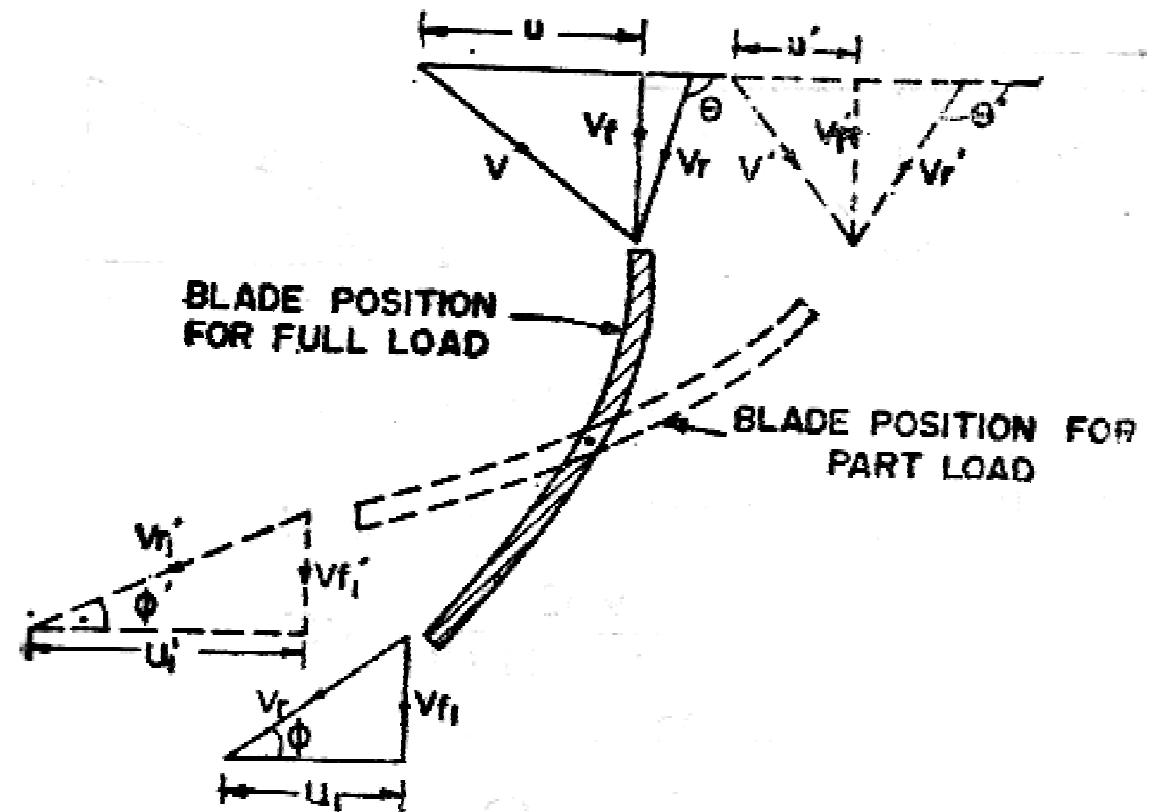
# Generator





The scroll casing, guide mechanism and the draft tube are similar to that in the Francis turbine. However, an elbow type draft tube is usually preferred in the Kaplan turbine because of head limitations. The shape of the runner blades is different from that of the Francis turbine. Moreover, the number of blades is also small. The blades of the Kaplan turbine are made of stainless steel.

Fig. shows two positions of the runner blade at full-load and at part-load. It may be noted that even at part-load, the water strikes the blade tangentially. The shape of the velocity triangles remains the same. Consequently, *the efficiency remains unaffected.* The expressions for work done, efficiencies and power developed are the same as in the case of a propeller turbine.



## Problem:

A Kaplan turbine produces 44145 kW (60000 h.p.) under a head of 25m with an overall efficiency of 90%. If the speed ratio and flow ratio are 1.6 and 0.5, respectively, **find the diameters and the speed of the turbine.** Take the hub diameter as 0.35 times the outer diameter.

