Hydraulic Pumps and Turbines

1. Hydraulic pumps :

- Centrifugal and axial pumps.
- Manometric head, suction head, delivery head;
- manometric efficiency, hydraulic efficiency, volumetric efficiency,
- overall efficiency; multi stage pumps.
- Characteristics of pumps

2. Hydraulic turbines :

- Classification; Module quantities;
- Pelton wheel, Francis turbine,
- Kaplan turbine and their velocity triangles.
- Draft tubes and their function.
- Characteristics of hydraulic turbines.

1. Hydraulic pumps :

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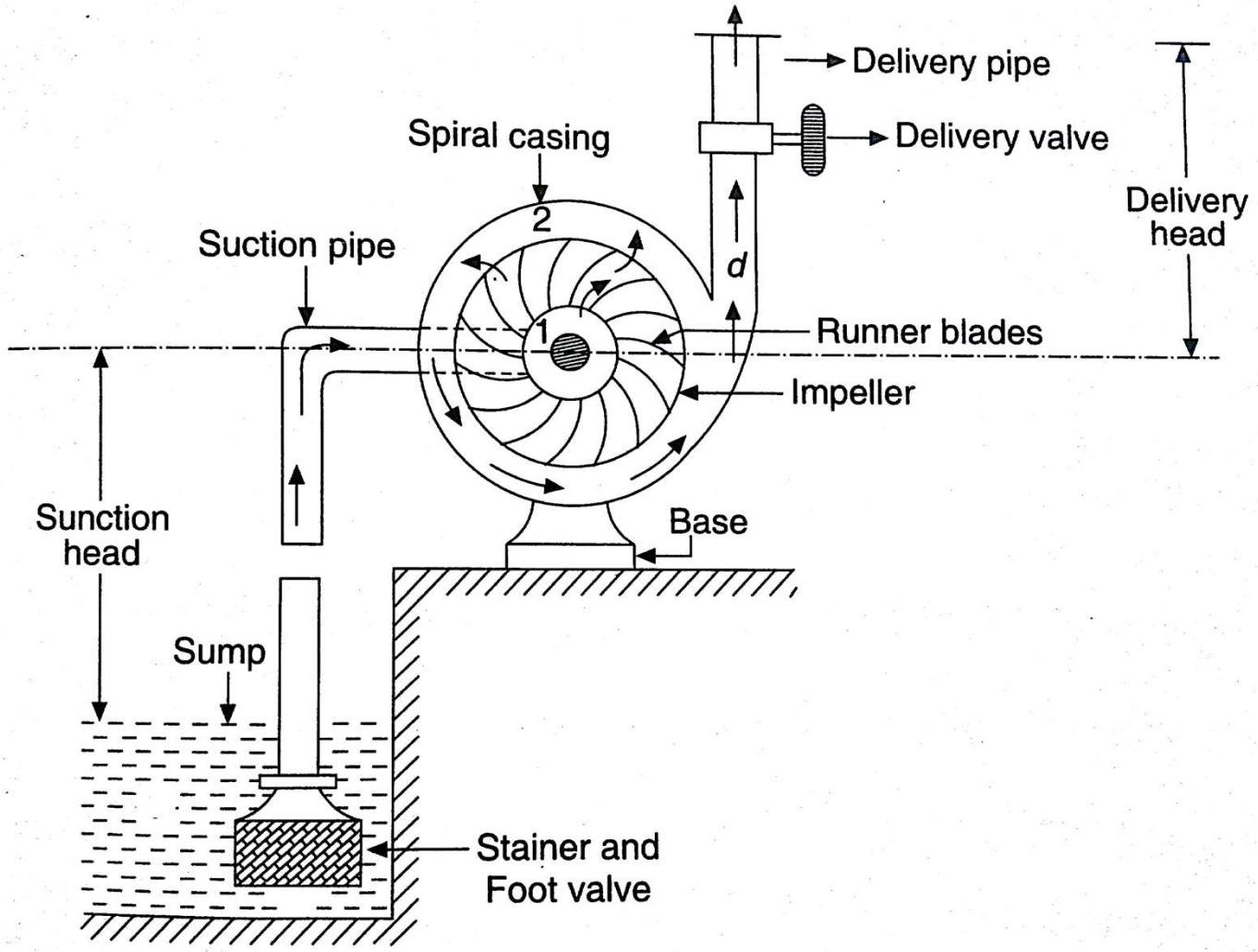
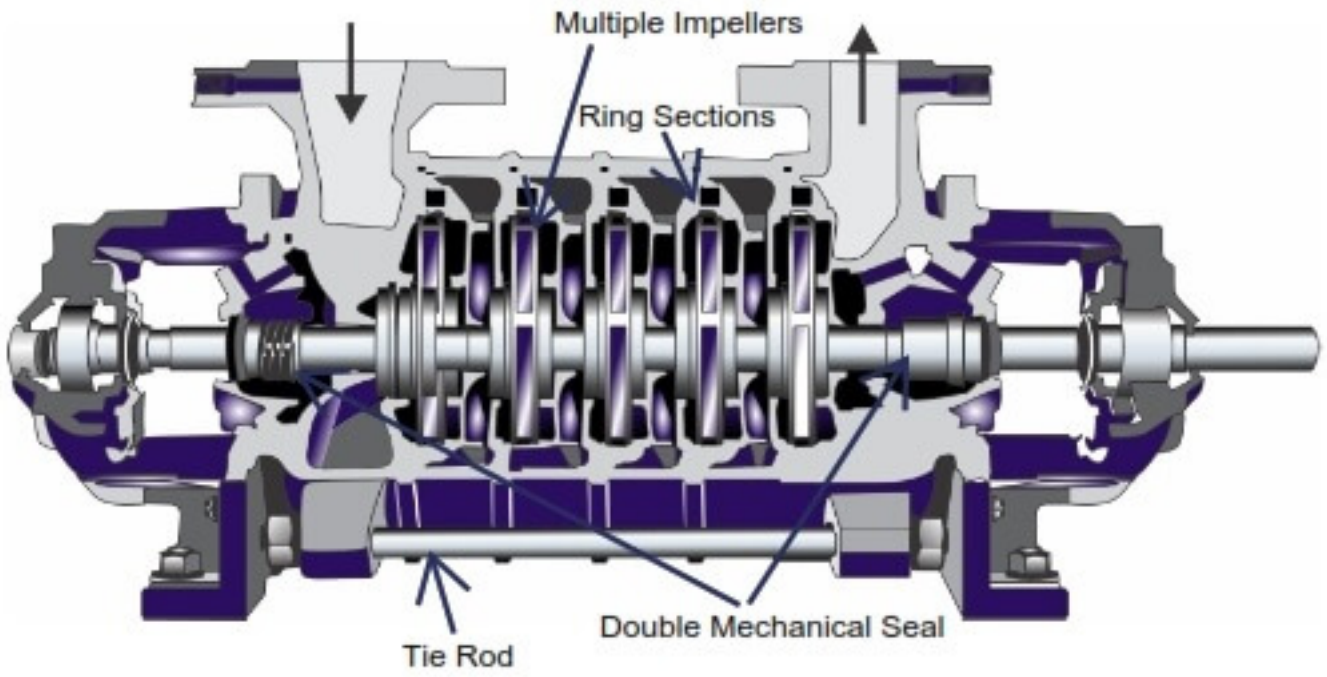
Centrifugal Pump

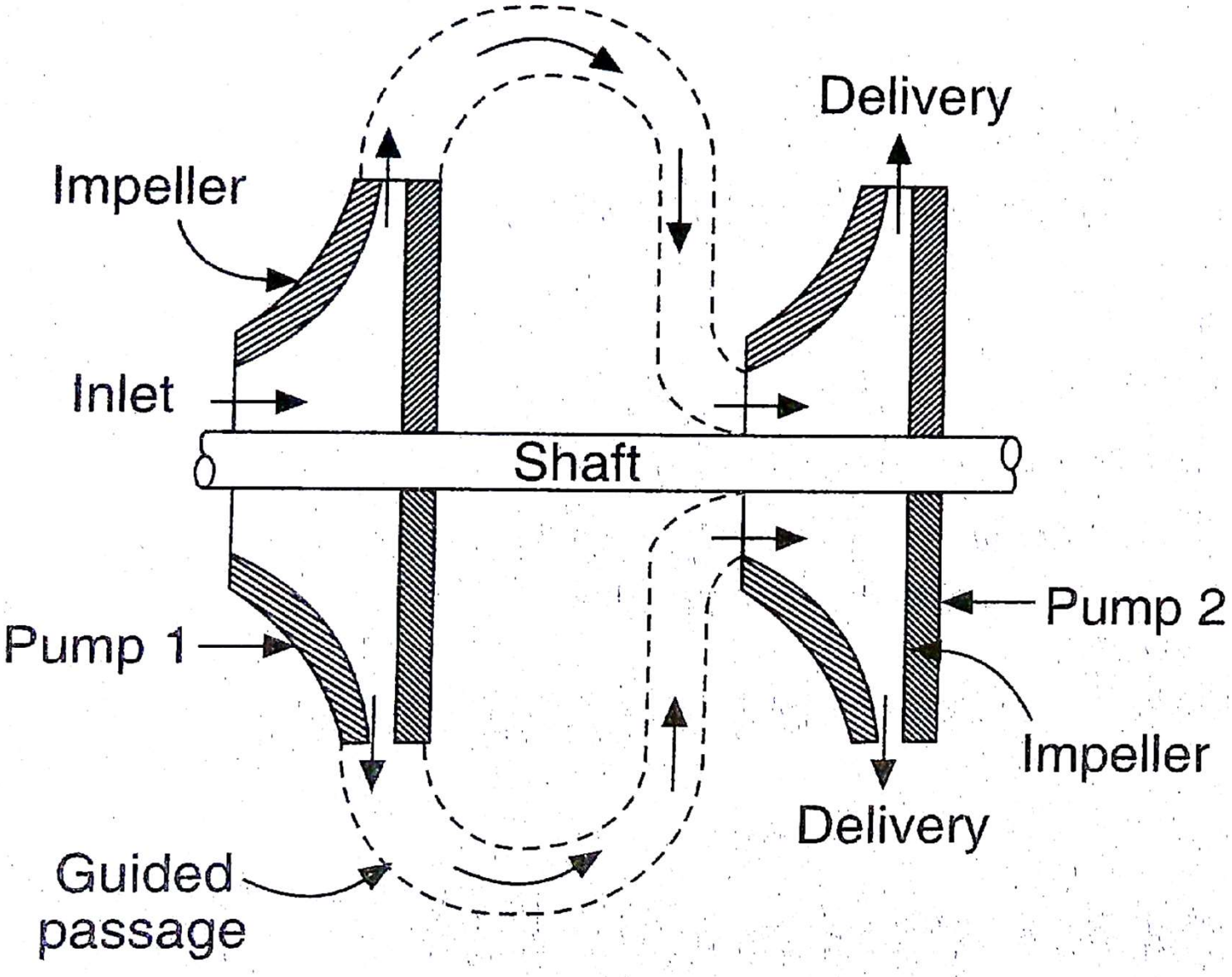


Multi Stage Pump

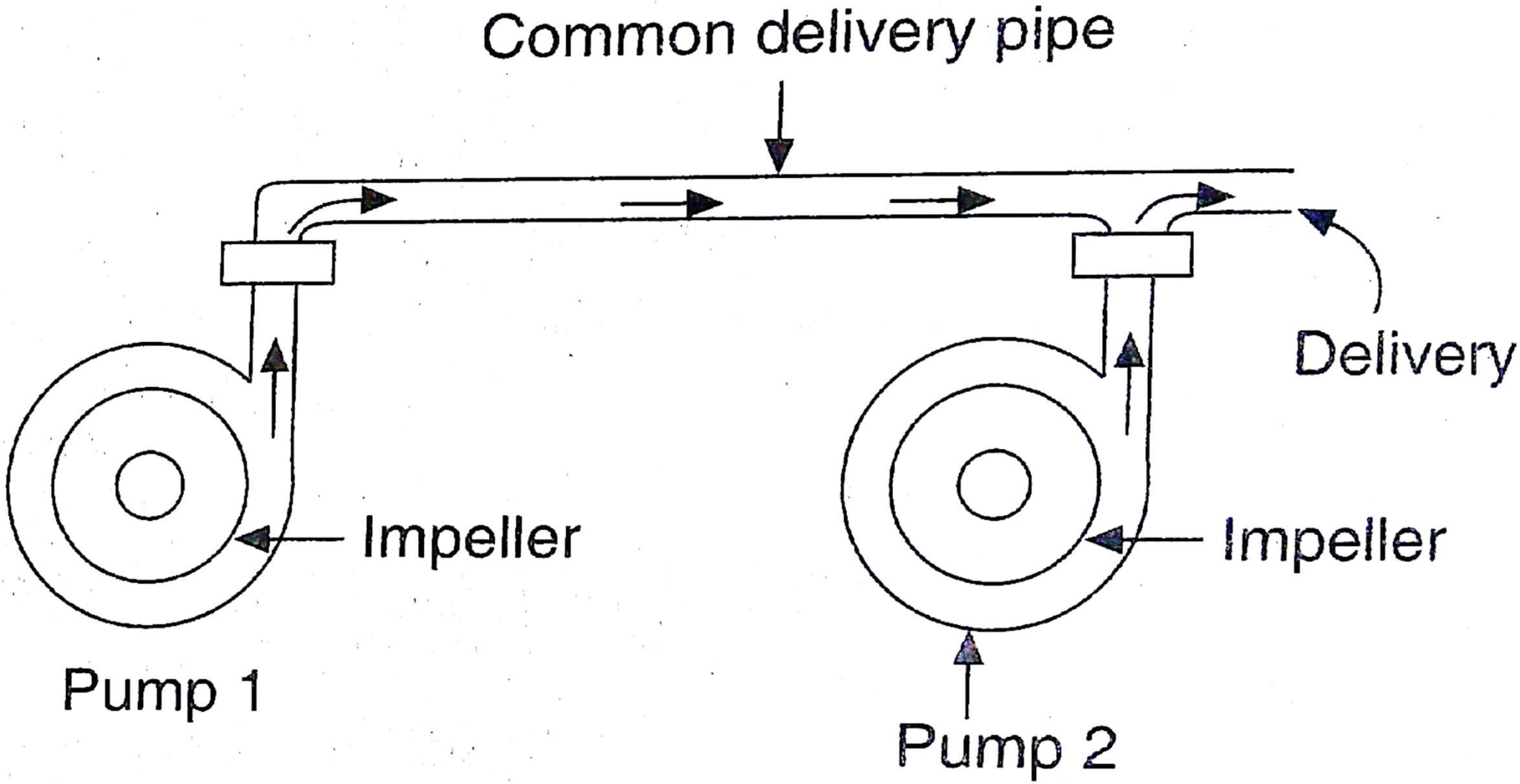
1. Series Arrangement
2. Parallel Arrangement



