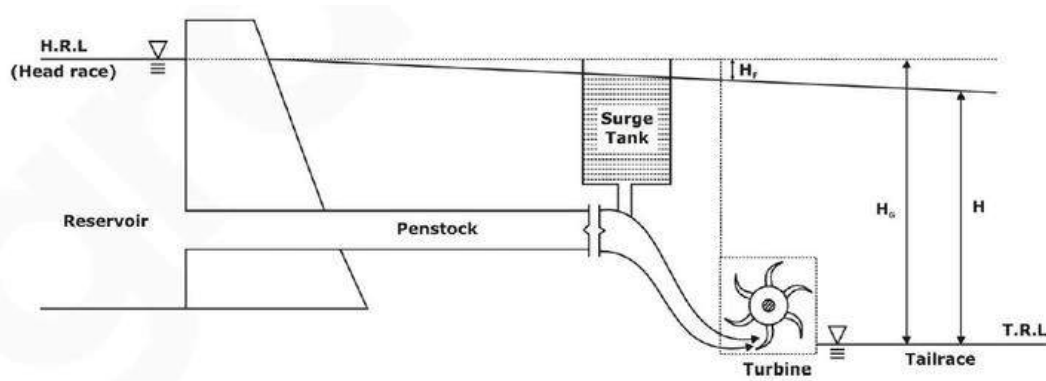


Hydraulic Turbine

The hydraulic turbine is one of the applications of mechanical devices, And they can be used to convert mechanical energy into electrical energy. It can be explained as follows:

- Devices used to convert hydraulic energy into mechanical energy or mechanical energy to hydraulic energy are known as Hydraulic Machines.
- The hydraulic machines used for converting hydraulic energy into mechanical energy are known as Turbines, which convert mechanical energy into hydraulic energy and are known as Pumps.



In a Hydroelectric plant, as shown above:

- A Dam is constructed across a river or a channel for storing water. The reservoir is also known as the Head race.
- Pipes of large diameter called Penstock carry water under pressure from the storage reservoir to the turbines. These pipes are generally made of [steel](#) or reinforced [concrete](#).
- Turbines have different types of vanes, buckets, or blades mounted on a wheel called a runner.
- Tail-race is a channel carrying water away from the turbine after the water has worked on the turbines. The water surface in the tail race is also referred to as the tail race.

Important Terms of Hydraulic Turbine

- **Gross Head (H_g):** Vertical difference between headrace and tailrace.
- **Net Head (H_{net}):** The actual head available at the inlet to work on the turbine is called the Net Head. It can be mathematically expressed as $H_{net} = H_g - h_L$.
- **Total Head Loss (h_L):** h_L is the total head loss during the transit of water from the headrace to the tail race, mainly the head loss due to friction, and is given by, $h_f = fLV^2/2gD = 4f'LV^2/2gD$. Where, 'f' is the coefficient of friction of penstock, which depends on the type of material of penstock, 'L' is the total length of the penstock, 'V' is the mean flow velocity of water through the penstock, 'D' the diameter of penstock and g is the acceleration due to gravity.

Types of Efficiencies

Efficiencies are classified based on the inputs and outputs parameters. Considering different forms of input and output, the efficiencies can be classified as follows:

- **Hydraulic Efficiency(η_h)**
 - The ratio of the power generated by the runner of a turbine to the power supplied at the inlet of the turbine is known as Hydraulic efficiency.
 - As the power supply is in the hydraulic form, and the possible losses occur between the striking jet and vane, it is rightly called hydraulic efficiency.
 - If R.P. is the Runner Power and W.P. is the Water Power:
 $\eta_h = \text{Runner Power/Water Power} = \text{R.P./W.P.}$
- **Mechanical Efficiency(η_m)**
 - The ratio of the power available at the shaft to the power generated by the runner of a turbine is called Mechanical Efficiency.
 - The runner's energy loss in the annular area between the nozzle and spear is due to slips and other mechanical problems.
 - If S.P. is the Shaft Power:
 $\eta_m = \text{S.P./R.P.}$
- **Overall Efficiency(η_o):**
 - The ratio of the power available at the shaft to the power supplied to the inlet of a turbine is termed overall efficiency.
 - Because this covers the overall problems of energy losses, it is known as overall efficiency.
 - It depends on both the hydraulic losses and the slips and other mechanical problems that will create a loss of energy between the jet power supplied and the power produced at the shaft available for coupling of the generator.
 $\eta_o = (\text{S.P./R.P.}) \times (\text{R.P./W.P.})$
- **Volumetric Efficiency**

$$\text{Vol. efficiency} = \frac{\text{Volume of water actually striking the runner}}{\text{Volume of water supplied to the turbine}}$$

$$\eta_{\text{vol}} = \frac{\text{Discharge striking the runner}}{\text{Discharge supplied by penstock}} = \frac{Q - \Delta Q}{Q}$$