## Solution:

$$\eta_o = \text{Shaft Horse Power (SHP)} / \text{Water Power } (\gamma QH)$$

$$0.9 = (44145 \times 1000) / (9.81 \times 1000 \times Q \times 25)$$

$$Q = 200 \text{ cumec or m}^3/\text{s}$$

$$Q = \pi/4 D^2 (1 - n^2) \phi \sqrt{2gH}$$

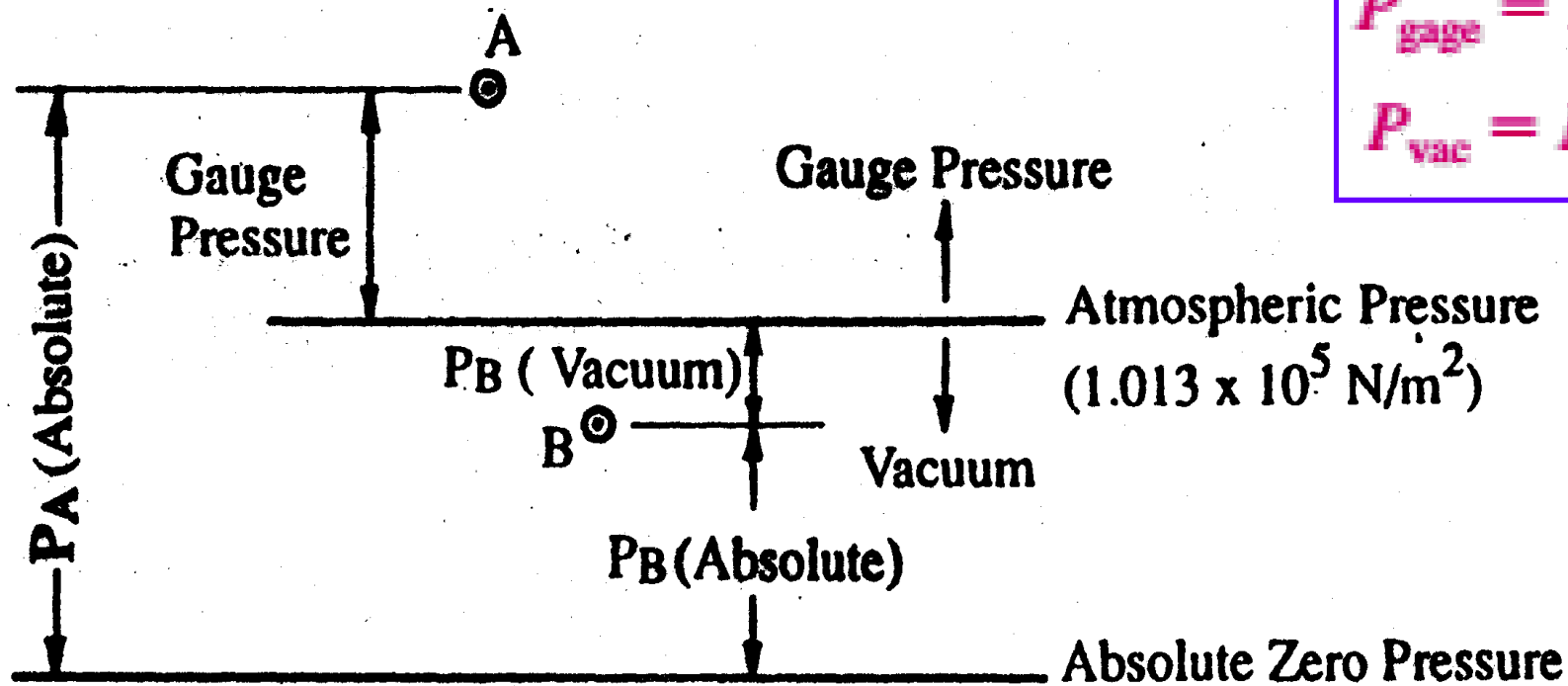
$$200 = \pi/4 \times D^2 (1 - 0.35^2) \times 0.50 \sqrt{2 \times 9.81 \times 25}$$

$$D = 5.12 \text{ m}$$

$$u = \phi \sqrt{2gH} = 1.60 \sqrt{2 \times 9.81 \times 25} = 35.4 \text{ m/sec}$$

$$\pi DN/60 = 35.4$$

$$N = \frac{35.4 \times 60}{\pi \times 5.12} = 132 \text{ r.p.m.}$$



$$P_{\text{gage}} = P_{\text{abs}} - P_{\text{atm}}$$

$$P_{\text{vac}} = P_{\text{atm}} - P_{\text{abs}}$$

It may be assumed that the separation occurs at an absolute pressure of 24.525 kN/m<sup>2</sup> (1.03 kgf/cm<sup>2</sup>) .

## Cavitation

According to the Bernoulli's equation, if the velocity of flow increases, the pressure will fall. In case of liquid, the pressure cannot fall below vapour pressure which depends upon the temperature and height above mean sea level of the site. Whenever the pressure in any turbine part drops below the evaporation pressure at that temperature, the liquid boils and a large number of small bubbles and vapour filled cavities are formed. It may happen that a stream of water cuts short of its path giving rise to eddies and vortices which may contain voids or bubbles.