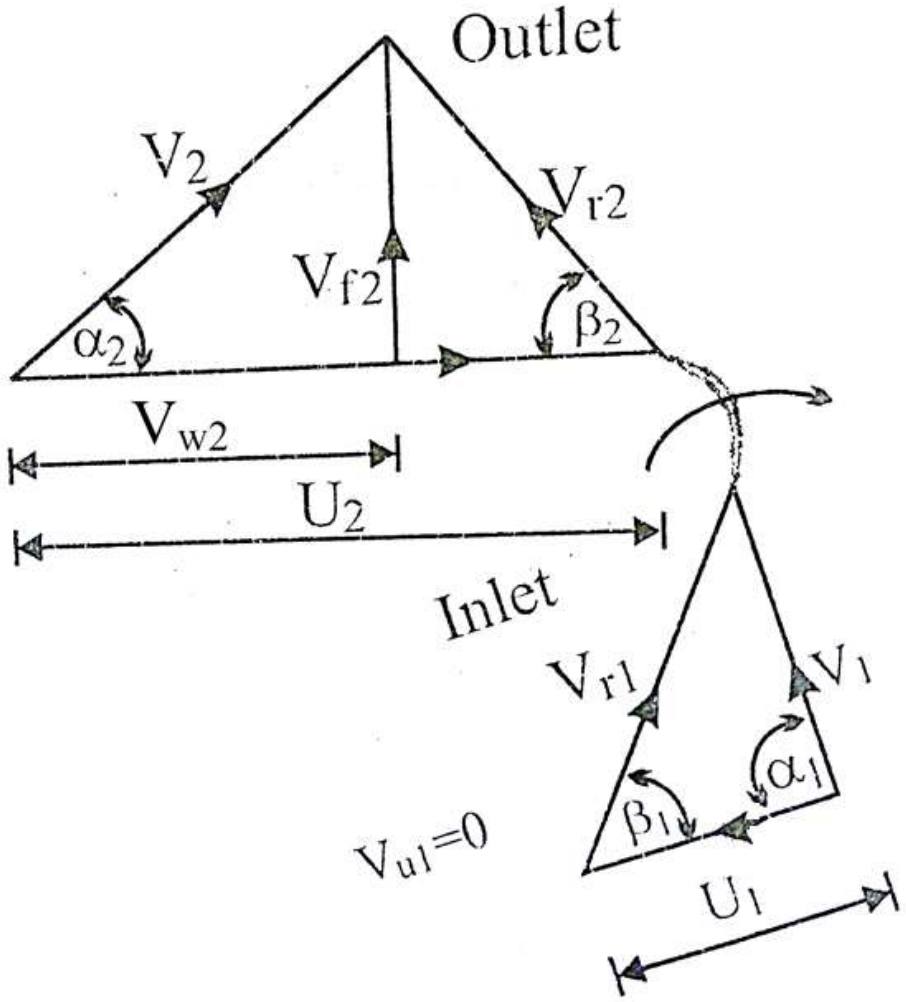
Series Arrangement



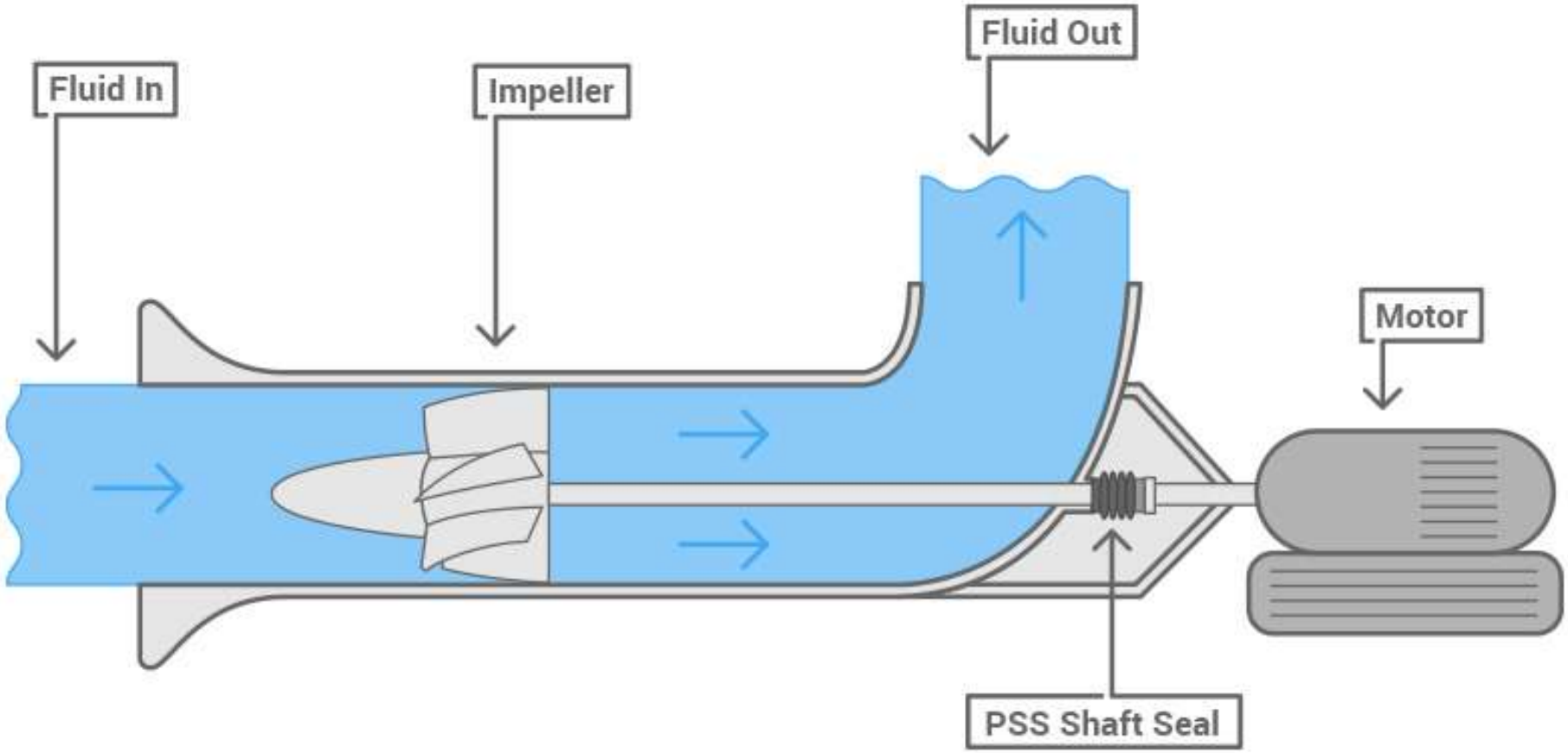
Parallel Arrangement



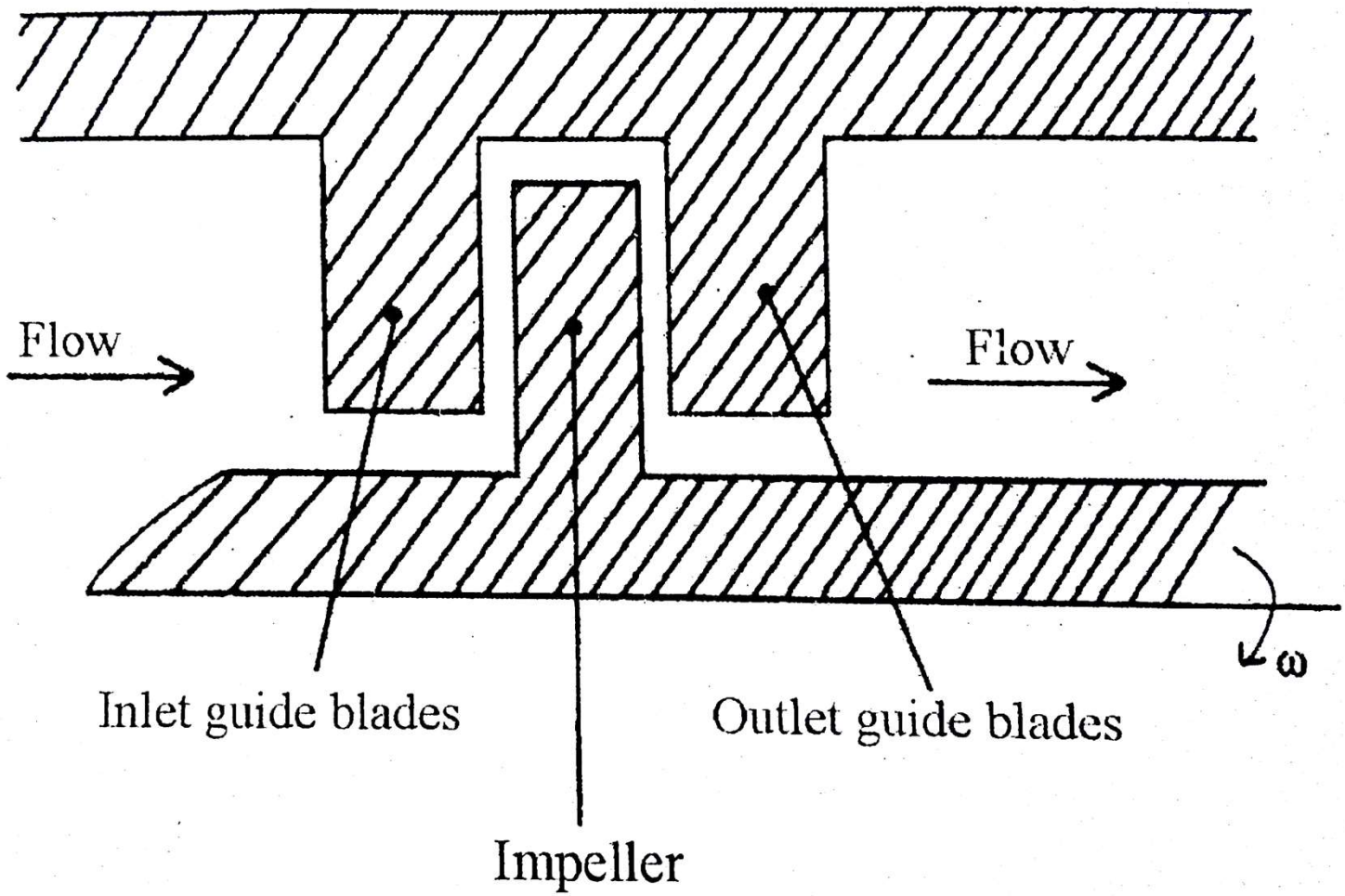
Work done by centrifugal pump



Axial Flow Pump

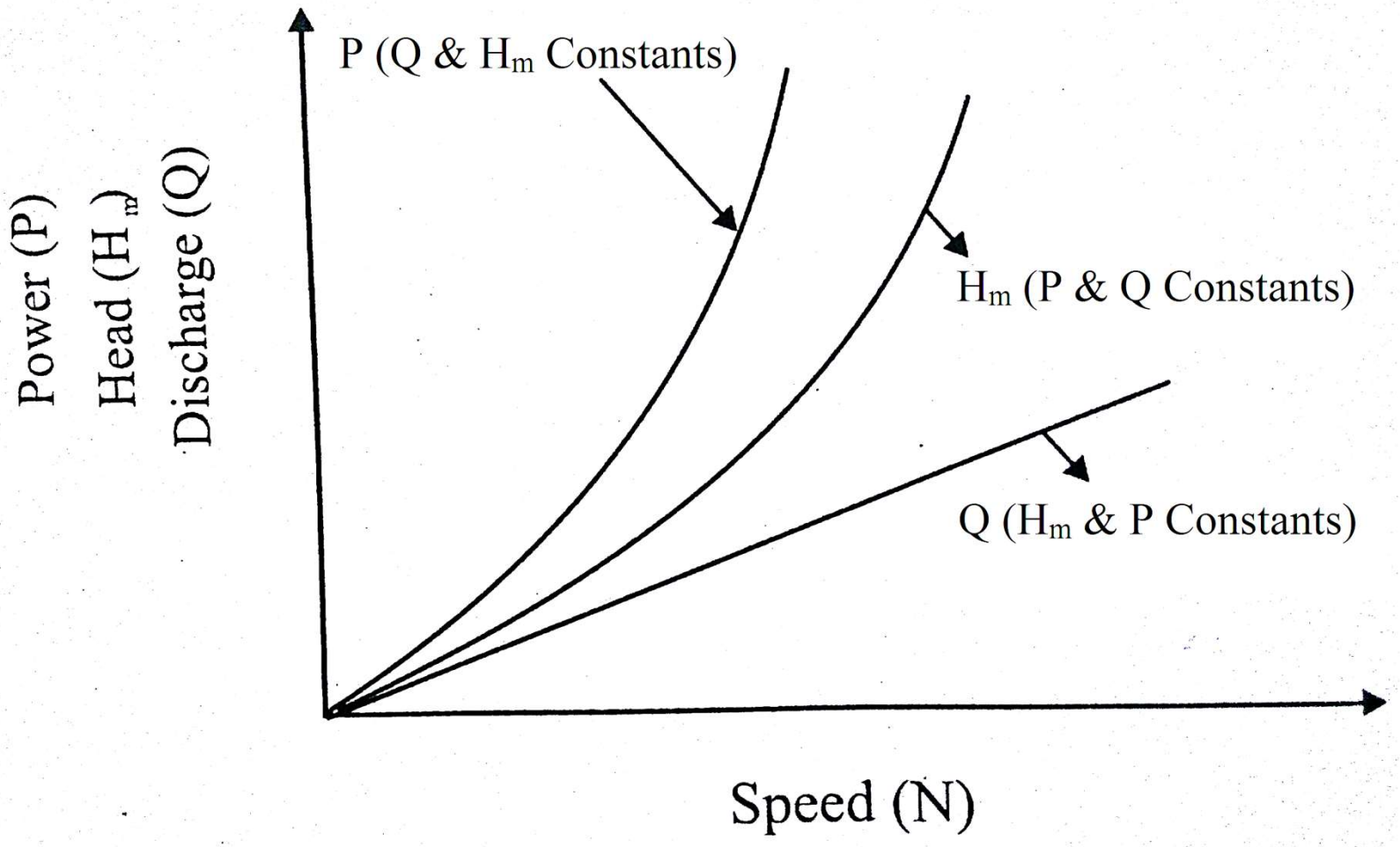


Axial Flow Pump

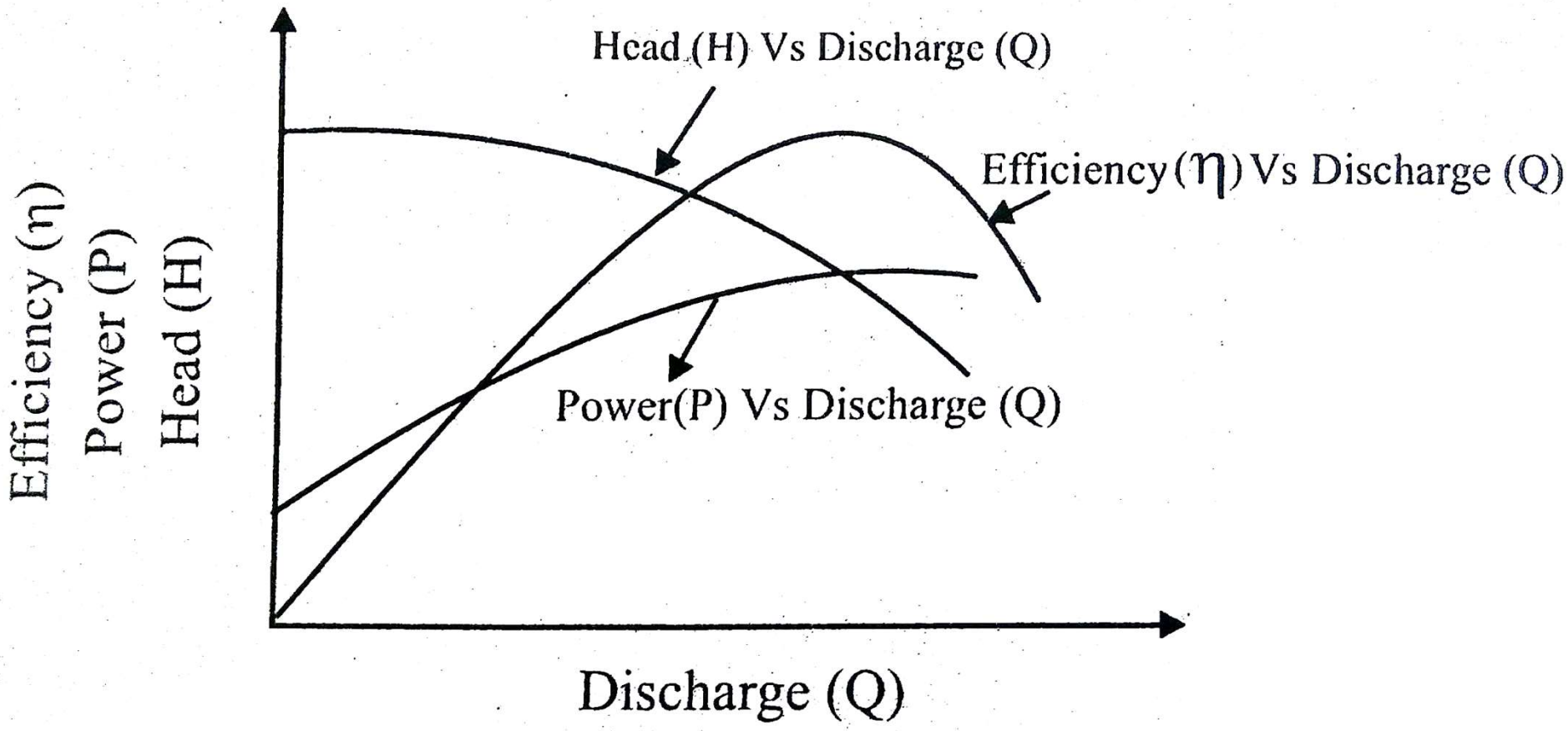


Characteristics of Pump

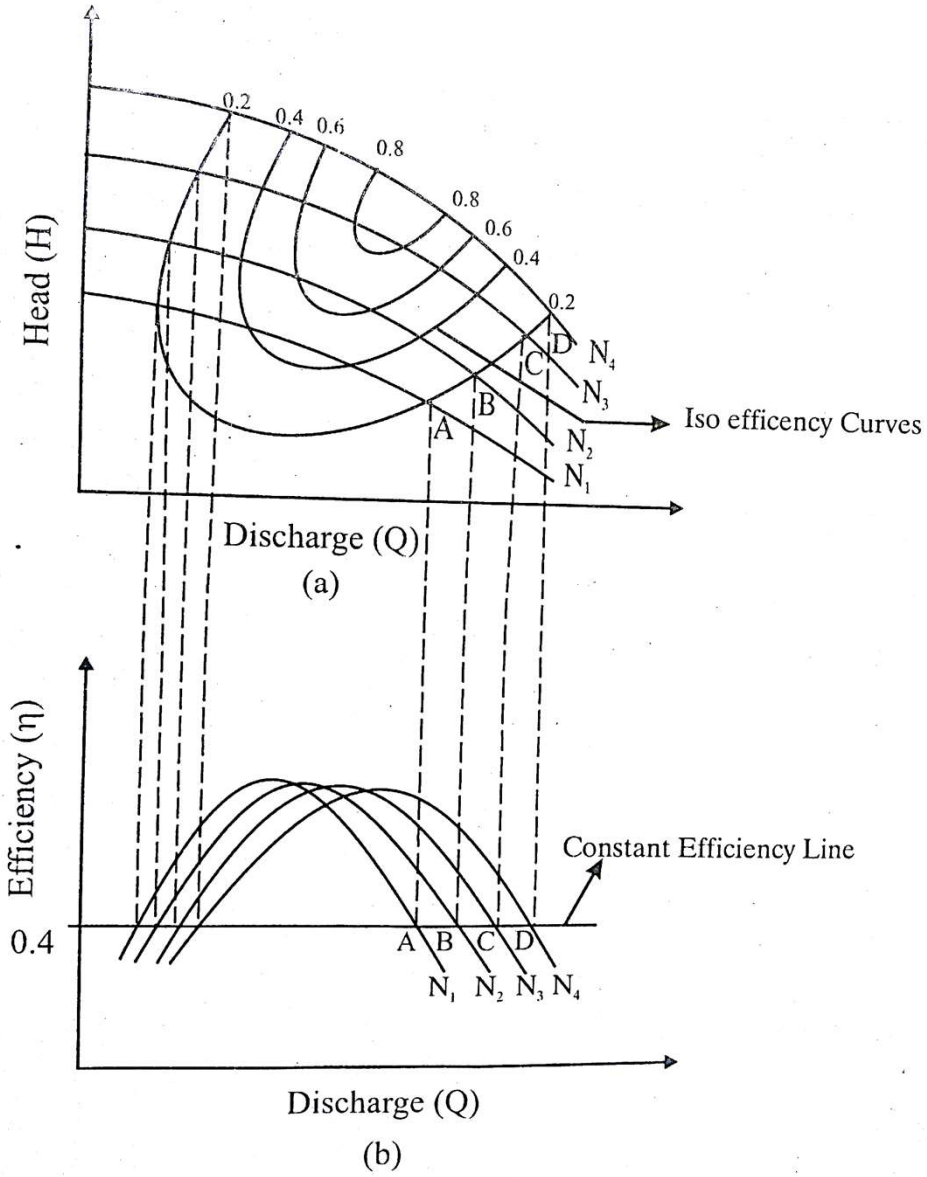
1. Main Characteristic curves



2. Operating Characteristic curves

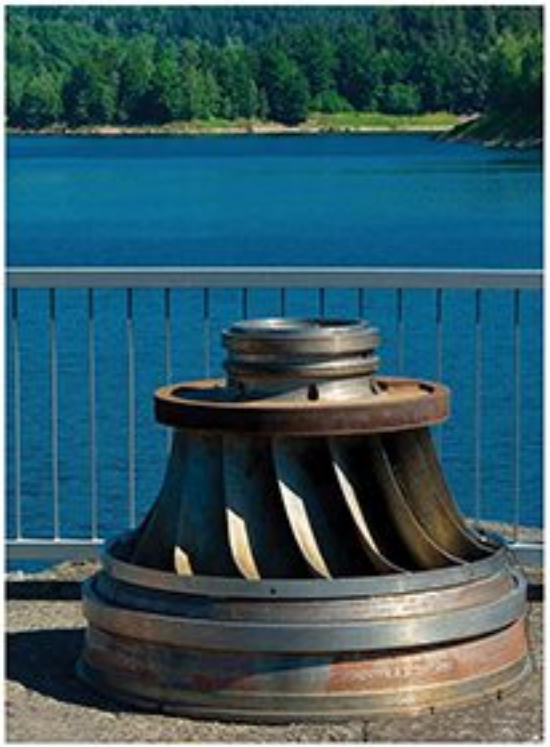


3. Constant Efficiency curves or Iso-Efficiency curves



2. Hydraulic turbines :

- Classification; Module quantities;
- Pelton wheel, Francis turbine,
- Kaplan turbine and their velocity triangles.
- Draft tubes and their function.
- Characteristics of hydraulic turbines.



Hydraulic turbine

A hydraulic turbine is a machine which converts hydraulic energy into mechanical energy. It uses the potential and kinetic energy of water and sets the rotor in motion by the dynamic action.

Classification of Hydraulic Turbines

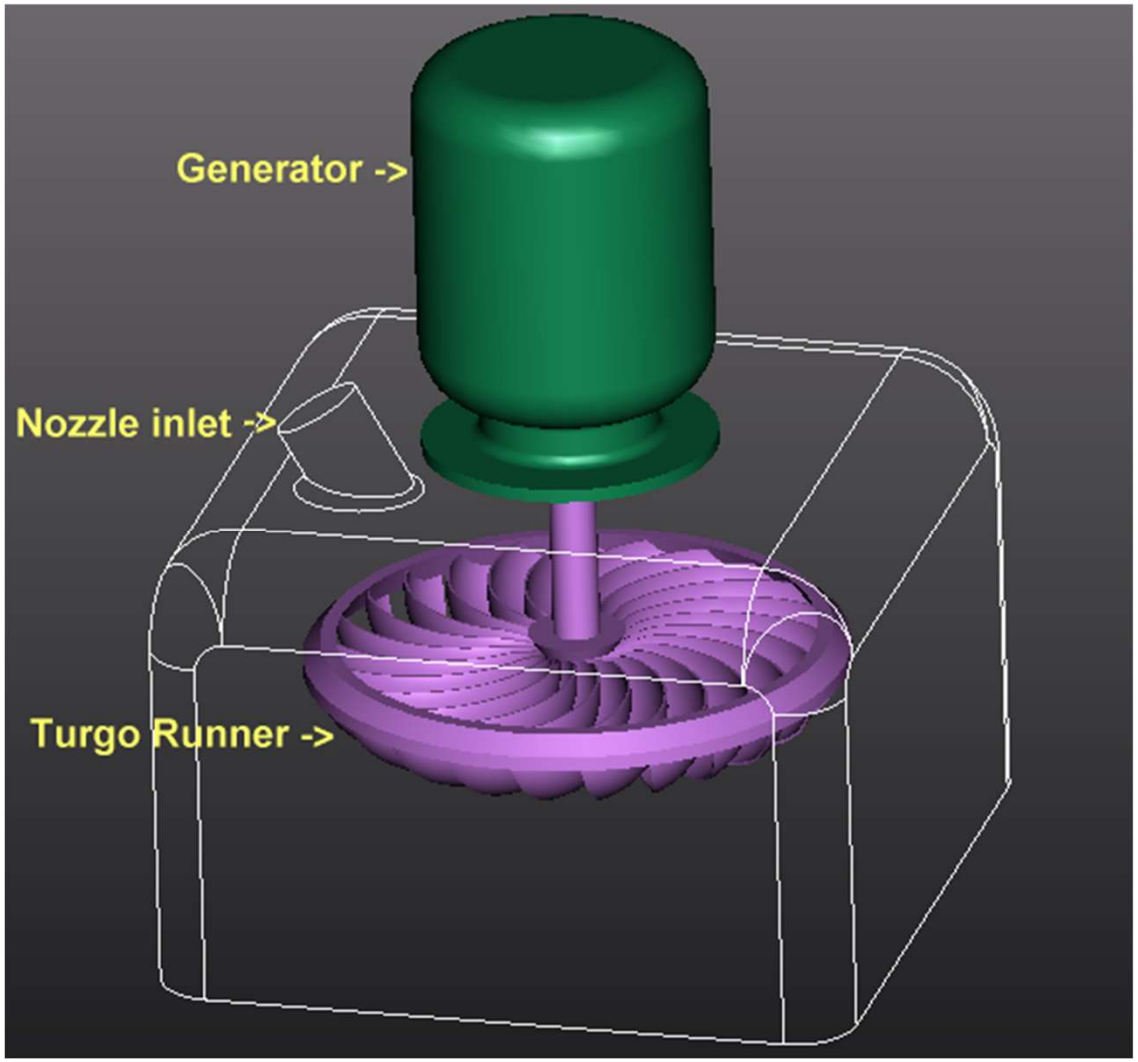
1. Based on type of energy at the inlet of turbine
   i. Impulse turbine – kinetic energy at the inlet. Eg: Pelton wheel, Turgo wheel.
   ii. Reaction Turbine – K.E and P.E at the inlet. : Tubular, Bulb, Propeller, Francis turbine.
2. Based on direction of flow of water through the runner
   i. Tangential flow: water flows in a direction tangential to the path of rotation, i.e. perpendicular to both axial and radial conditions. Eg: Pelton Wheel
   ii. Radial inward flow: Eg: Thomson, Girard and old Francis turbine.
   iii. Radial outward flow:

Classification of Hydraulic Turbines

1. Based on type of energy at the inlet of turbine
   i. Impulse turbine
      Eg: Pelton wheel
   i. Reaction Turbine
      Eg: Francis turbine
2. Based on direction of flow of water through the runner
   i. Tangential flow: Pelton wheel
   ii. Radial inward flow: Old Francis turbine
   iii. Radial outward flow
   iv. Axial flow: Kaplan turbine
   v. Mixed flow: Modern Francis turbine

3. Based on the head under which turbine works
   i. High head : Pelton wheel
   ii. Medium head : Francis turbine
   iii. Low head : Kaplan turbine
4. Based on the specific speed of the turbine
   i. Low specific speed : Pelton wheel
   ii. Medium Specific speed: Francis turbine
   iii. High specific speed: Kaplan turbine
5. Based on the position of rotating shaft
   i. Horizontal Shaft
   ii. Vertical Shaft

Turgo Wheel



Module quantities or unit quantities

The unit quantities of similar fluid machines will be equal. Hence these quantities are used to predict the performance of similar machines. The condition of the turbine under unit head are such that the efficiency of the turbine remain unaffected.