Classification of Hydraulic Turbines

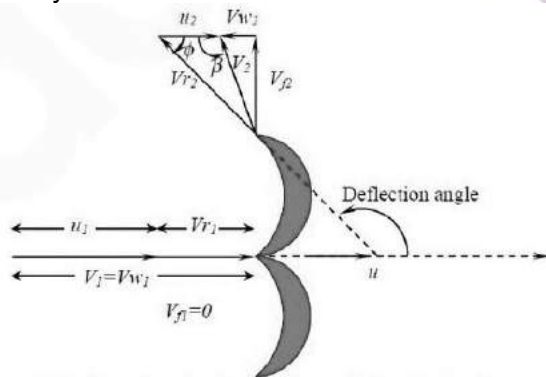
Hydraulic Turbines are the equipment that converts hydraulic energy into mechanical energy. It can be classified based on different parameters.

- The hydraulic turbines can be classified based on the type of energy at the inlet, the direction of flow through the vanes, the head available at the inlet, discharge through the vanes, and specific speed.
- They are classified as:

Turbine		Type of energy	Head	Discharge	Direction of flow	Specific Speed
Name	Type					
Pelton Wheel	Impulse	Kinetic	High Head > 250m to 1000m	Low	Tangential to runner	Low <35 Single jet 35 – 60 Multiple jet
Francis Turbine	Reaction Turbine	Kinetic + Pressure	Medium 60 m to 150 m	Medium	Radial flow	Medium 60 to 300
Kaplan Turbine					Mixed Flow	
			Low < 30 m	High	Axial Flow	High 300 to 1000

1. Pelton Turbine

- The Pelton wheel turbine is an impulse turbine. In this type of turbine, the nozzle is connected at the exit of the penstock, which converts the available energy head into a velocity head.



Where,

- u = wheel velocity
- V = Jet velocity
- V_r = relative velocity
- V_w = whirl velocity
- ϕ = Angle by the relative velocity at the outlet
- β = Guide blade angle at the outlet and $u_1 = u_2 = u = 2\pi N/60$ where N = no. of rotation of the wheel

Tangential flow Impulse Turbine

Basic components of [Impulse Turbine](#) are:

- Nozzle

- Runner and buckets
- Casing
- Breaking Jet

The power is given to the Pelton turbine = $\rho a V_1 (V_{w1} \pm V_{w2}) u$ Nm/sec
 Hydraulic efficiency is given by

$$\eta_h = [(V_1 - u)(1 + k \cos \Phi) u] (V_1^2 / 2)$$

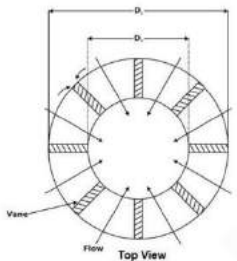
For maximum efficiency $d\eta_h / du = 0$
 $(\eta_h)_{\max} = (1 + k \cos \Phi) / 2$

Point to Remember

- The velocity of jet: $V_1 = C_v \times \sqrt{2gH}$ where $C_v = 0.98$ to 0.99 and called the coefficient of velocity.
- The velocity of wheel: $u = \phi \sqrt{2gH}$ where ϕ = Speed ratio (u/V_1) (0.43 to 0.48)
- The velocity of wheel $u = \pi D N$ (rps)
- Jet ratio (m) = D/d (pitch diameter ratio to jet diameter; generally 12).
- Number of bucket $Z = 15 + (D/2d) = 15 + 0.5 m$
- The number of jets is the ratio of the total flow rate to the Rate of flow by a single jet.