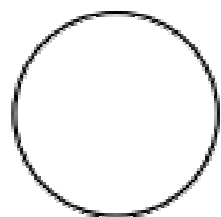
The negative pressure at any point in a turbine should not exceed the limiting pressure given by

$$H_n = H_a - H_v$$

Where,  $H_n$  = negative pressure head,  $H_a$  = atmospheric pressure,  $H_v$  = vapour pressure

Whenever the negative pressure in any part of the turbine exceeds the above limit, vapour bubbles are formed and cavitations takes daces. Once the cavitations occurs, are carried by the stream to higher pressure zones where the vapours condense and the bubbles suddenly collapse, as the vapours are condensed to liquid again. This results in the

# P-H DIAGRAM

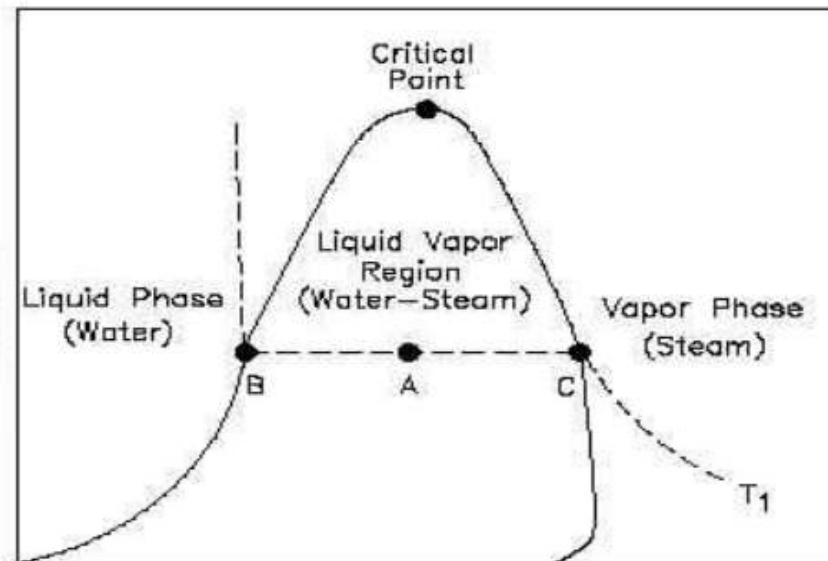


Spherical  
Bubble



*Bubble Collapse  
Process*

*Microjet  
Formation*



Enthalpy



formation of a cavity and the surrounding liquid rushes to fill it. The streams of liquid coming from all directions collide at the centre of cavity giving rise to a very high local pressure whose magnitude may be as high as 7,000 atmospheres. Formation of cavity and high pressure are repeated many thousand times a second. When the cavities collapse on the surface of a component part (runner blades or draft tube), due to the repeated hammering action the metal is eaten away. This is known as pitting. The component parts become rough, pitted and eventually they fail. Some parts of turbine e.g. runner blades may be torn away completely by this process.

As the volume of air cavities is many times more than the volume of liquid, actual volume of liquid flowing through the runner is reduced. This causes sudden drop in output and efficiency. Irregular collapse of cavities also causes vibration of parts and the turbine foundation and noise. The sound of the noise is similar to one made by a gravel in a rotating vessel.

**Cavitation is more likely to take place in the following places:**

- (a) Draft tube of the hydraulic turbines.
- (b) Venturi or the minimum area section of passages.

- (a) Boundaries in the vicinity of high velocity flow.
- (b) Siphon passages.
- (c) Suction sides of the pumps.

To avoid cavitation, the component parts of the turbine should be properly Designed. Thoma gave a parameter, known as Thoma's cavitation number, which determines whether cavitation will occur or not. The number is given by

$$\sigma = \frac{H_s - H_v - H_s}{H}$$

Where,  $H_s$  = suction head (vertical distance between the runner exit and tail race level) and  $H$  = working head of the turbine.

For a turbine, upto a certain value of  $\sigma$ , other factors remaining the same, the overall efficiency remains constant. This value of  $\sigma$  is called the critical cavitation number of the turbine ( $\sigma_c$ ). The efficiency of the turbine drops suddenly as the value of  $\sigma$  decreases below the critical cavitation number of the turbine ( $\sigma_c$ ). The critical cavitation number may be determined experimentally by noting the value of  $\sigma$  at which there is a sudden drop in efficiency of the turbine. It may be noted that the value of  $\sigma$  decreases as the suction ( $H_s$ ) is increased. Thus there is a limit on the suction head.

*The critical cavitation number depends upon the type of turbine and is a function of the specific speed.*

(a) For Francis turbine, it is given by

$$\sigma_c = 0.625(N_s/381)^2$$

$$\sigma_c = 0.0431(N_s/100)^2$$

(b) For propeller turbines, the critical cavitation number is given by

$$\sigma_c = 0.3 + 0.0036(N_s/100)^{2.73}$$

(c) For Kaplan turbines,  $\sigma_c$  is 10% higher than that for a similar propeller turbine.