Unit speed (N_u)

It is the speed of a turbine working under unit head (1m).

$N_u = \frac{N}{\sqrt{H}}$

Unit discharge (Q_u)

It is the discharge through a turbine which is working under unit head (1m).

$Q_u = \frac{Q}{\sqrt{H}}$

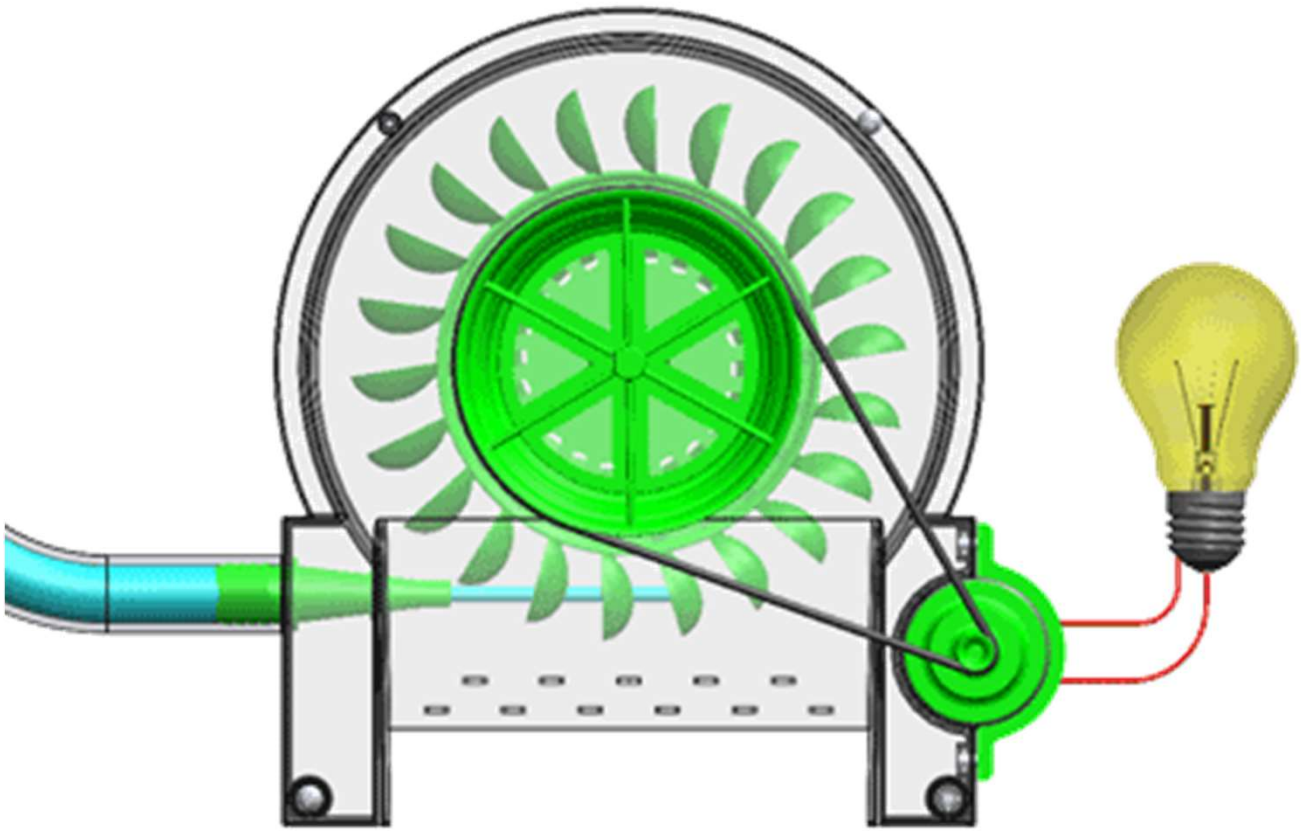
Unit Power (P_u)

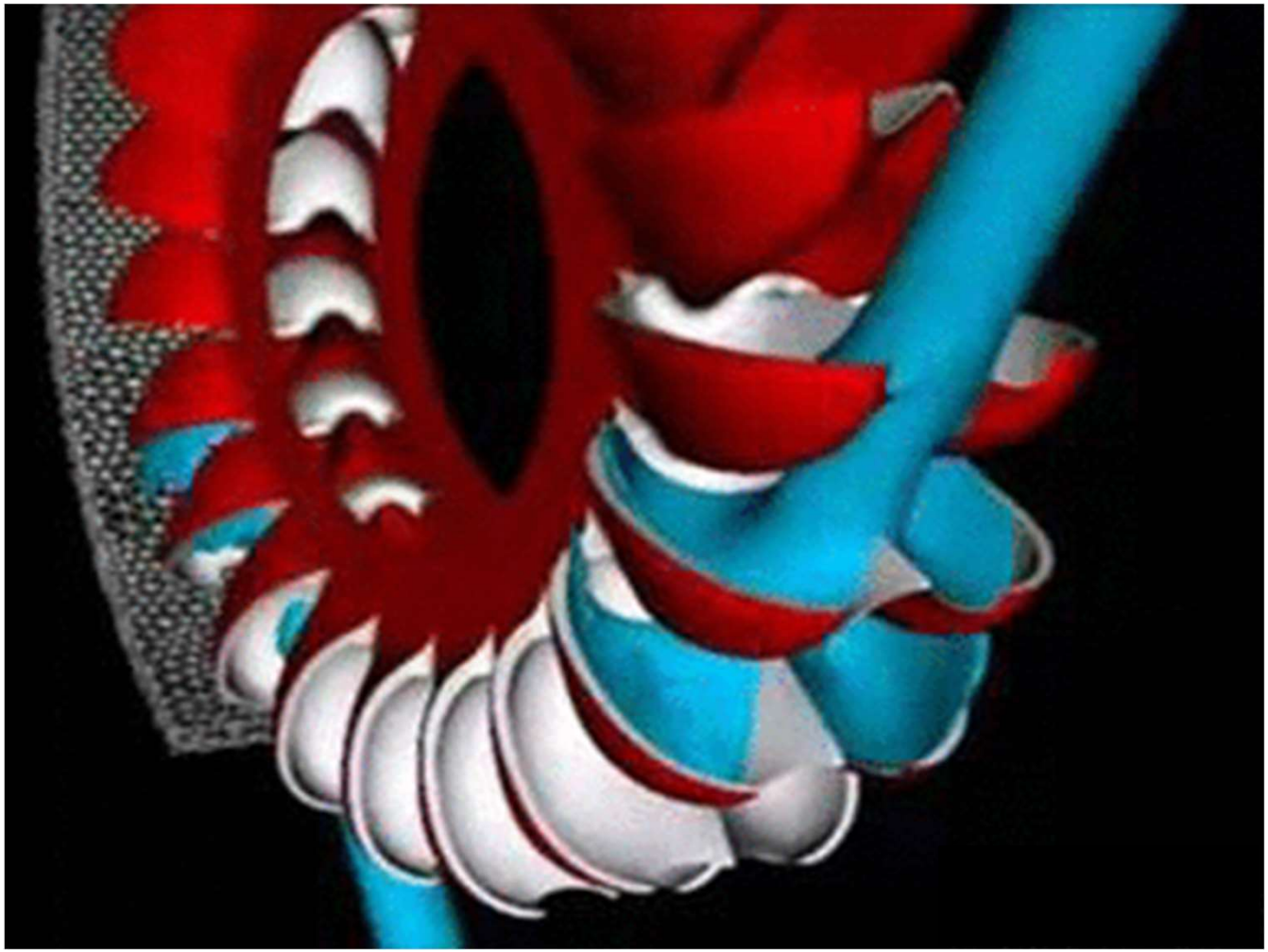
It is the power developed by a turbine which is working under unit head (1m).

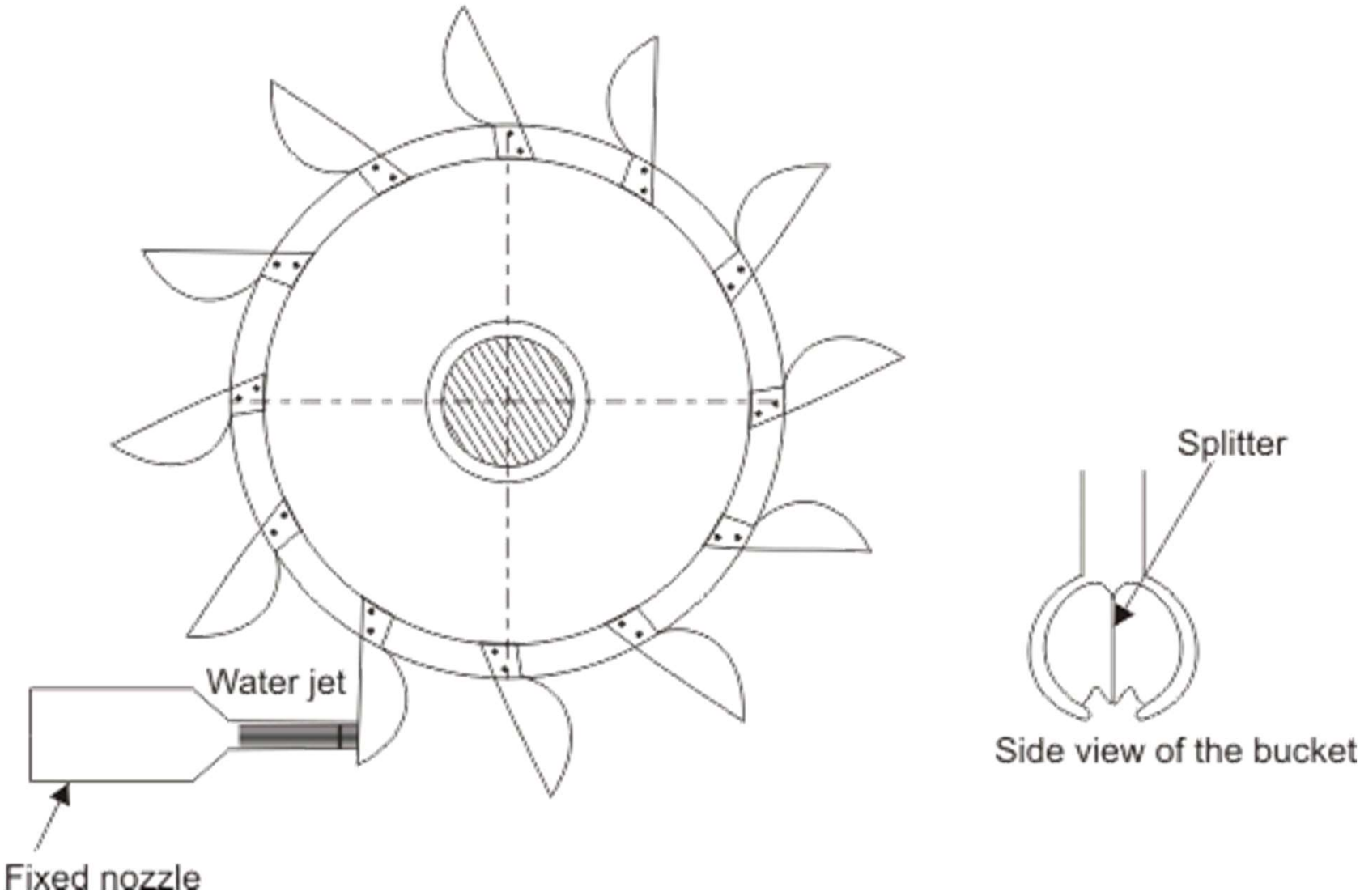
$P_u = \frac{P}{\sqrt{H^3}}$

Pelton wheel

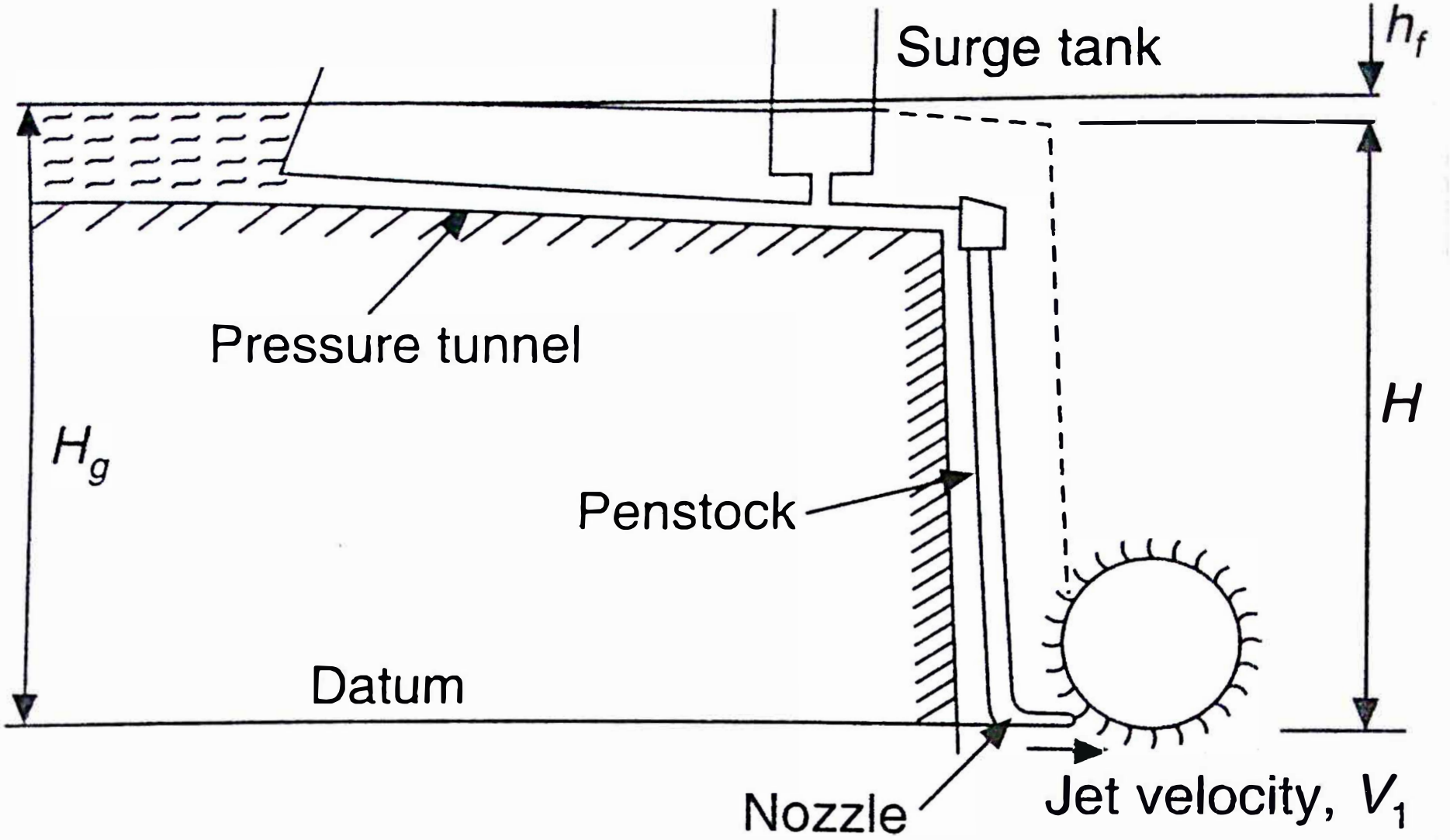
- Reaction Turbine
- Axial flow
- High head (300 to 4000m)
- Low flow rate
- High Specific speed





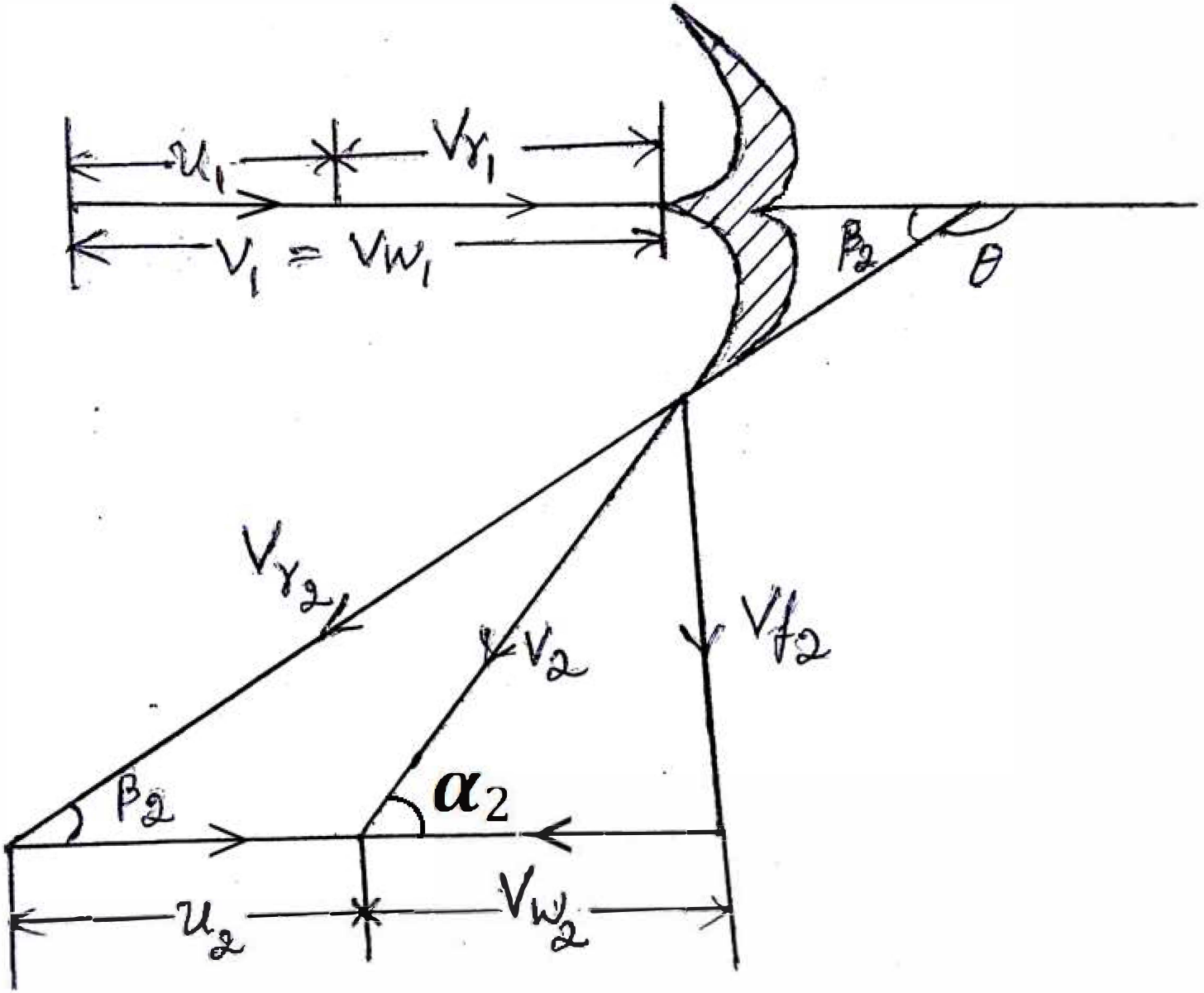

Water jet
Fixed nozzle
Splitter
Side view of the bucket

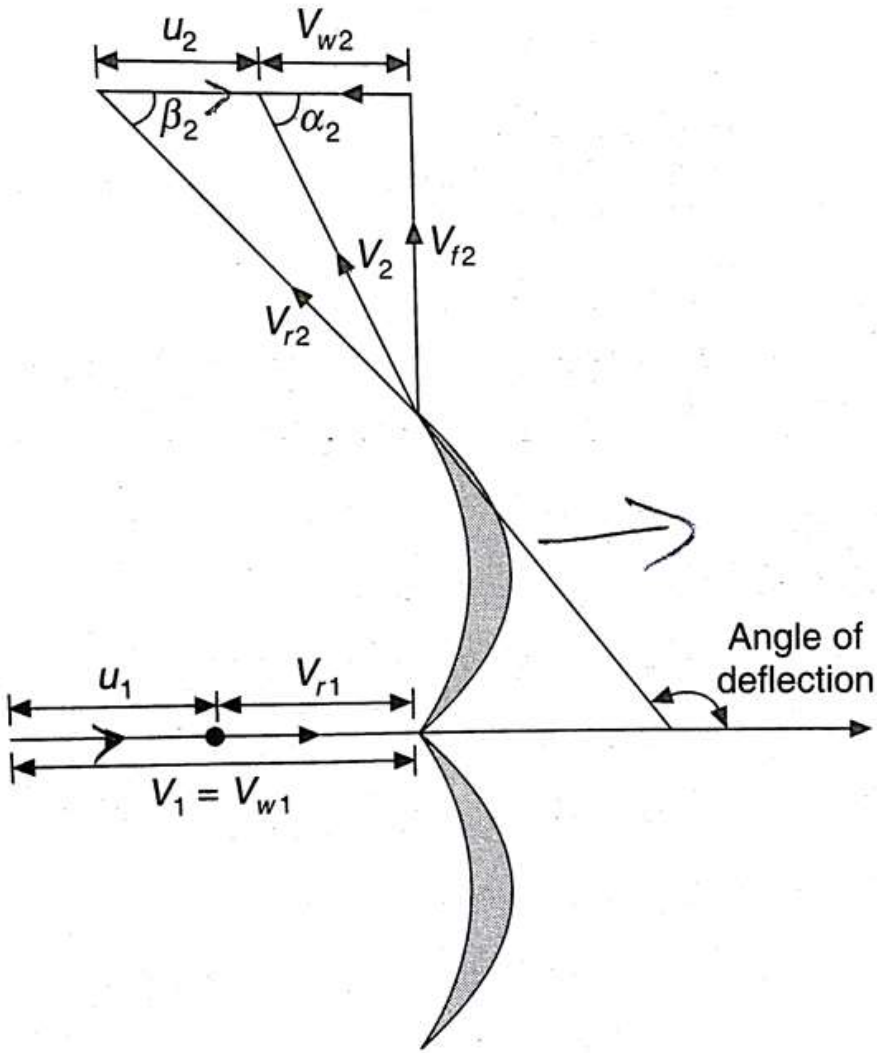
Terminology



1. Gross Head (H_g)
2. Net or effective head (H)
3. Pipe losses(h_f)
4. Head available at nozzle inlet (H)
5. Head available at nozzle outlet (h_{NO})
6. Pipe line transmission efficiency($\boldsymbol{\eta}_{trans}$)
7. Nozzle efficiency($\boldsymbol{\eta}_{nozzle}$)
8. Nozzle velocity coefficient(C_v)