2. Radial Flow Reaction Turbine

- In this type of turbine, the water strikes the runner, and it has both a kinetic energy head and a pressure energy head. Due to the KE head, the impulse will generate, which is similar to the case of an impulse turbine.
- Impulse: kinetic head
 Reaction: Pressure head



- Let B_1, B_2 = width of the runner at the inlet and outlet
 Area of flow at inlet: $A_1 = \pi D_1 B_1$
 Area of flow at inlet: $A_2 = \pi D_2 B_2$
 If vane thickness is taken into consideration:
 Net Area of flow = $[\pi D_1 - nt] \cdot B_1 = k\pi D_1 B_1$
 K is a factor for the net area, and n is the number of vanes.

$$Q = A_1 V_{f1} = A_2 V_{f2}$$

$$Q = \pi D_1 B_1 V_{f1} = \pi D_2 B_2 V_{f2}$$

$$F_{\text{radial}} = m(V_{f1} - V_{f2})$$

Since $V_{f1} = V_{f2}$

Thus F_{radial} should be zero

Hence, $\pi D_1 B_1 = \pi D_2 B_2$

$D_1 B_1 = D_2 B_2$

$D_1 > D_2$

$B_1 < B_2$

Note: If it is given that $B_1 = B_2$, then $V_{f1} \neq V_{f2}$

3. Francis Turbine

- [Francis turbine](#) is an inward flow reaction turbine.
- To maximize runner power, V_2 should be minimum. It can be done by converting the absolute velocity direction into the radial direction of the runner at the exit.

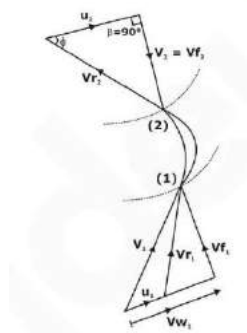
It means that

$\beta = 90^\circ$

$V_2 = V_{f2}$

$V_{w2} = 0$

Hence, R.P. = $\rho Q V_{w1} u_1$

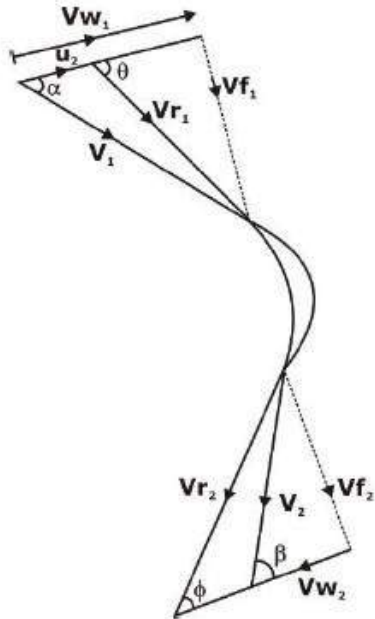


Hydraulic efficiency (η_h) = $RP/HP = \rho Q V_{w1} u_1 / \rho Q g H = V_{w1} u_1 / g H$

$\eta_h = V_{w1} u_1 / g H$

4. Axial Flow Reaction Turbine

- [Kaplan turbine](#) and propeller turbines are examples of axial flow reaction turbines.



$$RP = m(V_{w1}u_1 + V_{w2}u_2)$$

What is Draft Tube?

The draft tube is the tube fitted at the exit location of the runner of the turbine. It is the diverging tube used to available kinetic energy at the exit of the runner.

- A draft tube is a pipe of a gradually increasing cross-sectional area, linking the runner outlet to the tailrace, and is used to discharge water from the turbine exit to the tail race.
- An end of the draft tube is linked to the runner outlet, and the other end is submerged under the water level in the tail race.

Functions

- It permits a negative head to be established at the outlet of the runner and thereby increasing the net head on the turbine.
- It converts a large proportion of kinetic energy being rejected at the outlet of the turbine into helpful pressure energy.

Specific Speed

- The value of a specific speed for a turbine is the speed of a geometrically similar turbine that would produce unit power (one kilowatt) under a unit head (one meter).
- This value is provided by the manufacturer (along with other ratings) and will always refer to the point of maximum efficiency.

$$N_s = N(P)^{0.5}/H^{(5/4)}$$

- Specific Speed is not a dimensionless number. Its dimension is $[M^{1/2}L^{-1/4}T^{-5/2}]$.