The practical utility of the critical cavitation number is to determine the maximum elevation above the tail race level at which a turbine can be set without cavitation hazard. A little amount of cavitation under extreme conditions is sometimes permitted in turbines.

## Performance of Hydraulic Turbines

Machines are always designed to work under a given set of conditions regarding head ( $H$ ), discharge ( $Q$ ), speed ( $N$ ), and efficiency ( $\eta$ ) or a limited range of conditions. A turbine may be designed for some particular data say  $H_o$ ,  $Q_o$ ,  $N_o$  and  $P_{to}$ , but in practice it may have to be used under conditions different from those for which it is designed. The performance of the machines changes with these variations. To predict the behaviour of the machines under varying conditions and to know the performance of machines of the same type but working under different conditions, scientific study is made. Graphical representation by means of curve of the results obtained from the tests, is known as Characteristic Curves of the machine. Practical data for these curves are obtained from experiments on models or actual sized machines. Each type of turbine has a particular shape of characteristic curves. Like the specific speed the characteristic curves give us an idea about the type of turbines or pumps. The behavior of a machine may be exhibited by the following curves :

- (i) Main characteristics (*constant head curves*).**
- (ii) Operating characteristics (*constant speed curves*).**
- (iii) Muschel curves (*constant efficiency curves*).**

### **(i) Main Characteristics or Constant Head Curve**

The **head is kept constant**, *speed varied by allowing a variable quantity of water to flow through the inlet opening*. Thus a series values of ***N*** & ***Q*** are obtained. For each value, (shaft power) brake horsepower is measured by braking mechanically or coupling with a generator. Such conditions usually occur in the laboratory only. Main characteristic curves are also known as **constant head characteristic curves**.

### **(ii) Operating Characteristics or Constant Speed Curves**

When a turbine is working for the generation of power its **speed must remain constant**. The other operating condition viz. ***Q*** and ***H*** may vary according to their availability. The operating characteristic curves are also known as **constant speed characteristic curves**.

Tables obtained from brake tests are used again and the following curves are drawn.

(1)  $P_t, \eta_t = f(Q)$

(2)  $\eta_t = f(P_t)$

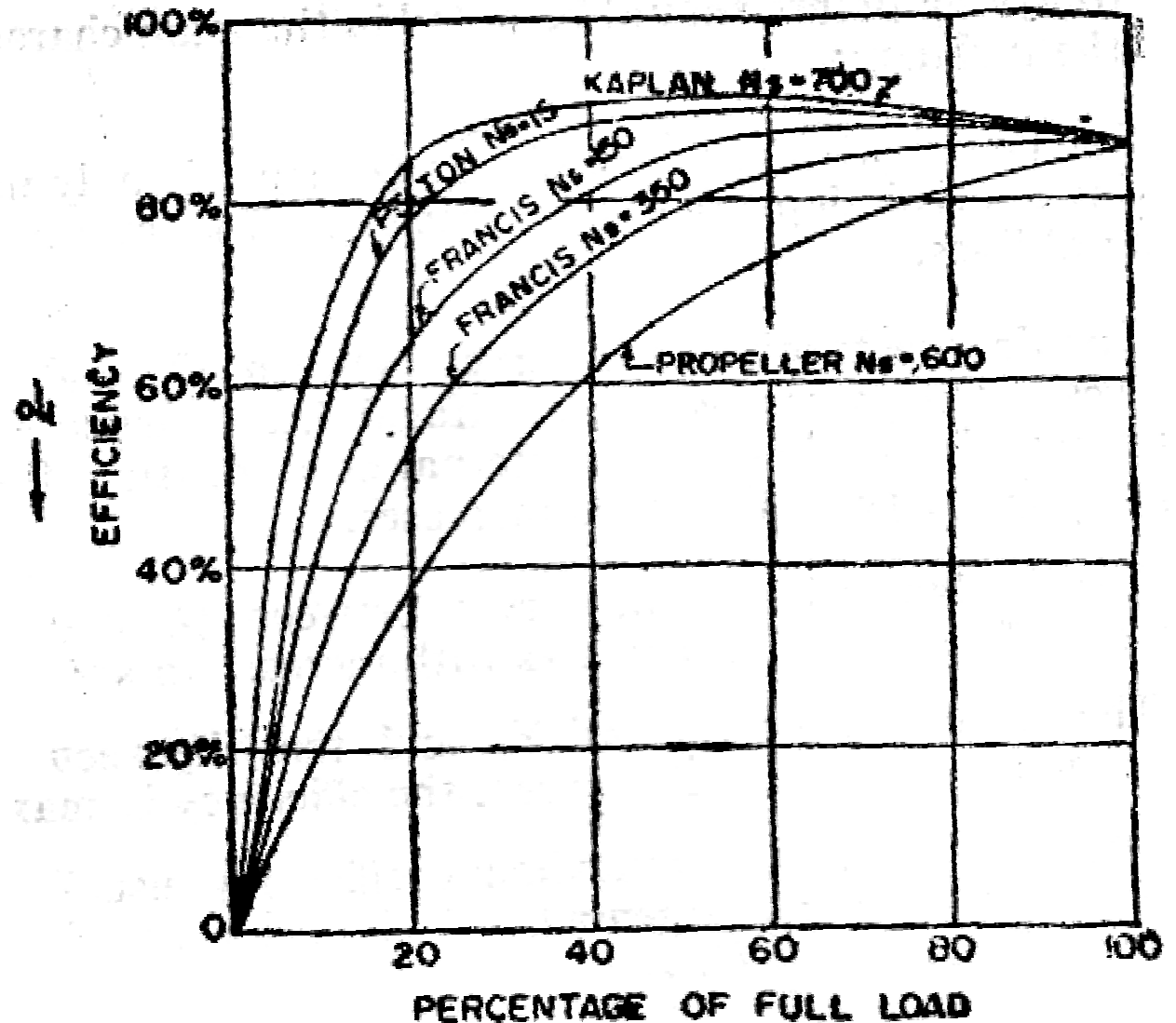
(3) % of max.  $\eta_t = f(\% \text{ full load})$