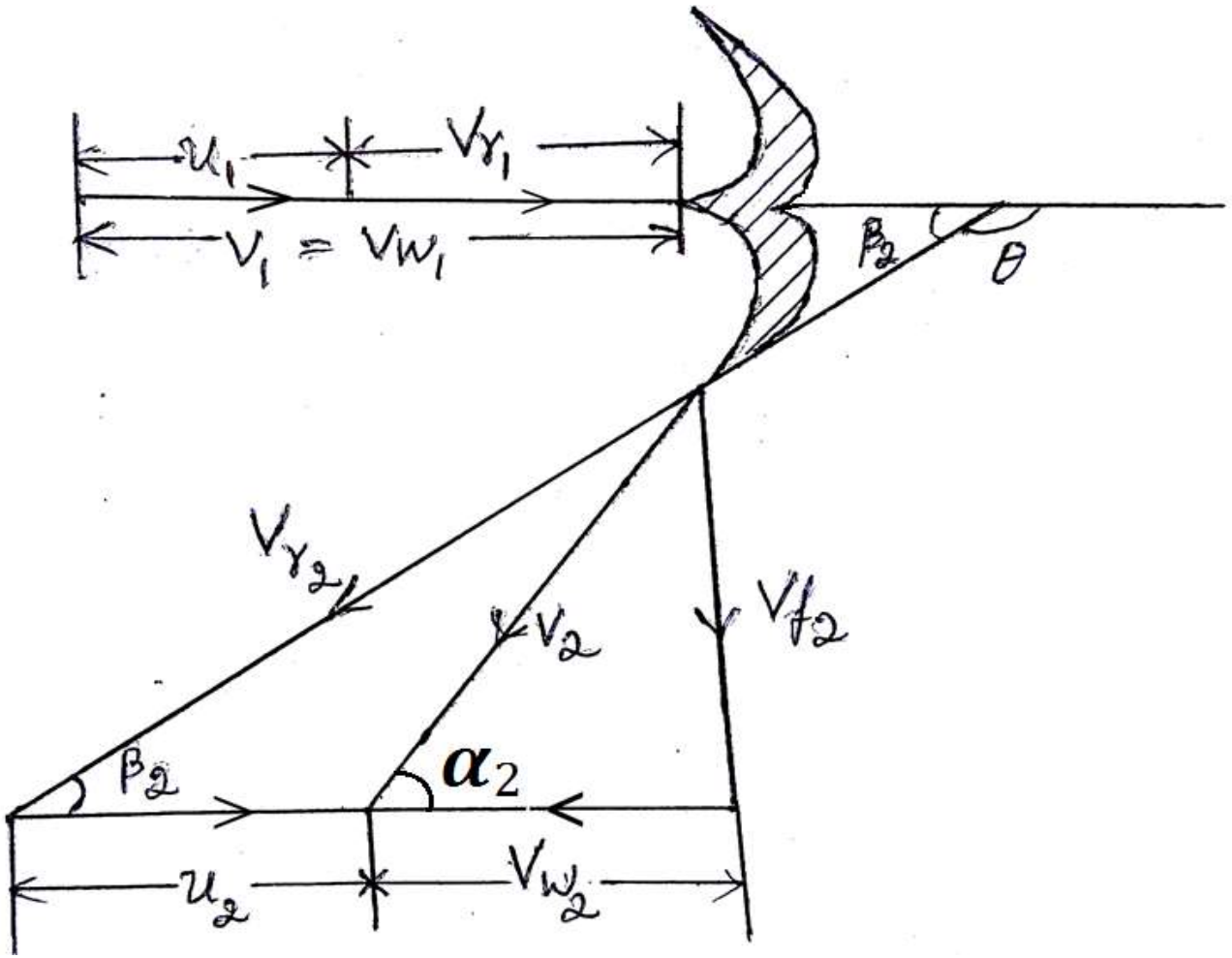
Velocity Triangle





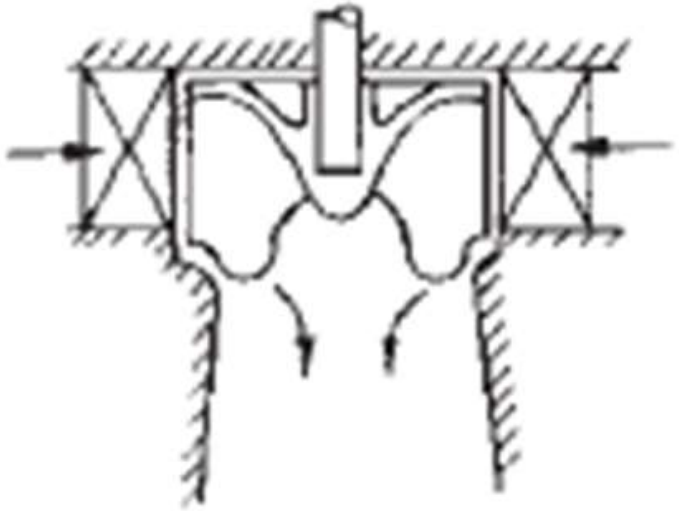
Velocity triangles for a Pelton wheel.

Work Done by Pelton Wheel

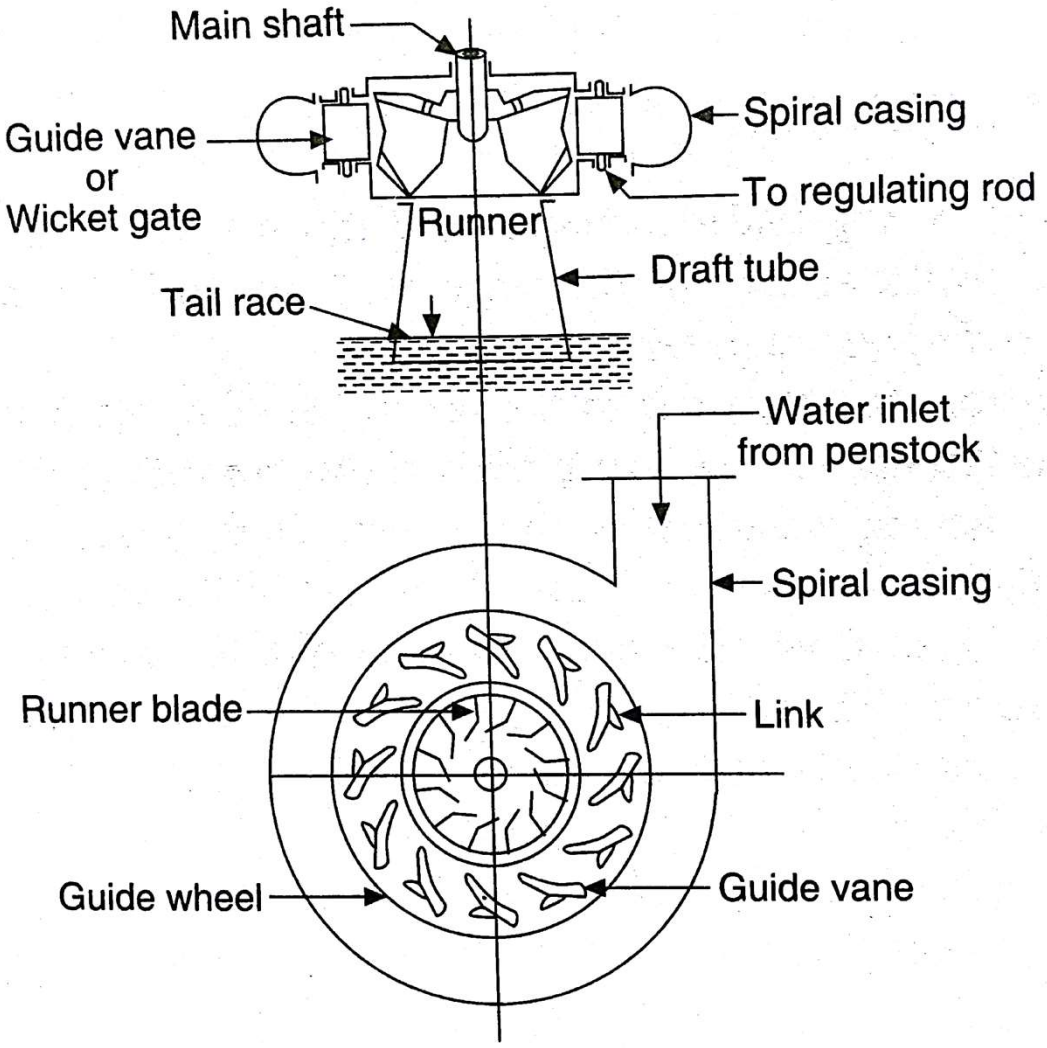


Francis Turbine

- Reaction Turbine
- Mixed flow
- Medium head
- Medium Flow rate
- Medium Specific speed



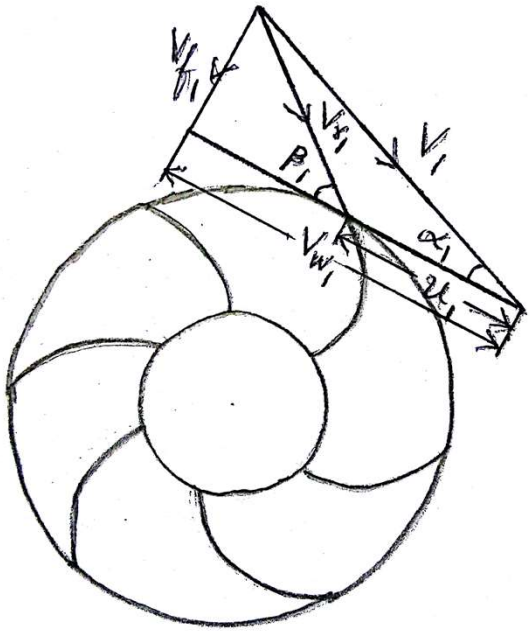
Francis Turbine

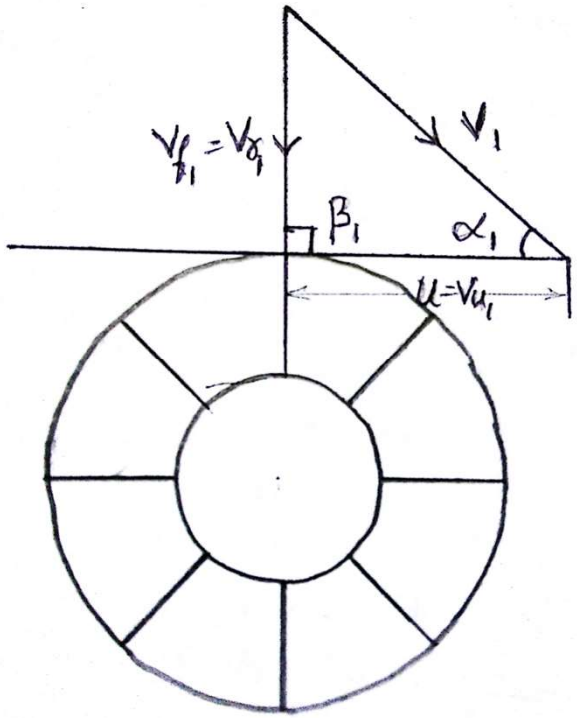


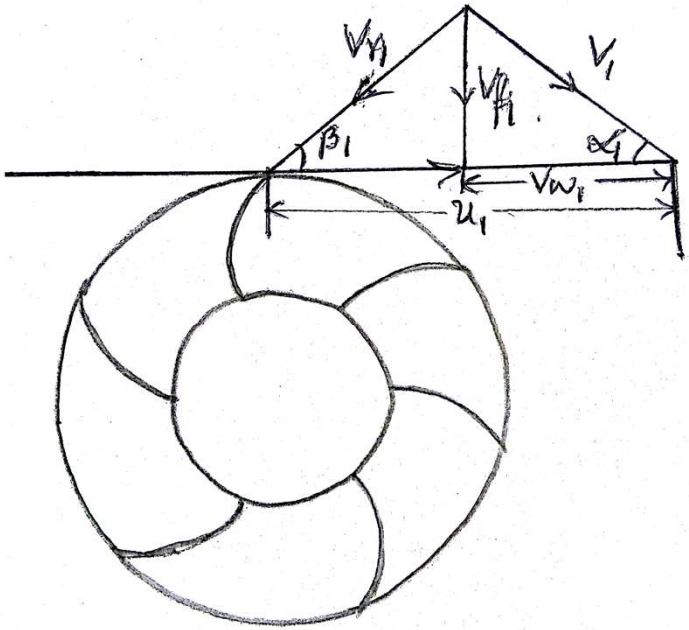
Francis turbine and its main components

Velocity triangles at inlet for various types of Francis Turbine

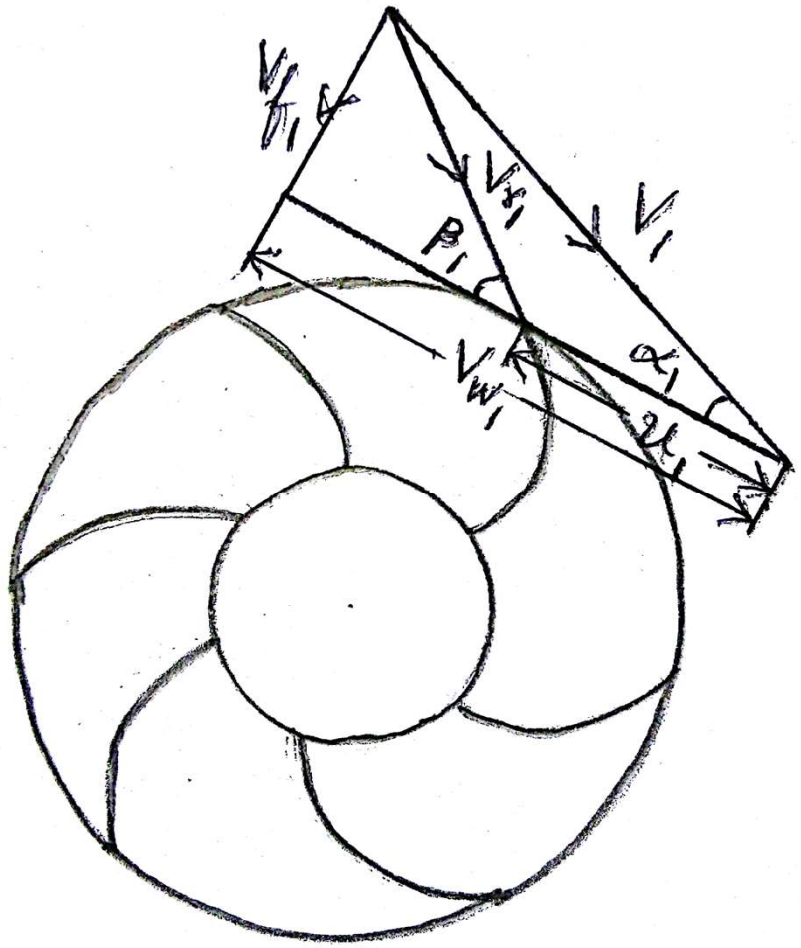
1. Low specific speed runner
2. Normal specific speed runner
3. High specific speed runner