Model Laws

$$\frac{Q}{D^3N} = \text{constant} \Rightarrow \frac{Q_1}{D_1^3N_1} = \frac{Q_2}{D_2^3N_2}$$

$$\frac{H}{D^2N^2} = \text{constant} \Rightarrow \frac{H_1}{D_1^2N_1^2} = \frac{H_2}{D_2^2N_2^2}$$

$$\frac{P}{D^5N^3} = \text{constant} \Rightarrow \frac{P_1}{D_1^5N_1^3} = \frac{P_2}{D_2^5N_2^3}$$

What are Centrifugal Pumps?

- A hydraulic machine that converts mechanical energy into hydraulic energy or pressure energy is known as a pump.
- A centrifugal pump (also called a Rotodynamic pump or dynamic pressure pump) works on the principle of centrifugal force.
- In Centrifugal pumps, the liquid is subjected to a whirling motion by the rotating impeller, which is made of several backward-curved vanes.

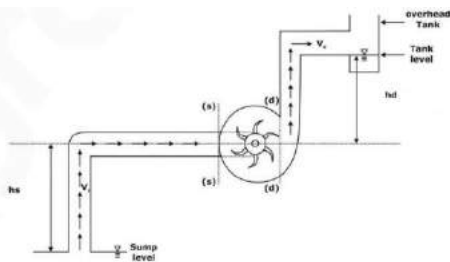
Classification of Centrifugal Pumps

centrifugal pumps can be categorized based on different parameters. These are explained as follows:

S. No.	Classification Criteria	Types of Pumps
1	Casing design	<ul style="list-style-type: none"> • Volute pump • Diffuser or turbine pump
2	Number of impellers	<ul style="list-style-type: none"> • Single-stage pump • Multistage or Multi impeller pump
3	Number of entrances to the Impeller	<ul style="list-style-type: none"> • Single suction pump • Double suction pump
4	Disposition of shaft	<ul style="list-style-type: none"> • Vertical shaft pump • Horizontal shaft pump
5	Liquid handled	<ul style="list-style-type: none"> • Semi-open impeller • Open impeller pump

6	Specific speed	<ul style="list-style-type: none"> • Low specific speed or radial flow impeller pump with Shrouded impeller • Medium-specific speed or mixed-flow impeller pump • High-specific speed/axial flow type/propeller pump
7	Head (H)	<ul style="list-style-type: none"> • Low head: $H < 40$ m • Medium head: $15 < H < 40$ m • High head: $H > 40$ m

Heads on a Centrifugal Pump



- **Suction head (h_s)**
 - It is the vertical distance between the liquid level in the sump and the center line of the pump.
 - It is expressed as meters.
- **Delivery head (h_d)**
 - It is the vertical distance between the center line of the pump and the liquid level in the overhead tank or the supply point.
 - It is expressed in meters.
- **Static head (H_s)**
 - It is the vertical difference between the liquid levels in the overhead tank and the sump when the pump is not working.
 - It is expressed as meters.
Therefore: $H_s = (h_s + h_d)$
- **Friction head (h_f)**
 - It is the sum of the head loss due to the friction in the suction and delivery pipes.
 - The friction loss in both pipes is calculated using Darcy's equation.
 $h_f = fLV^2/2gD = 4fLV^2/2gD$
- **Total head (H)**
 - It is the sum of the static head H_s , friction head (h_f), and the velocity head in the delivery pipe ($V_d^2/2g$). Where, V_d =velocity in the delivery pipe.
 $H_m = h_s + h_d + h_{fs} + h_{fd} + V_d^2/2g$
- **Manometric head (H_m)**
 - It is the total head developed by the pump.

- This head is slightly less than the head generated by the impeller due to some losses in the pump.

$$H_m = H + \frac{V_s^2}{2g} - \frac{V_d^2}{2g}$$

- **Power of pump**

(i). Power requirement of pump = shaft power (SP)

(ii). Impeller power (IP) = SP – (mechanical frictional losses)

(iii). Manometric power or output power (MP) = ρQgH_m

SP > IP > MP

Applications of Hydraulic Turbine

Here are some common applications of hydraulic turbines:

- Generating electricity in hydroelectric power plants
- Providing mechanical power for industrial processes, such as milling and pumping
- Driving water pumps for irrigation and water supply systems
- Assisting in flood control and water management by regulating the flow of water in rivers and reservoirs
- Providing propulsion for ships and submarines using water propulsion turbines.