From the measured discharge, head and power developed, the overall efficiency is calculated. A curve can be plotted between  $\eta_o$  and P. the abscissa is usually taken as the percentage of full load. the percentage of full load is equal to the ratio of the measured load (Power) to the full load.

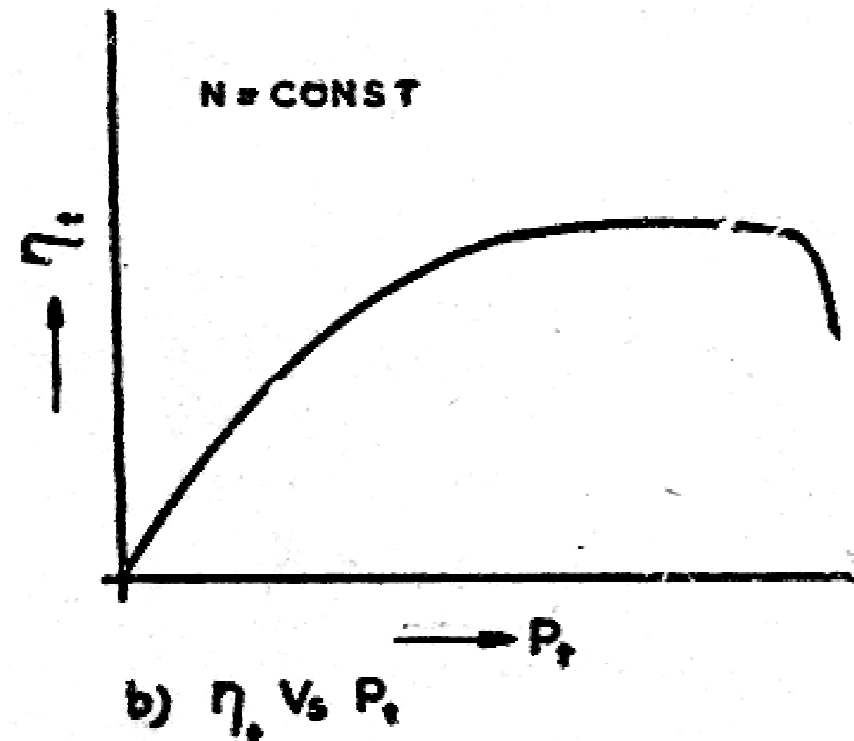
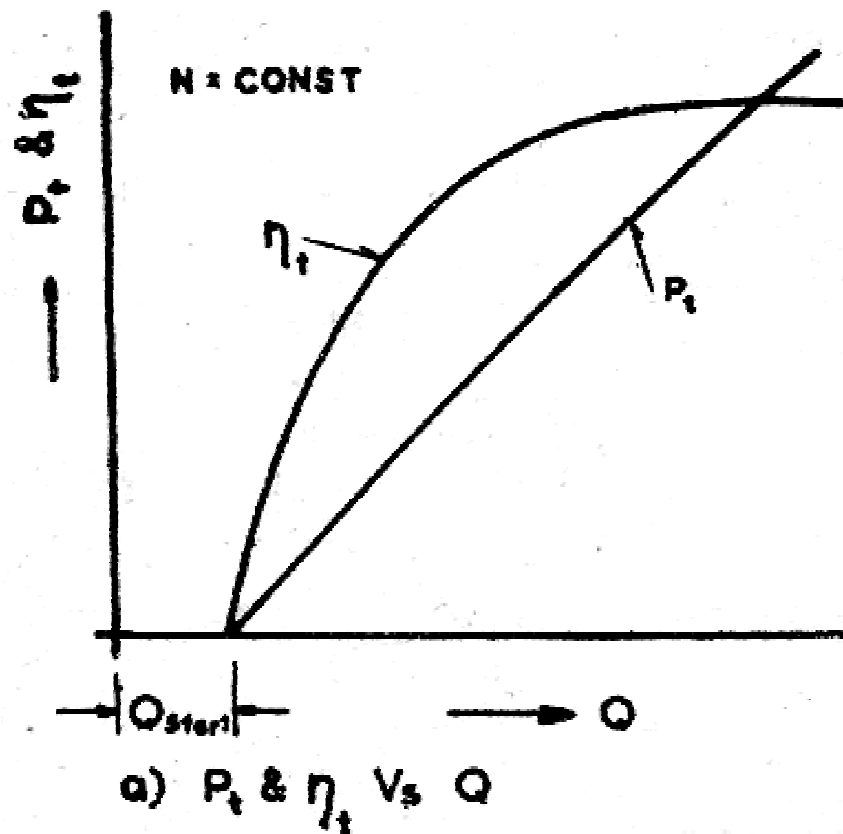
*Fig. shows the operating characteristic curves for the four turbine described before.*