V_{f_1}
V_{θ_1}
V_1
β_1
V_{w_1}
α_1
u_1

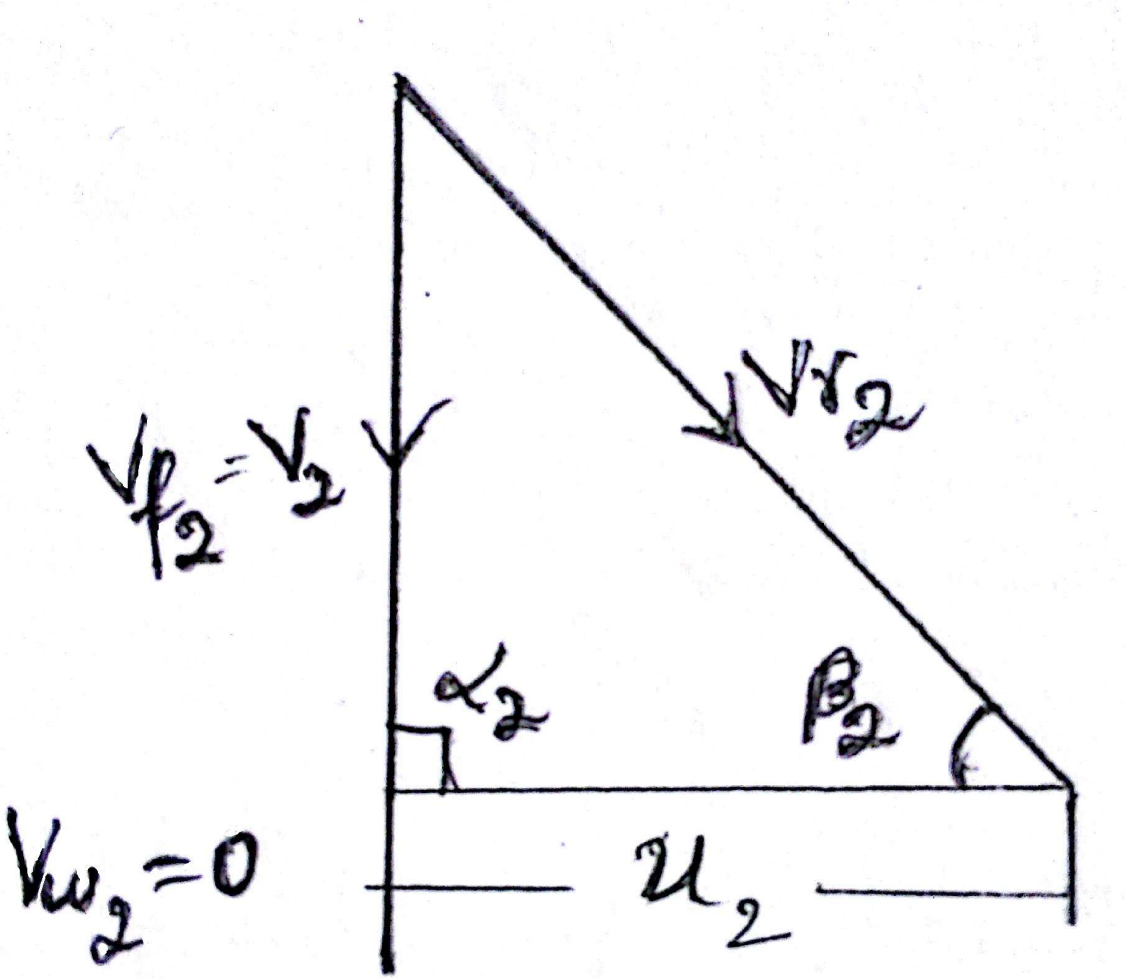

$V_{f_1} = V_{\theta_1}$
V_1
β_1
α_1
$u = V_{u_1}$

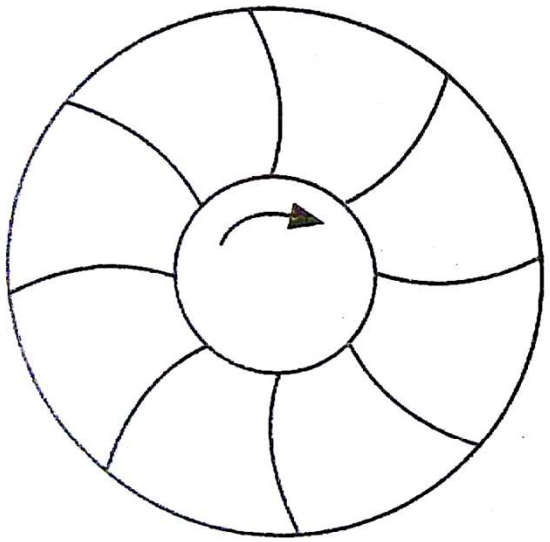

V_{f_1}
V_{f_1}
V_1
β_1
α_1
V_{w_1}
u_1

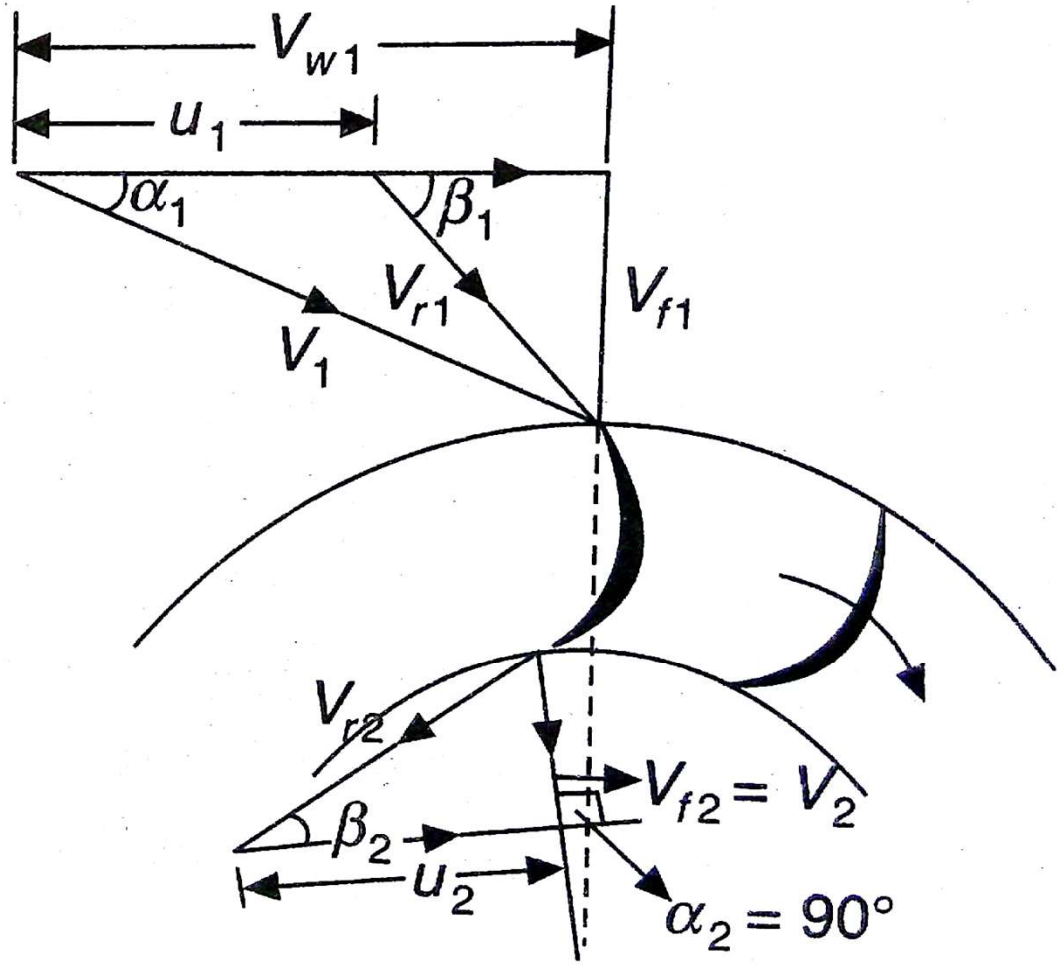
Velocity Triangle at the inlet



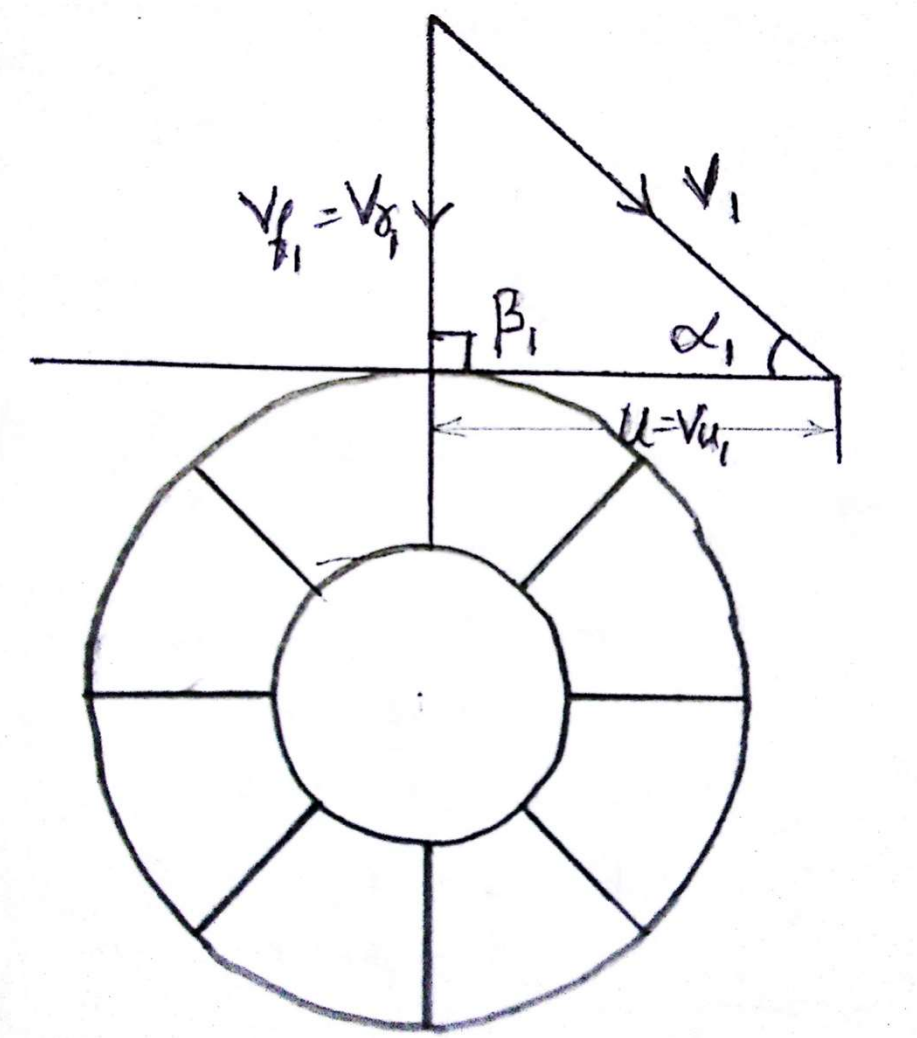
Velocity Triangle at the outlet



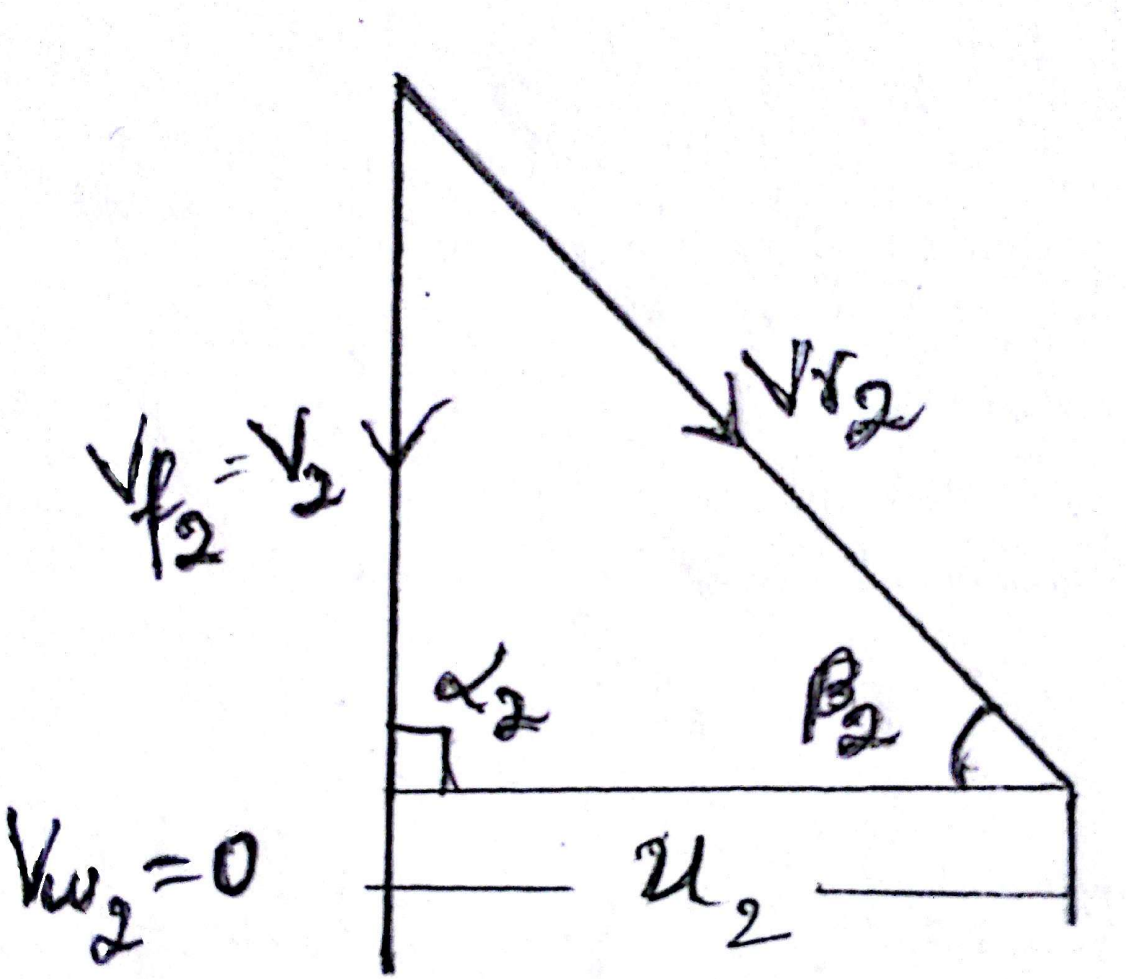


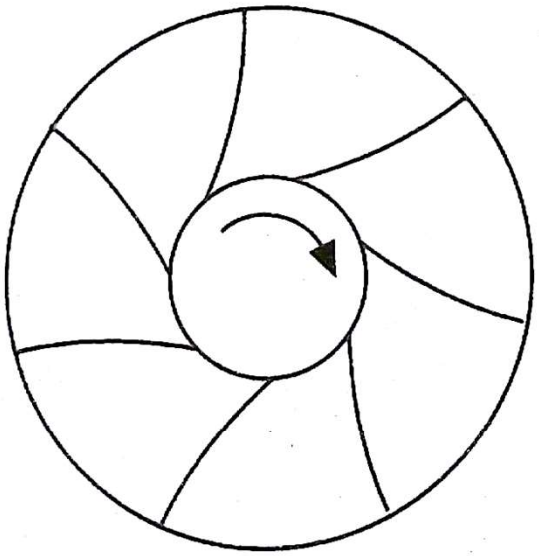

V_{w1}
u_1
α_1
β_1
V_{r1}
V_{f1}
V_1
V_{r2}
$V_{f2} = V_2$
β_2
u_2
$\alpha_2 = 90°$

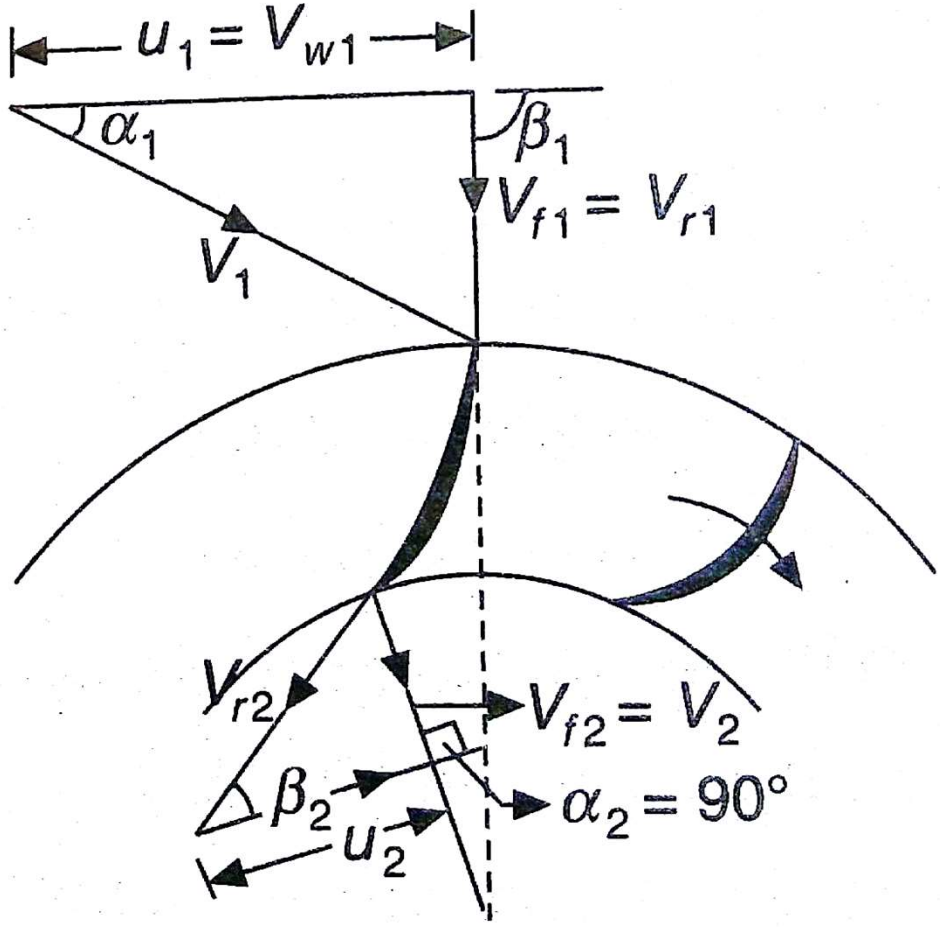
Velocity Triangle at the inlet



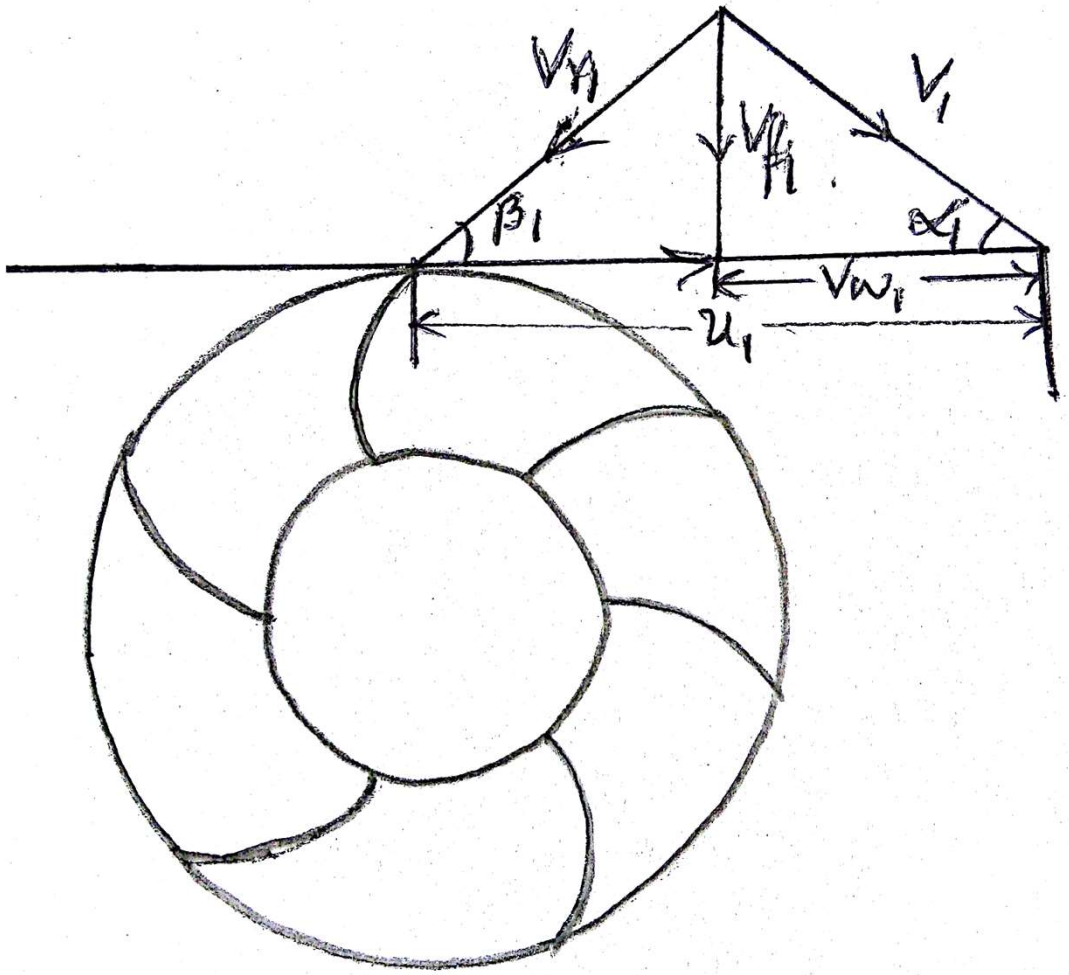
Velocity Triangle at the outlet



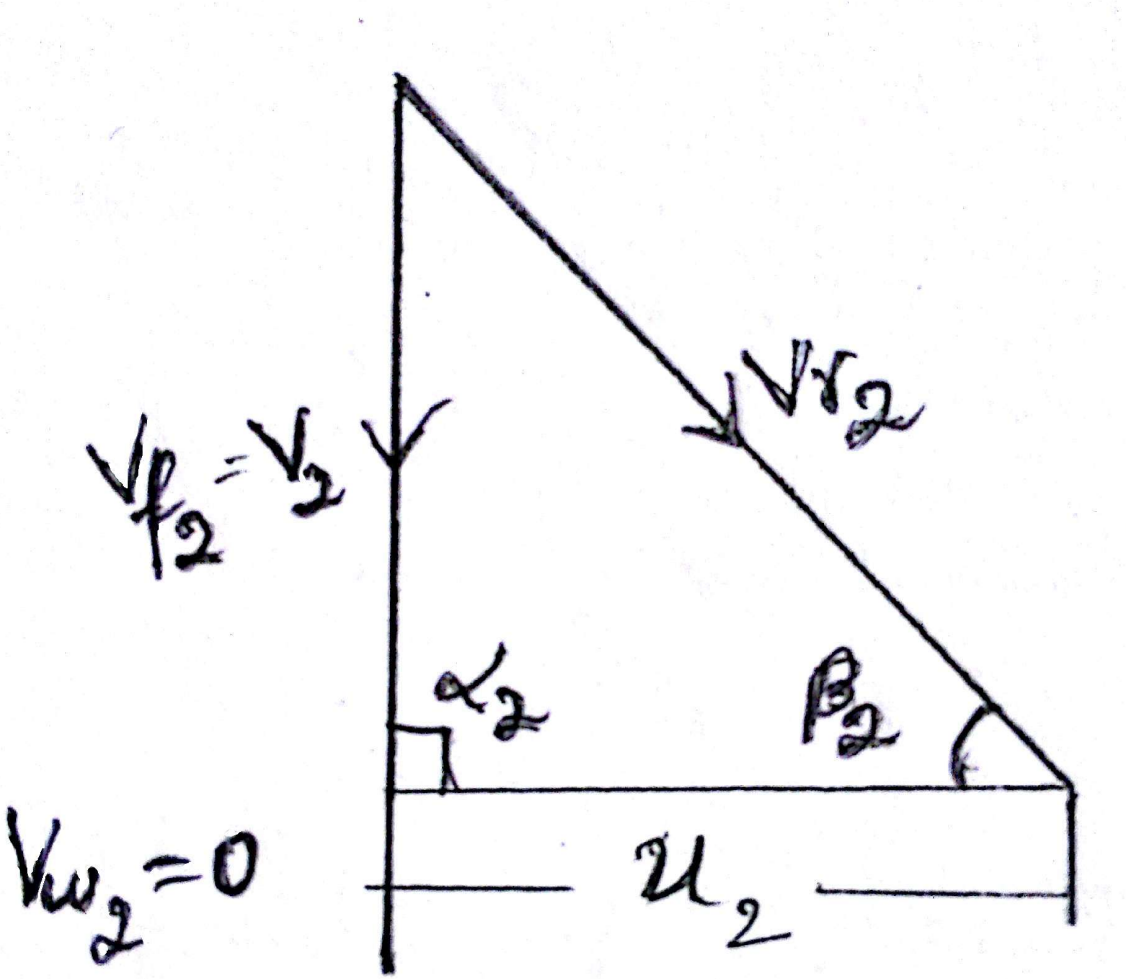


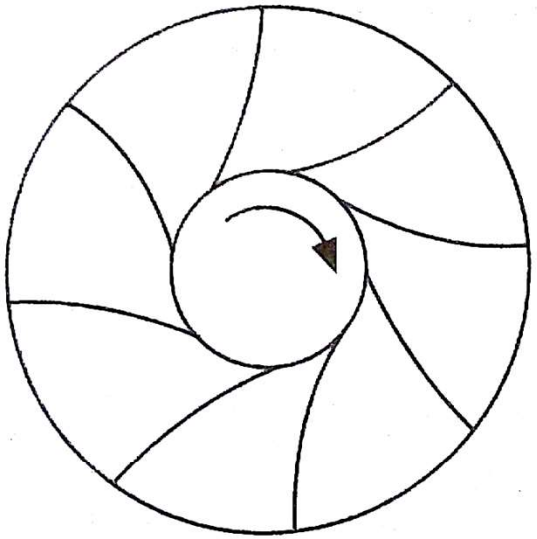

$u_1 = V_{w1}$
α_1
β_1
$V_{f1} = V_{r1}$
V_1
V_{r2}
$V_{f2} = V_2$
β_2
$\alpha_2 = 90°$
u_2