The following points should be noted from the operating characteristic curves.

(1) The Kaplan turbine gives good performance even at part loads. This is because by adjusting the vane angles, a high efficiency can be attained.



- (2) The Pelton wheel also gives fairly good performance even at part loads.
- (3) The worst performance is indicated by the propeller turbine at part loads. This is the reason why propeller turbines are not used when there are large fluctuations in the load.
- (4) The maximum overall efficiency of all the turbine is almost the same (about 85%).



### (iii) Constant Efficiency Curves (Muschel- Curve)

The curves indicating the constant efficiency are known as constant efficiency curves. These curves are also called iso-efficiency curves. The constant efficiency curves may be obtained from the main characteristic curves.

### Surge Tank

A surge tank is a storage reservoir fitted at some opening made on a long penstock to receive the rejected flow when the penstock is suddenly closed by a valve fitted at its steep end. Surge tank, therefore, relieves the pipe line of excessive pressure produced due to closing of penstock, thus eliminating positive water hammer effect by admitting in it a large mass of water which otherwise would have flown out of the pipe line. It is necessary for medium and high head water power plants, especially when the water has to travel a long way from the intake to the power house. It is also used in a large pumping plant to control the pressure variation resulting from rapid changes in the flow.

Surge tank also serves the purpose of supplying initial water for an increasing load on the turbines while the water in the pipeline is being accelerated.

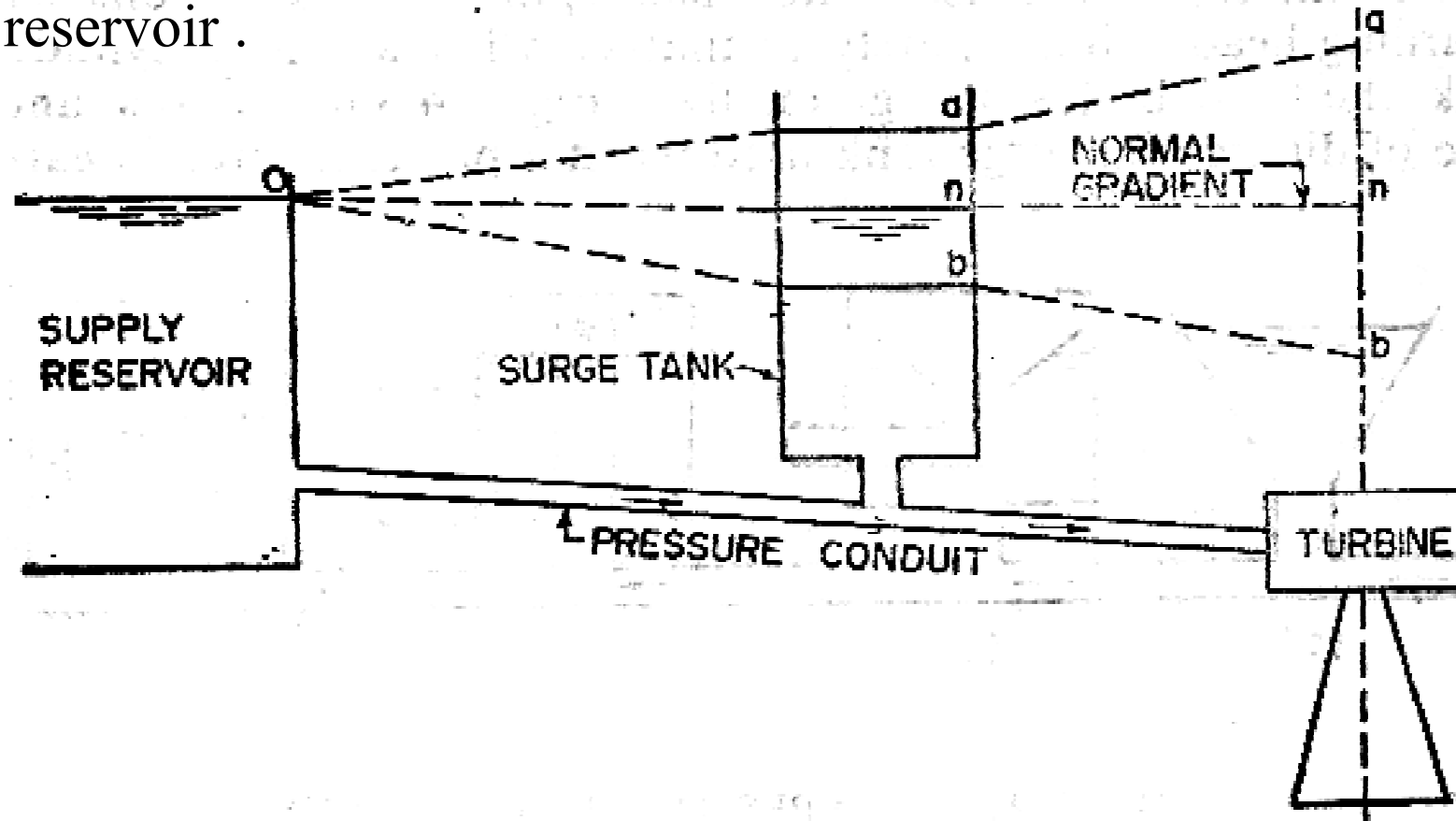
## **Function of Surge Tank**

- (a) Control of pressure variations resulting from rapid changes of flow in penstock, relieving the line of excessive pressure, thus eliminating water hammer effects.
- (b) Regulation of flow in power and pumping plants by providing necessary accelerating or retarding head. The more effectively the accelerating or retarding head is applied the shorter will be the duration of surge, less amount of water will then have to be stored or given up by the tank, thereby smaller will be the size of the tank required.
- (c) Regulation of turbine speed with the help of (b).

## **Location of Surge Tank**

Theoretically a surge tank should be located as close to a power or pumping plant as possible. The ideal place in case of power plants is at the turbine inlet, but it is seldom possible in case of medium and high head plants because it will have to be made very high. In order to reduce its height, it is generally located at the junction of pressure tunnel and penstock or on the side of the mountain.

A surge tank is a small storage tank with open top. It is connected to the pressure conduit carrying water to the turbine. The upper lip of the surge tank is set at a suitable level above the maximum water level in the supply reservoir .



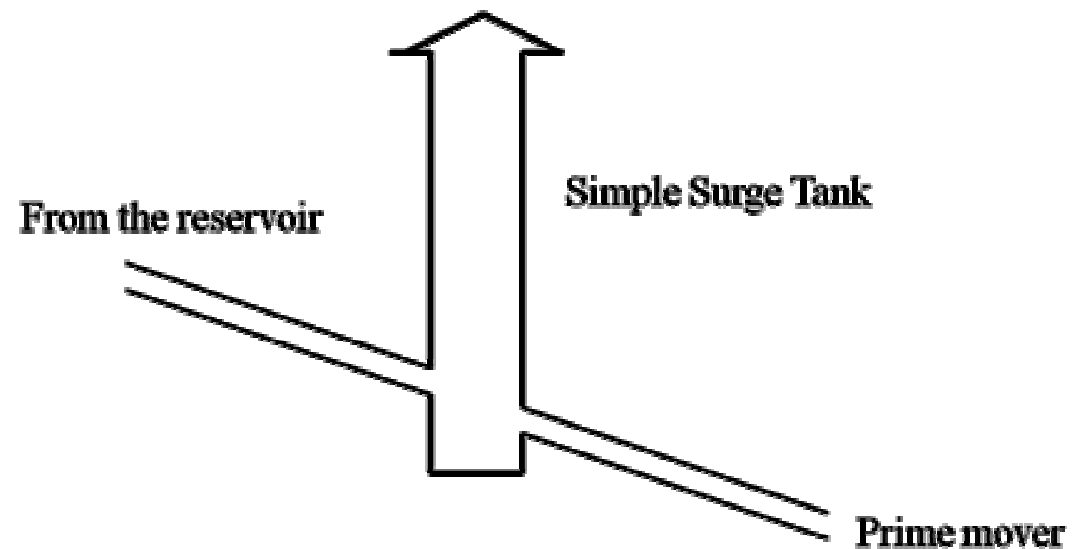
When the load on the turbine is steady, the velocity of water in the conduit is constant. The normal hydraulic gradient line is shown by the line *onn*. The level in the surge tank is lower than the supply reservoir; the difference of levels being equal to the loss of head due to friction. As the load on the turbine increases, more water is drawn and the hydraulic gradient line is