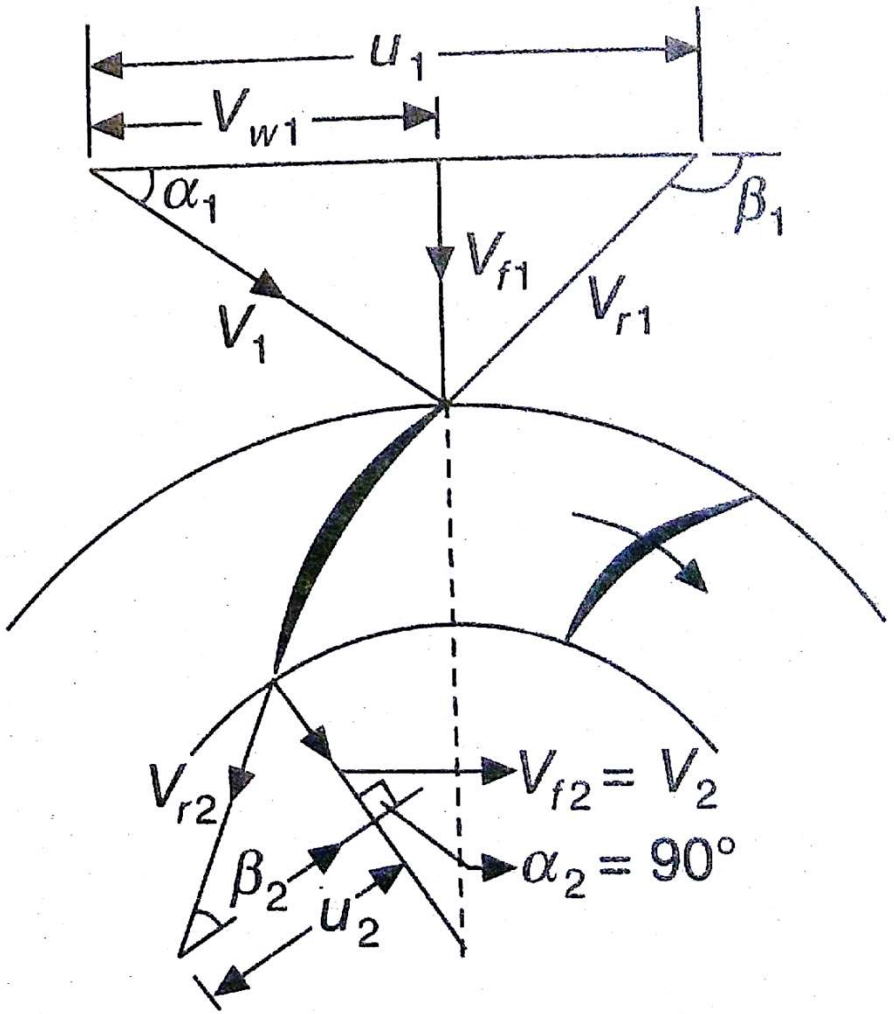
Velocity Triangle at the inlet



Velocity Triangle at the outlet

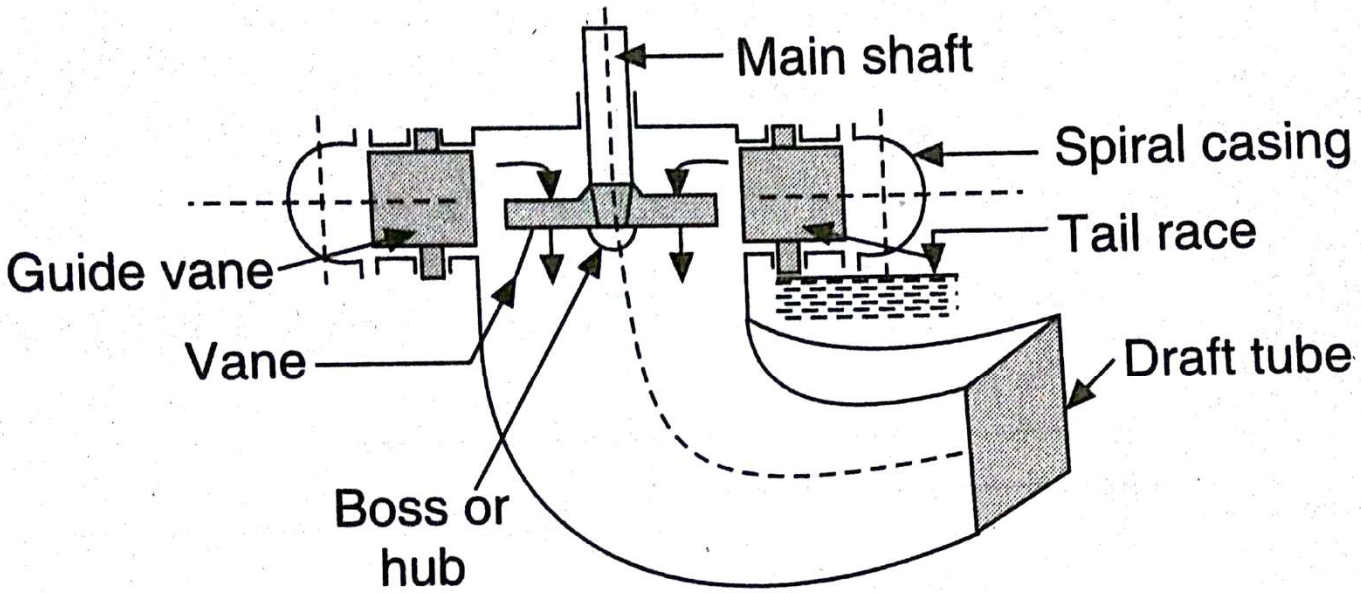


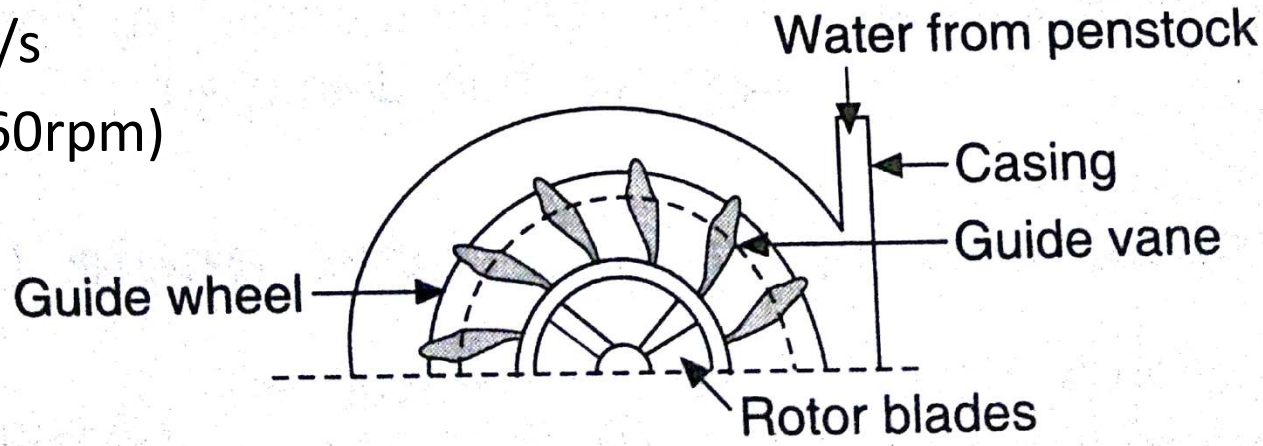


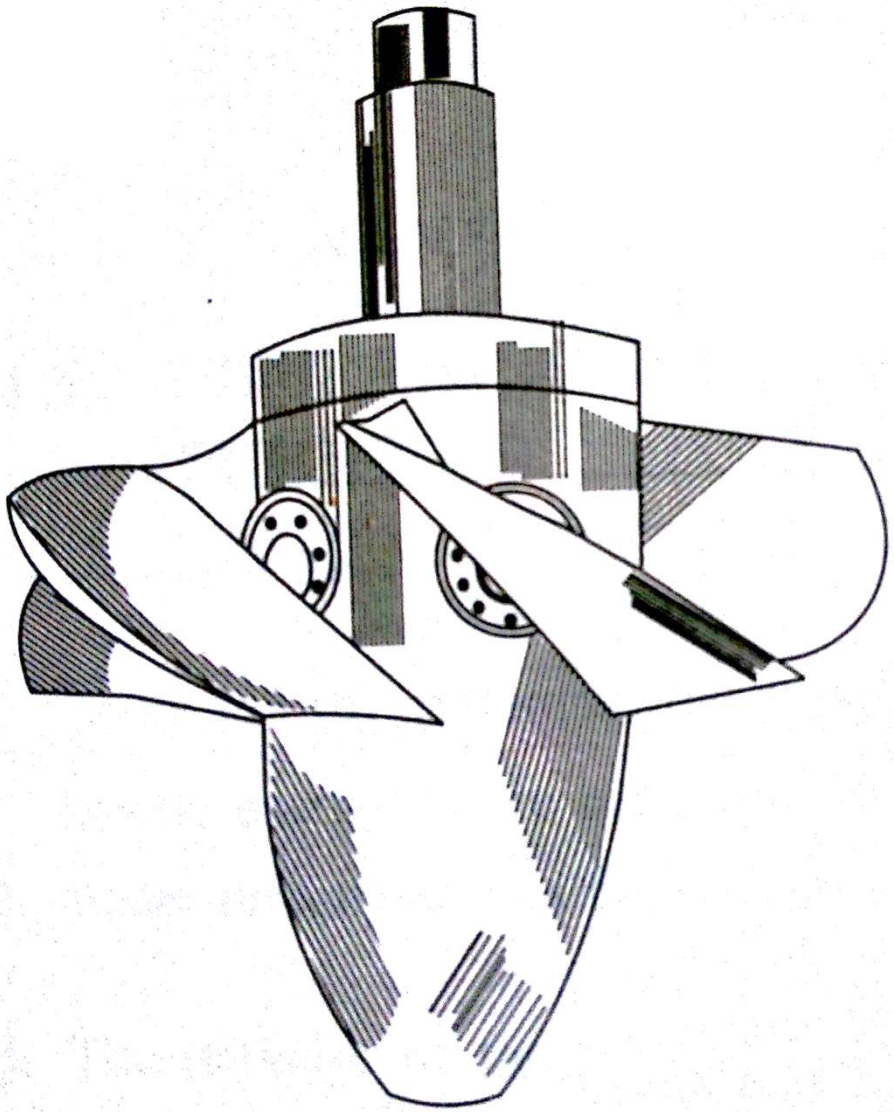

u_1
V_{w1}
α_1
β_1
V_{f1}
V_{r1}
V_1
V_{r2}
$V_{f2} = V_2$
$\alpha_2 = 90°$
β_2
u_2

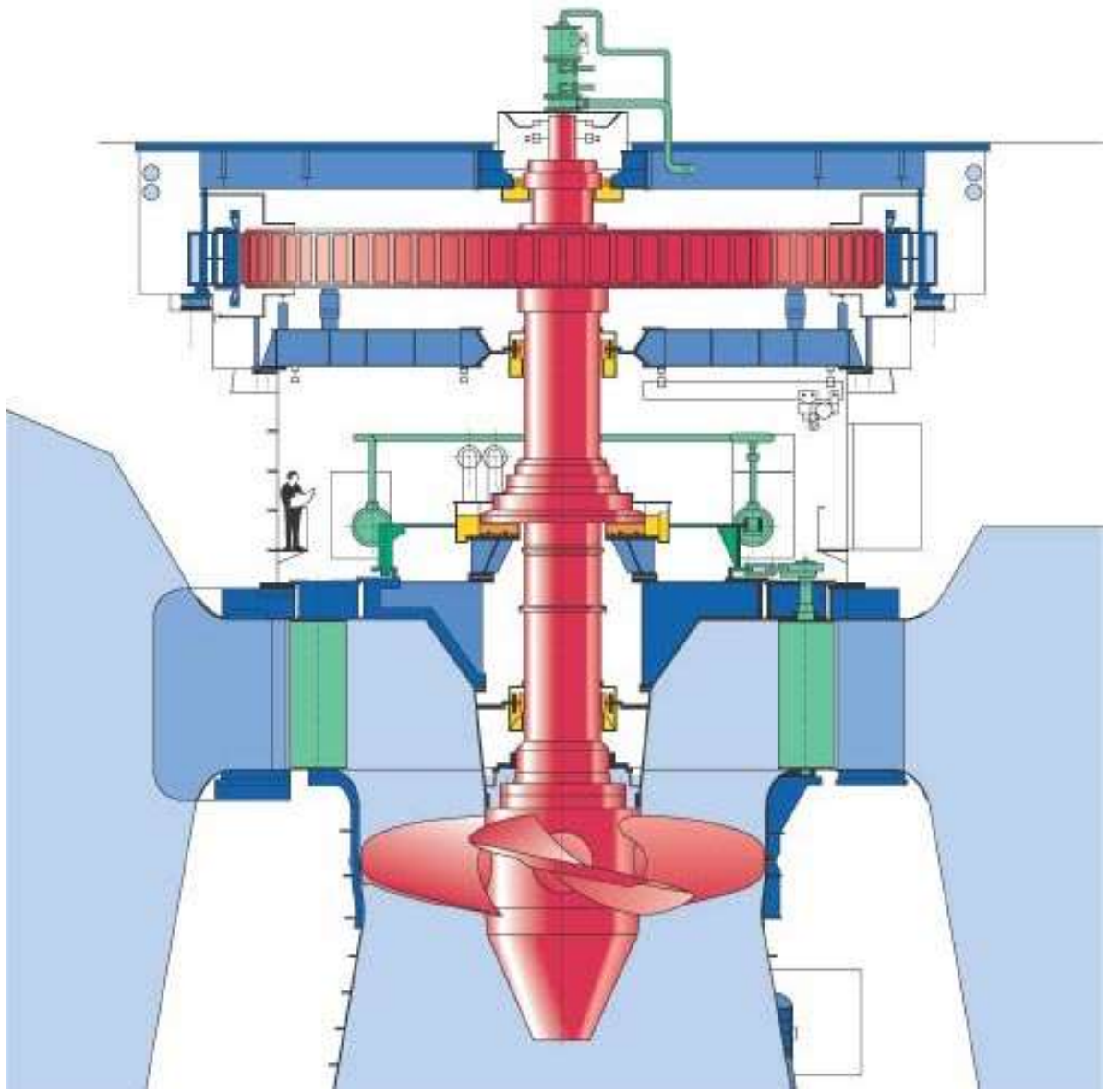
Kaplan Turbine

- Reaction Turbine
- Axial flow
- Low head (2.5 to 50m)
- High water flow (70 to 800m^3/s
- High Specific speed (255 to 860rpm)

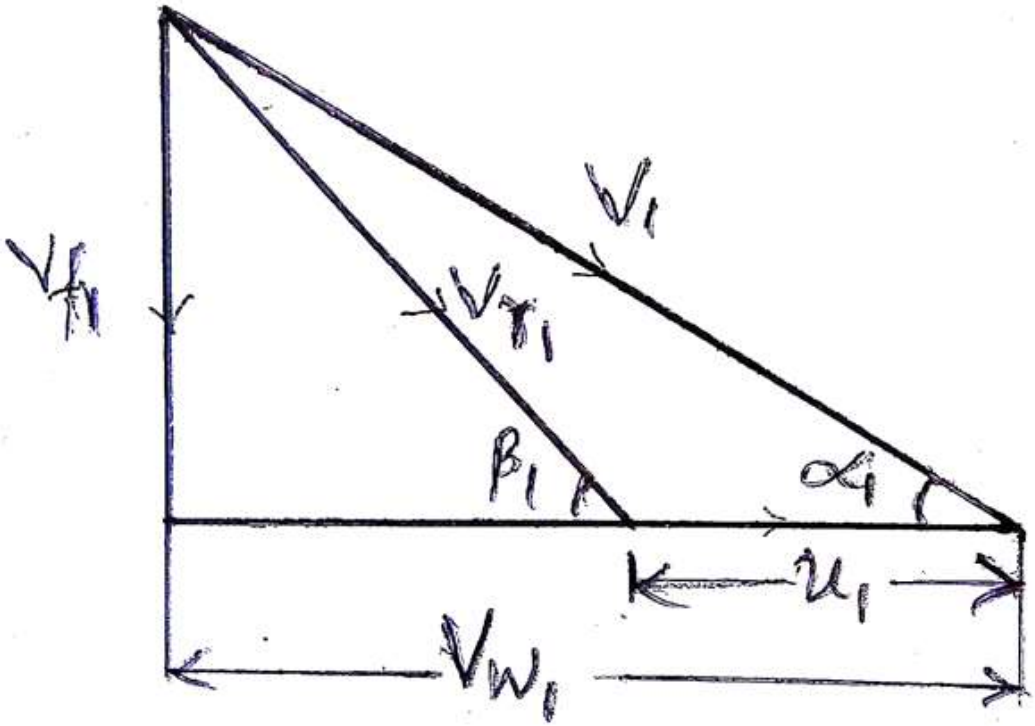




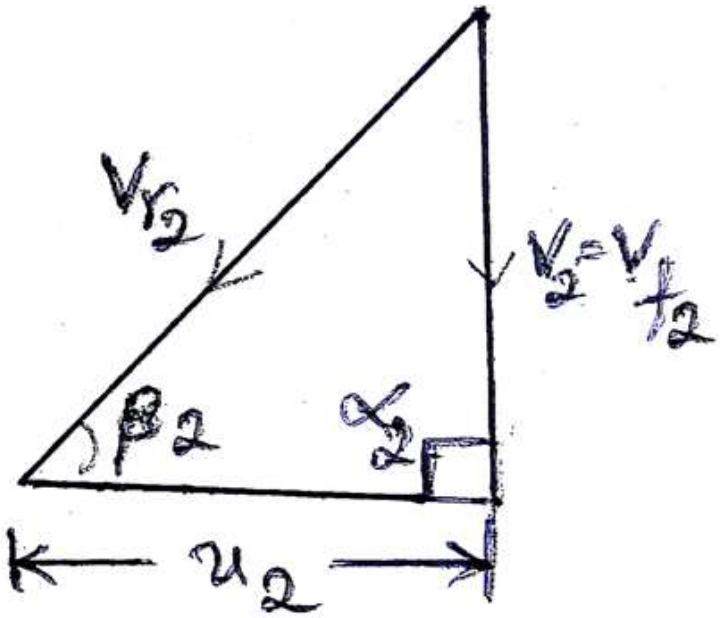




Velocity triangle for Kaplan Turbine



Inlet Velocity Triangle



Outlet Velocity Triangle

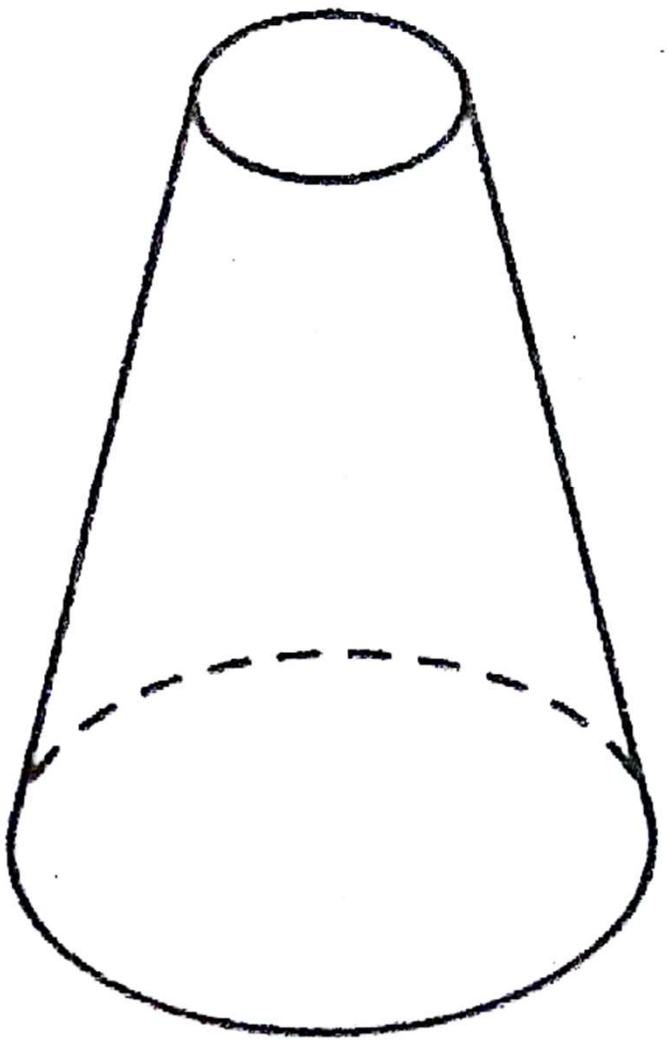
Draft Tube

Draft tube is an integral part of reaction turbines.

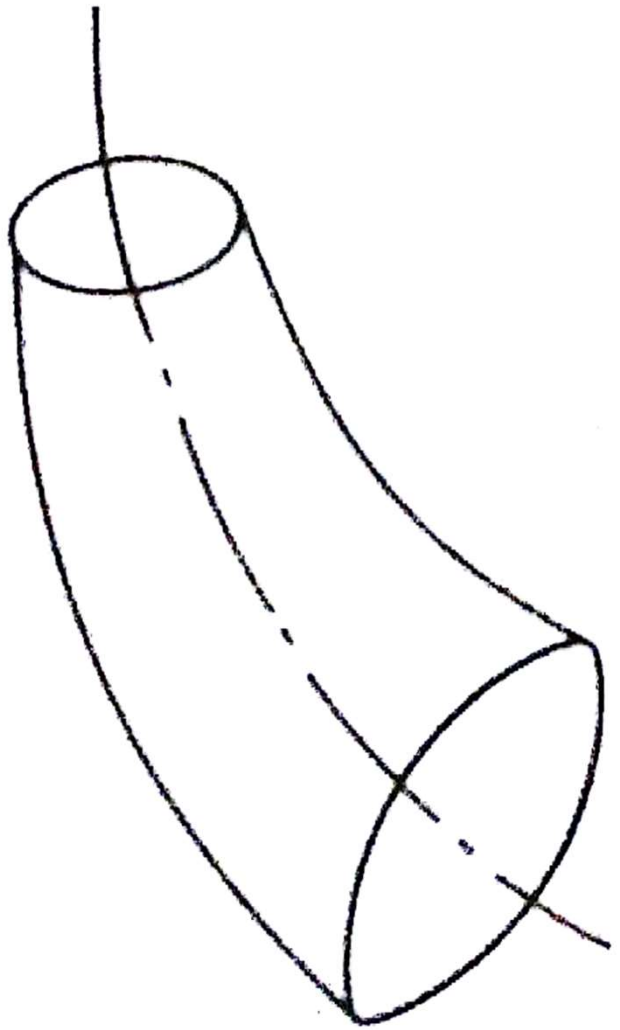
The main functions of draft tube are,

Types of draft tubes

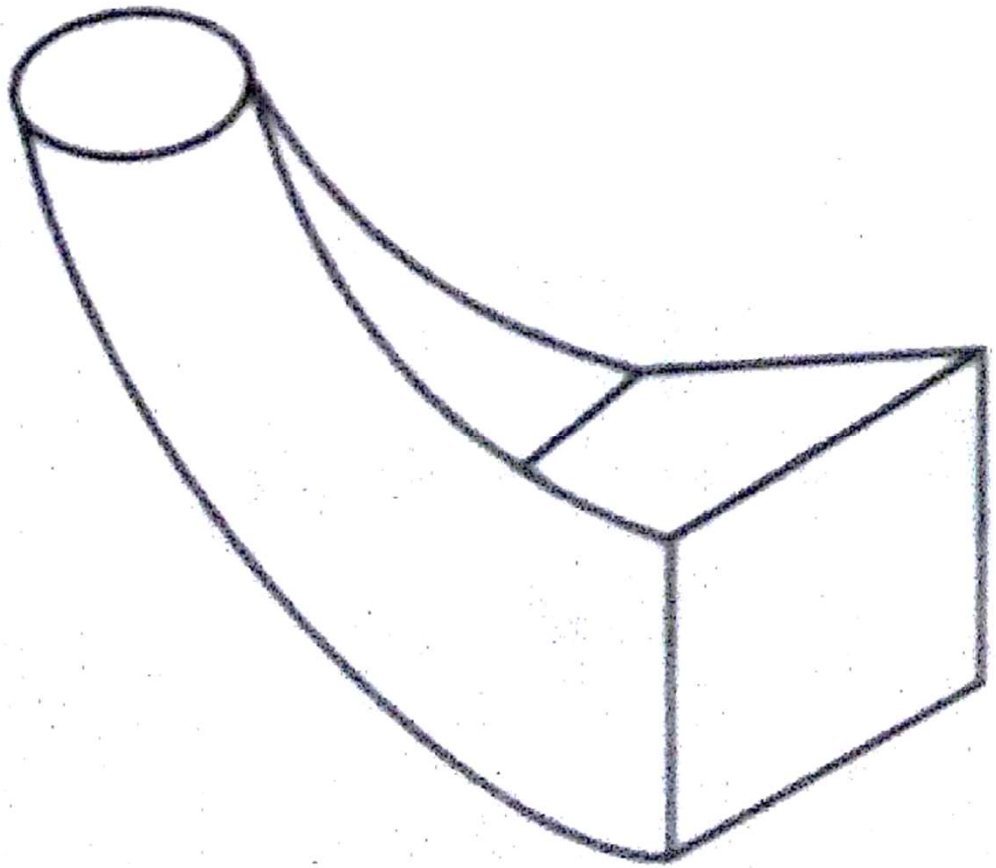
Conical type



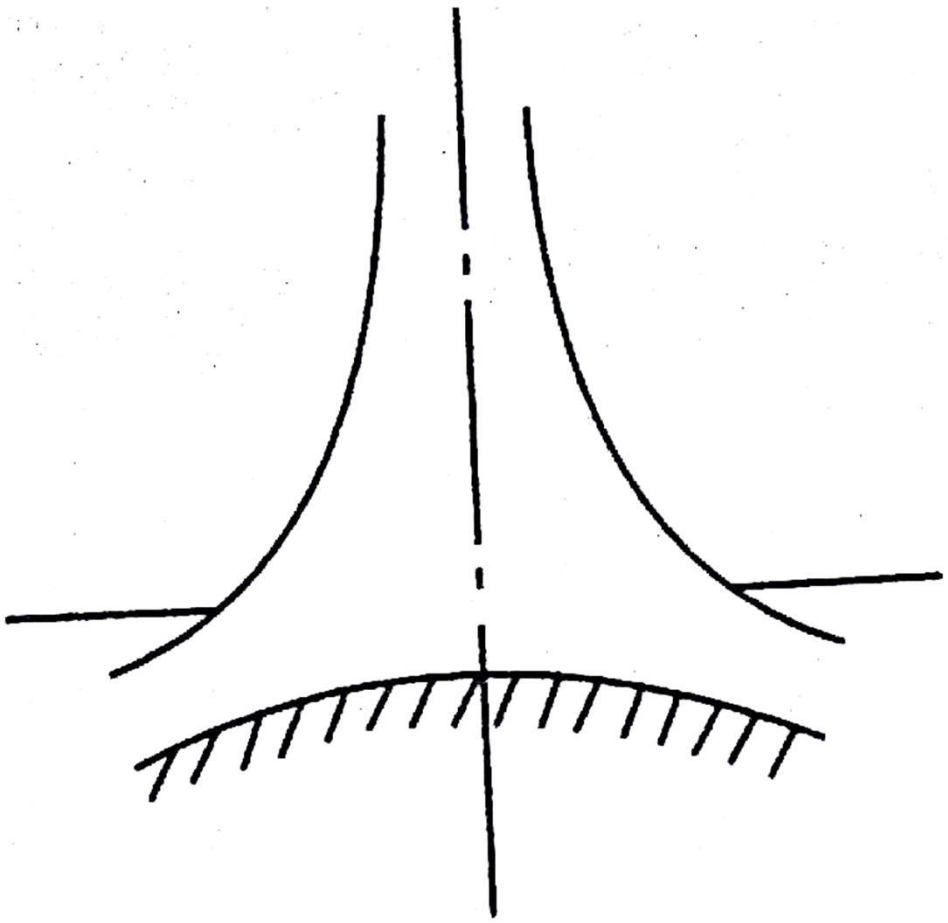
Simple elbow type



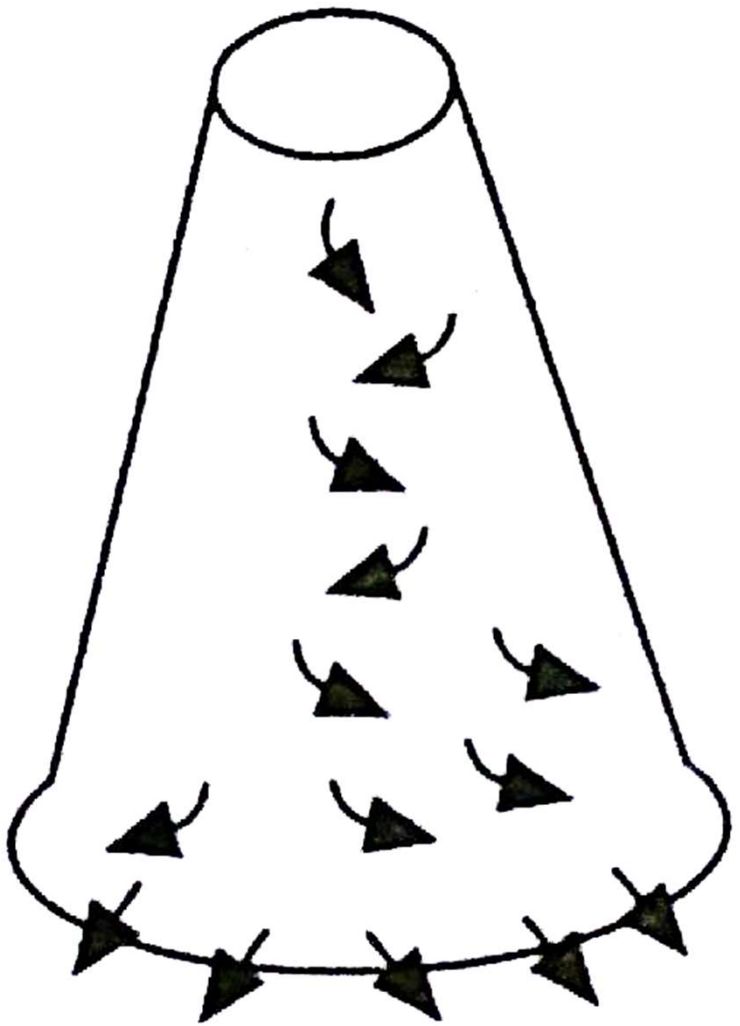
Elbow having circular cross section at inlet and rectangular cross section at outlet.



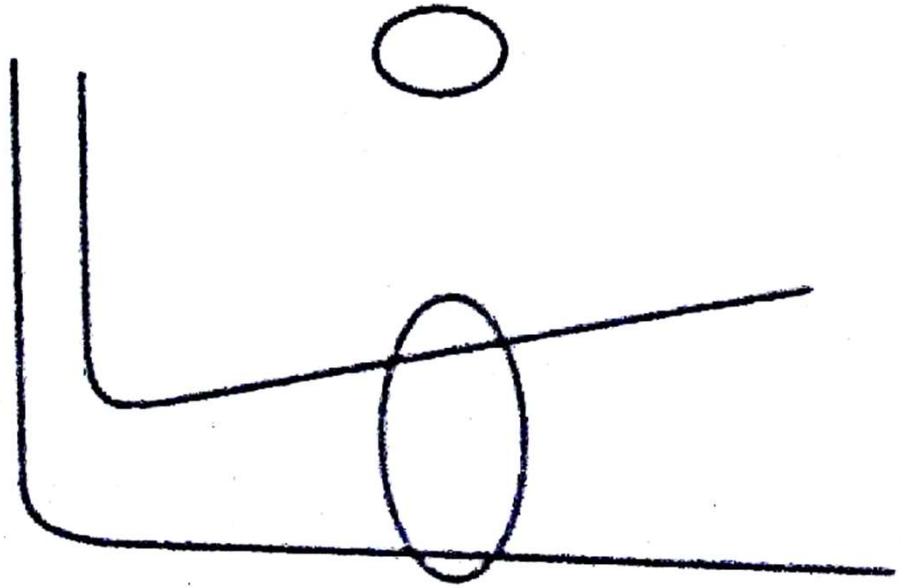
Moody spreading or hydrocone



Bell Mouthed conical draft tube



Elbow type having circular sections at inlet and outlet



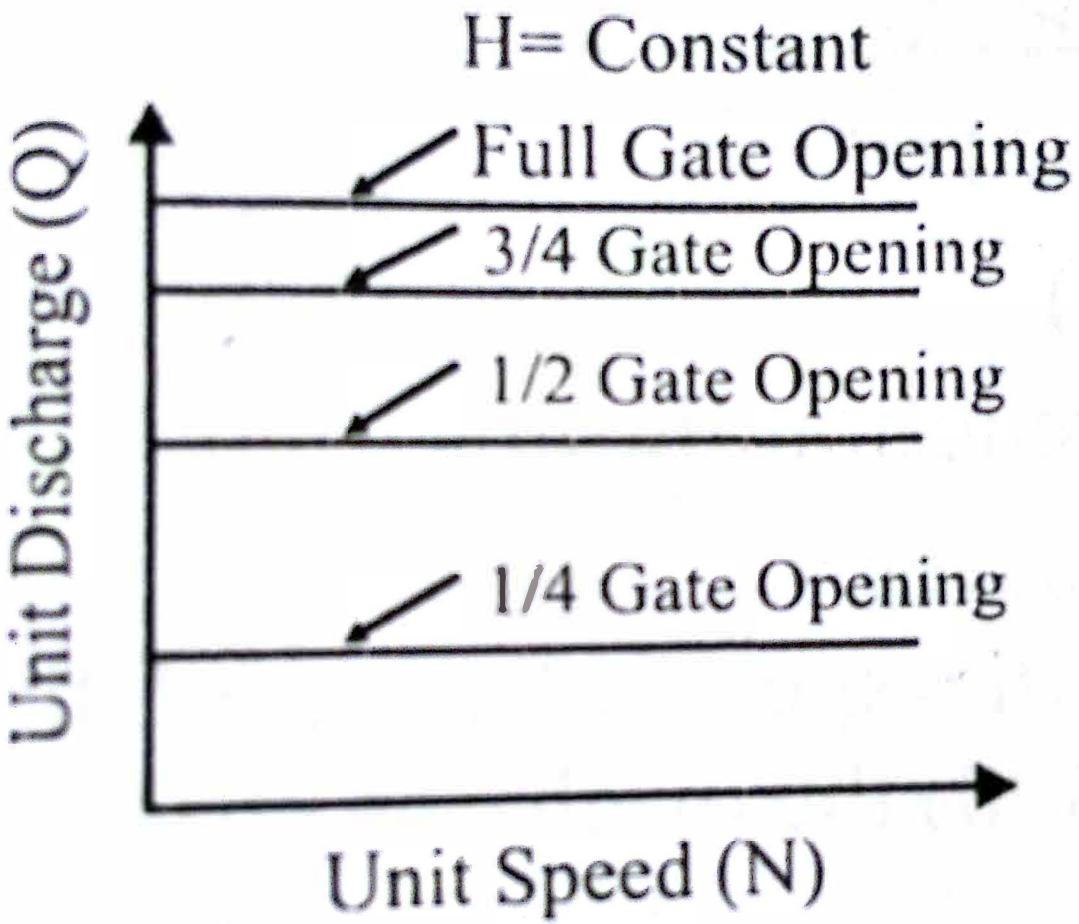
Characteristics of hydraulic turbines

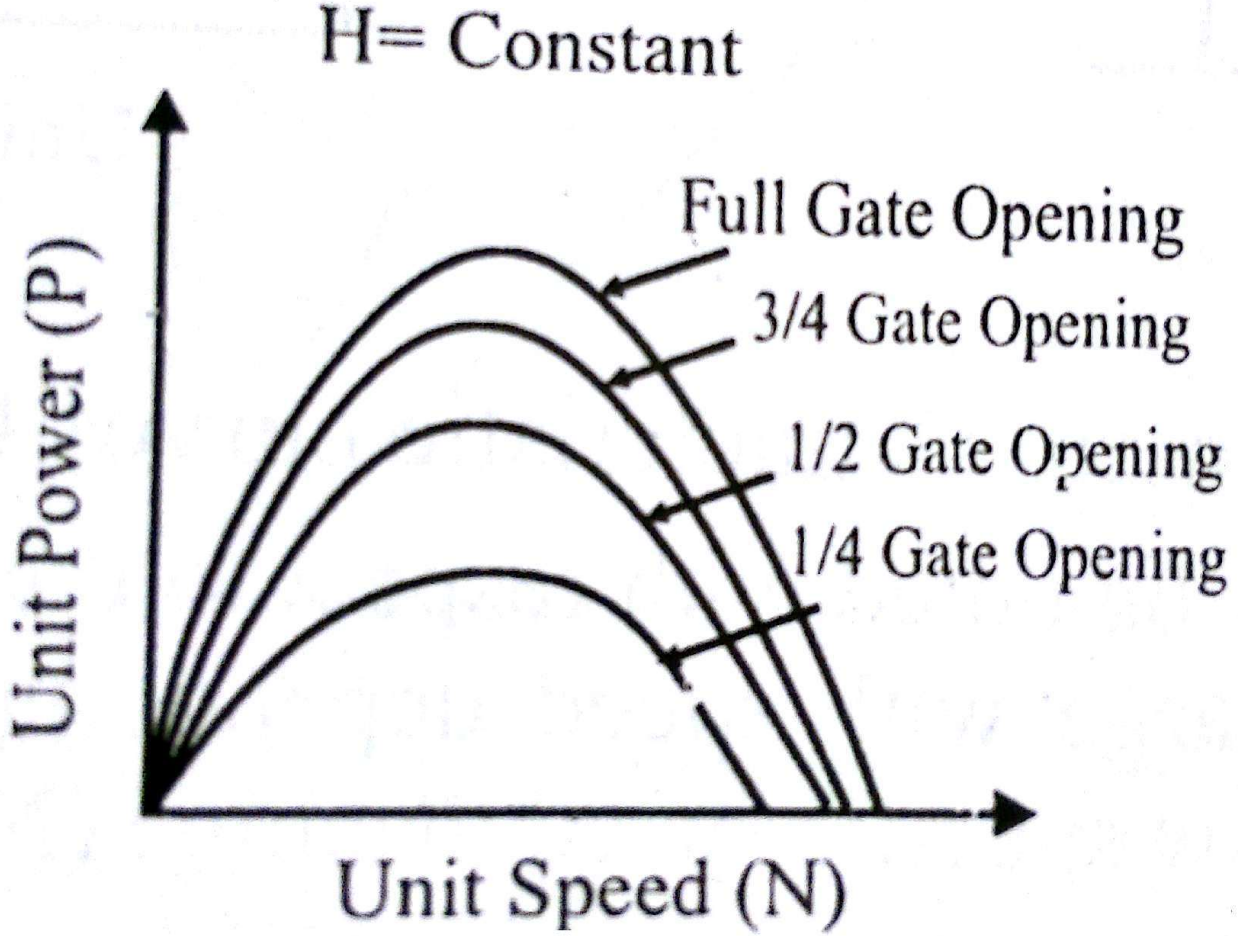
1. Main Characteristic curves
2. Operating Characteristic curves

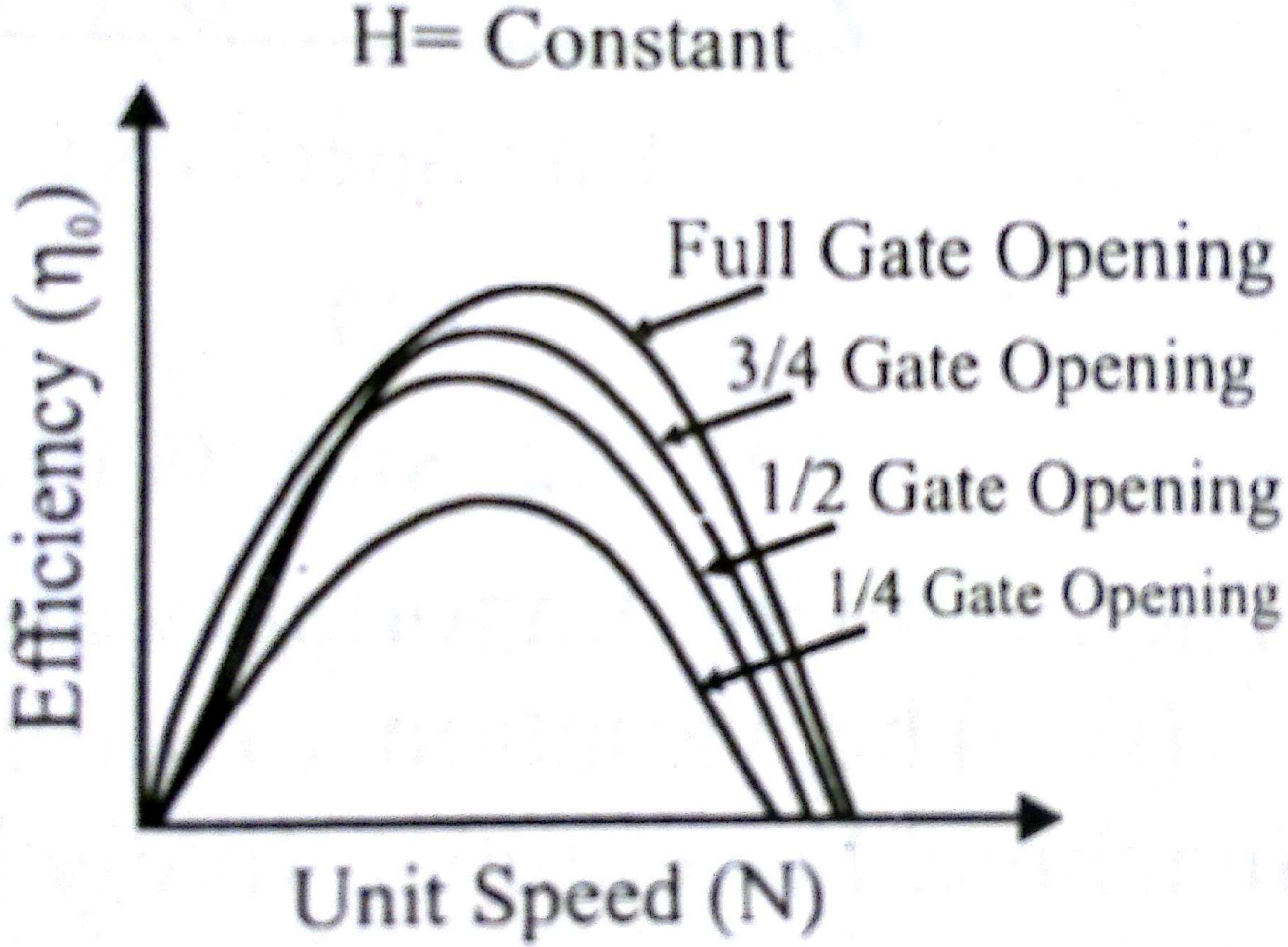
Independent parameters: Head (H), Speed (N), Discharge (Q)