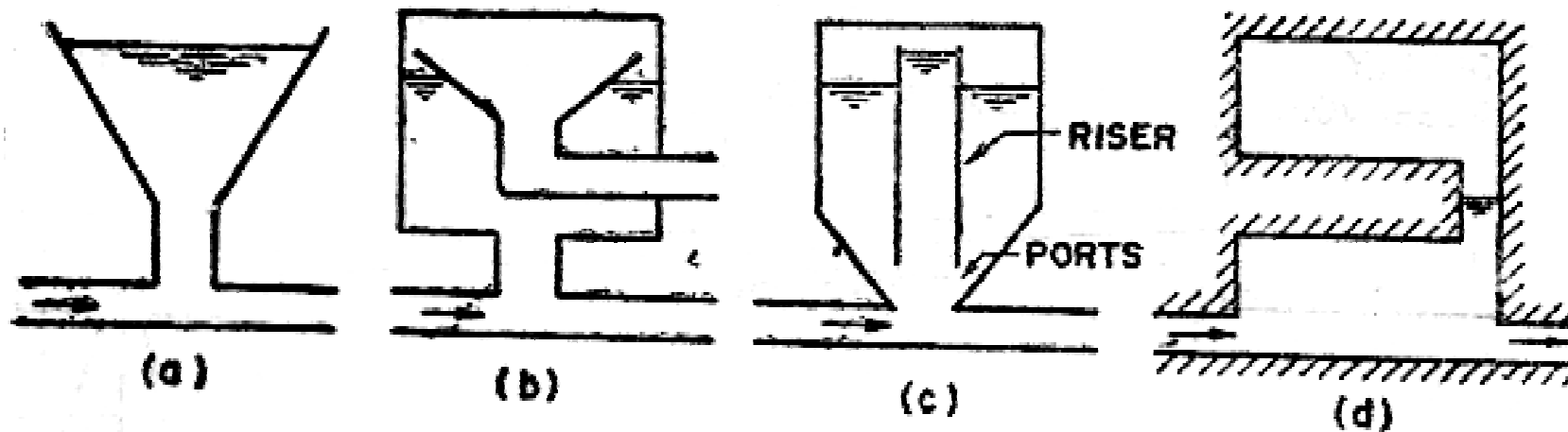
indicated by line *obb*. The increased demand of water is met with the fall of water level in the surge tank (from *n* to *b*). Thus the surge tank supplies the extra water needed.

When the load on the turbine decreases, the gate openings are partly closed and the discharge is reduced. The pressure rises at the turbine end of the conduit and the hydraulic gradient is represented by *oaa*. The extra water is stored in the surge tank (from *n* to *a*). The raised water level in the surge tank reduces the velocity in the conduit.

Thus the surge tank reduces the water hammer effects and at the same time supplies extra water in the case of increased demand stores extra water when it is not needed by the turbine in the case of decreased load.

Other types of surge tanks are also used. Fig. (a) simple conical surge tank, the working of which is similar to that of a cylindrical tank. It is a reservoir directly connected to a pipe line (penstock) as shown in fig. in this type of surge tank, the





accelerating and retarding heads induced by a change of water surface accumulate slowly, therefore its action is sluggish. It is liable to set up considerable oscillations unless it is of such a large size as to render its cost prohibitive. Now-a-days it is seldom used.

Fig. (b) shows a tank with an internal bell-mouthed spillway. It permits the overflow to be easily disposed of.

Fig.(c) shows differential type surge tank. The advantage of this type is that for the same stabilising effect, the capacity of the tank is less than that of a cylindrical tank. When the pressure in the conduit rises, a small quantity of water enters the surge tank through ports. But the bulk of water rises to the top of the riser and then spills. Thus a considerable retarding head is immediately available, whereas in a cylindrical tank, the head builds up gradually. Fig. (d) shows another type of differential surge tank.

Sometimes, especially in case of medium and low head installations, a **forebay** is provided instead of a surge tank. A forebay is a wide channel. The function of forebay is also to store the excess water when not needed by the turbine and to supply the extra water when needed.