Dependent parameters: Power (P), Torque(T), Efficiency($\boldsymbol{\eta}$)

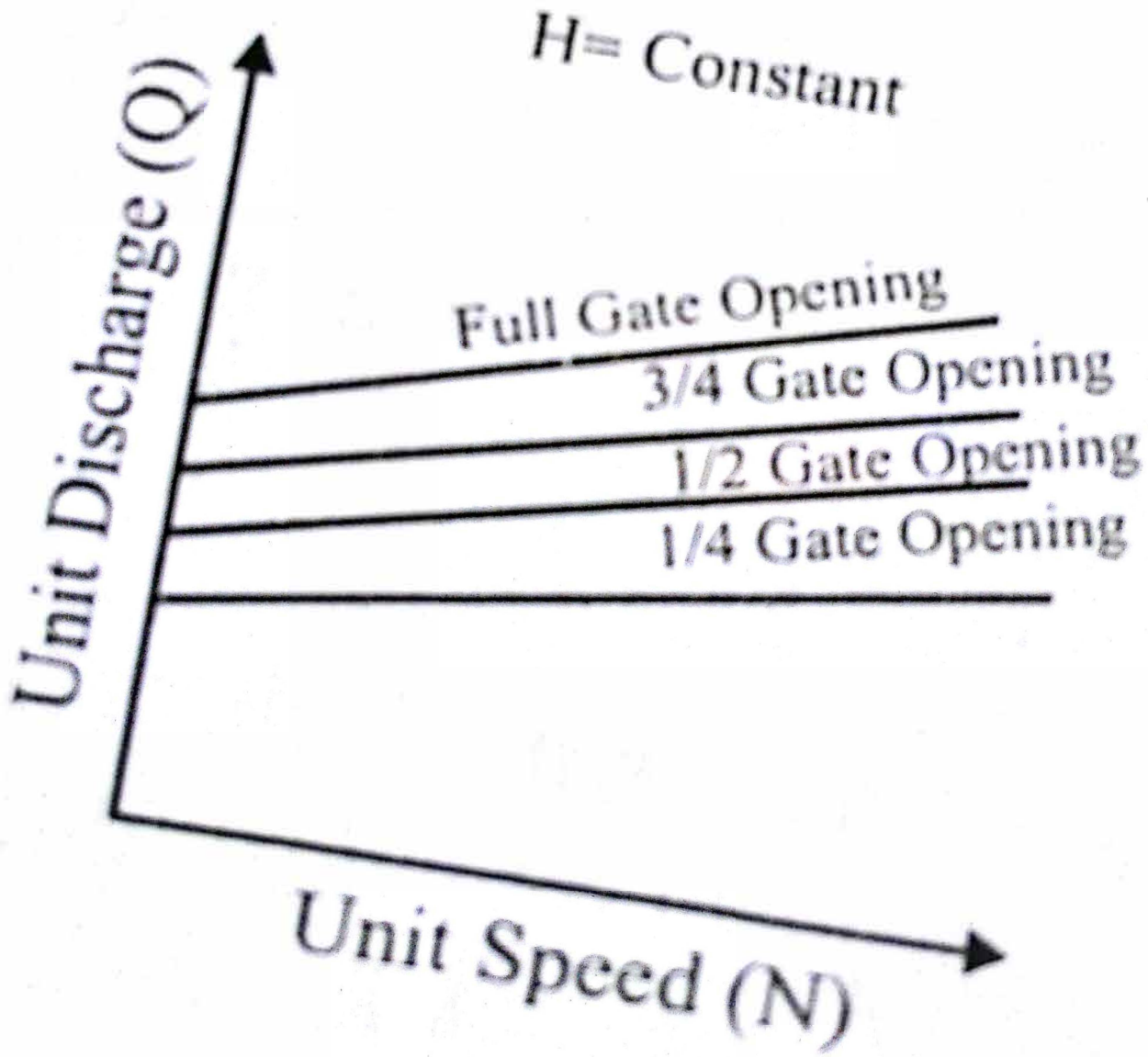
Main Characteristics of Impulse Turbine – Pelton Wheel

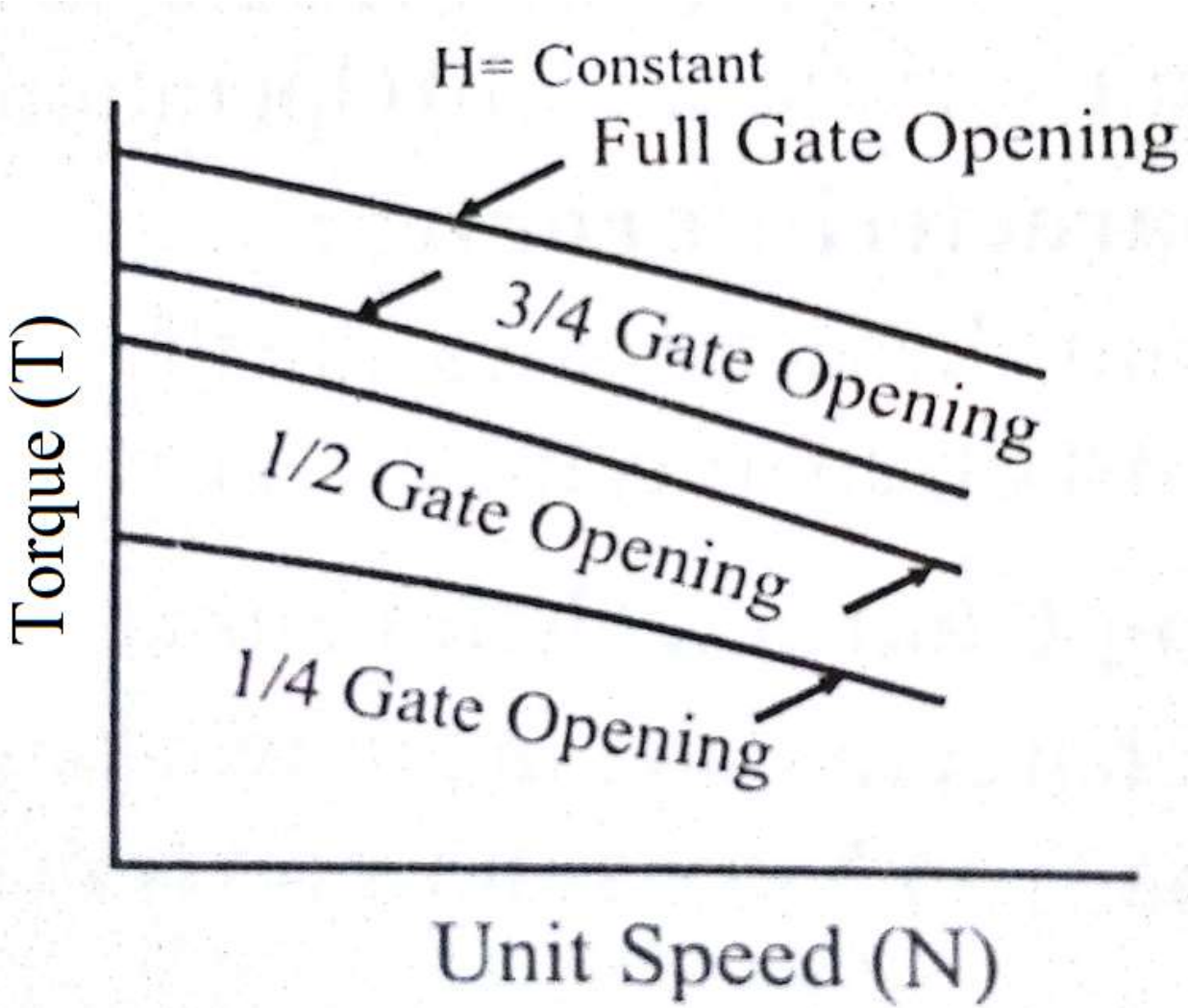


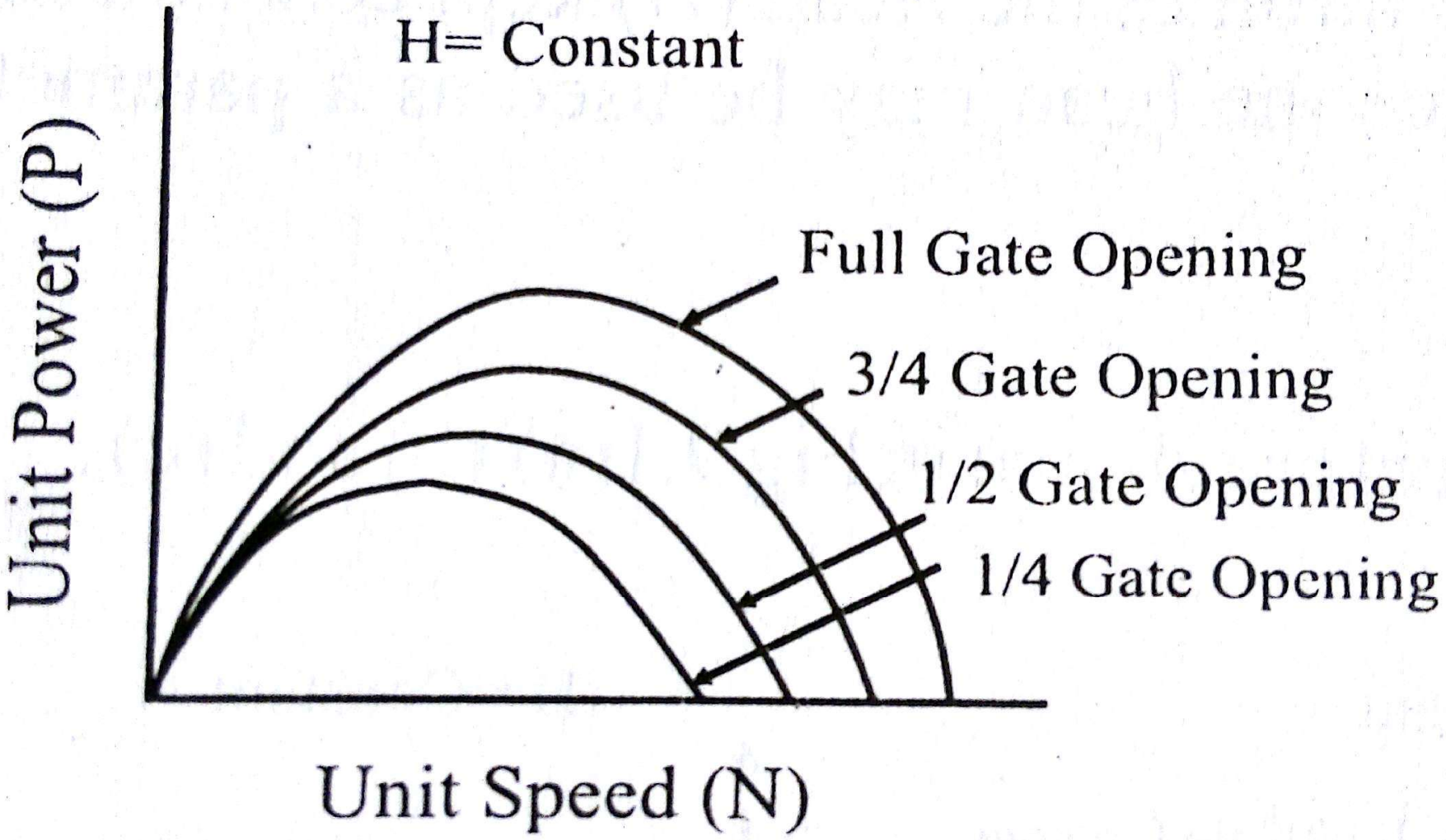

H= Constant
Full Gate Opening
3/4 Gate Opening
1/2 Gate Opening
1/4 Gate Opening
Unit Power (P)
Unit Speed (N)

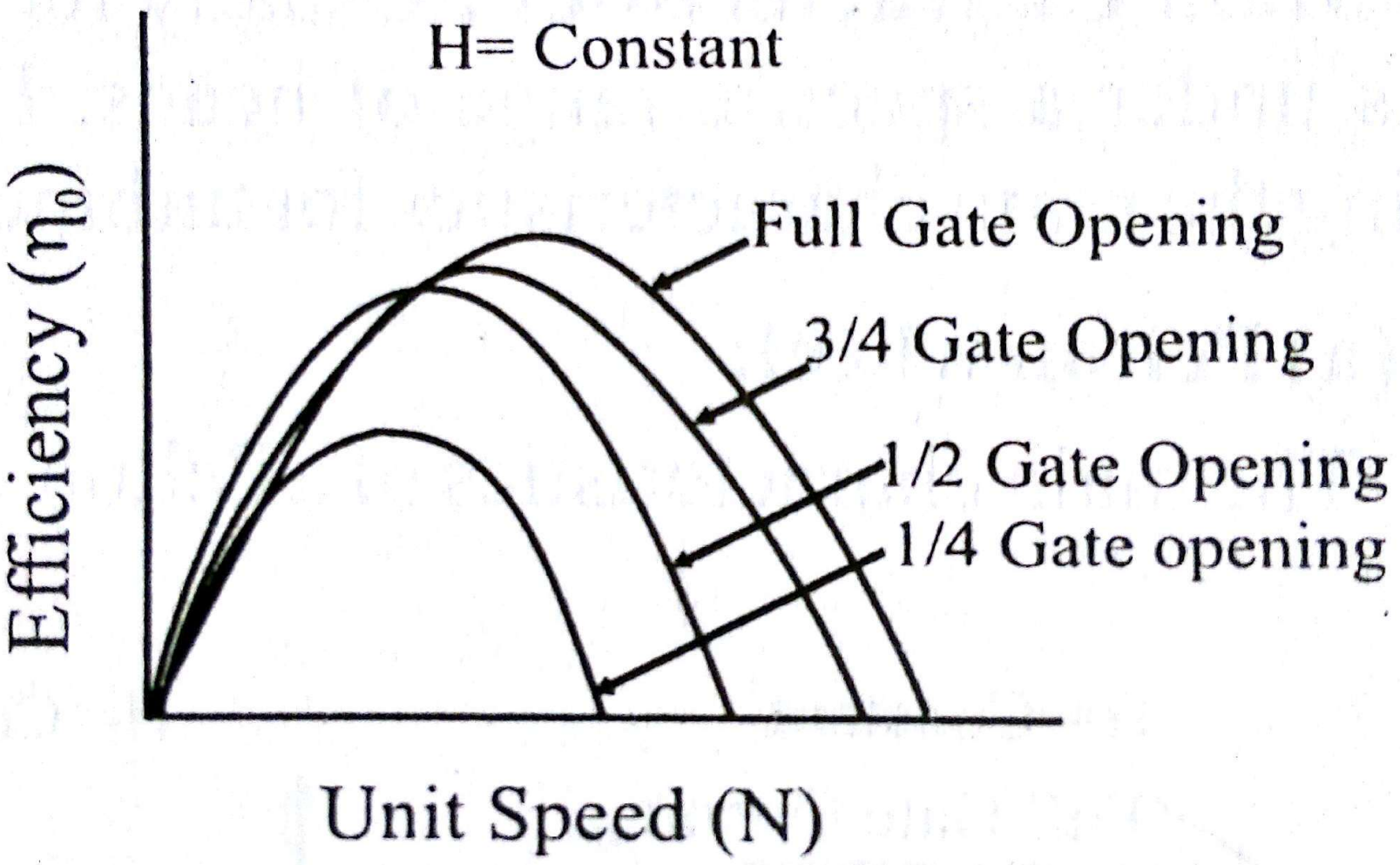

H= Constant
Efficiency (η_o)
Full Gate Opening
3/4 Gate Opening
1/2 Gate Opening
1/4 Gate Opening
Unit Speed (N)

Main Characteristics of Reaction Turbine


H= Constant
Unit Discharge (Q)
Full Gate Opening
3/4 Gate Opening
1/2 Gate Opening
1/4 Gate Opening
Unit Speed (N)


H= Constant
Full Gate Opening
3/4 Gate Opening
1/2 Gate Opening
1/4 Gate Opening
Torque (T)
Unit Speed (N)


H= Constant
Unit Power (P)
Full Gate Opening
3/4 Gate Opening
1/2 Gate Opening
1/4 Gate Opening
Unit Speed (N)

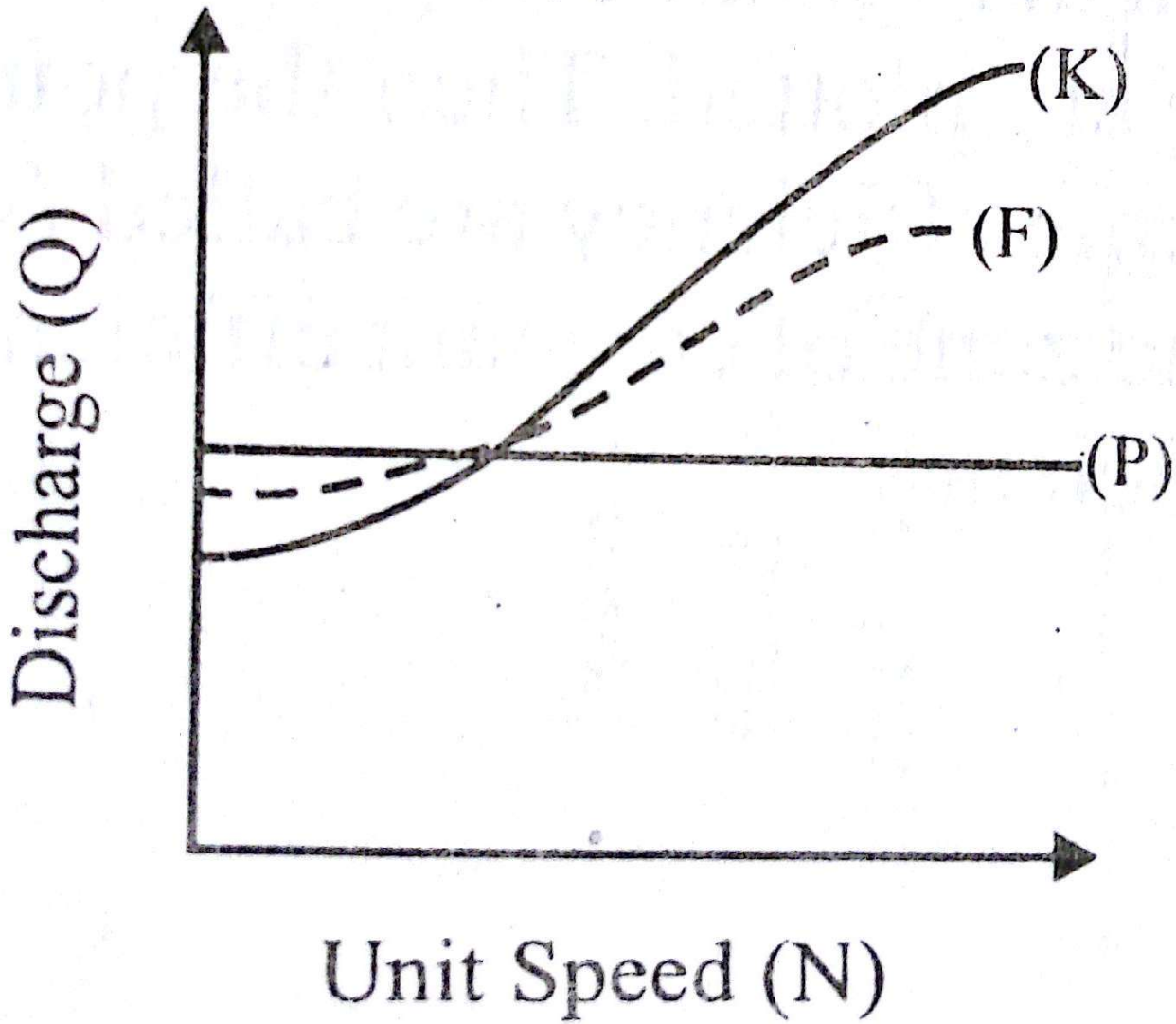

H= Constant
Efficiency (η_0)
Full Gate Opening
3/4 Gate Opening
1/2 Gate Opening
1/4 Gate opening
Unit Speed (N)

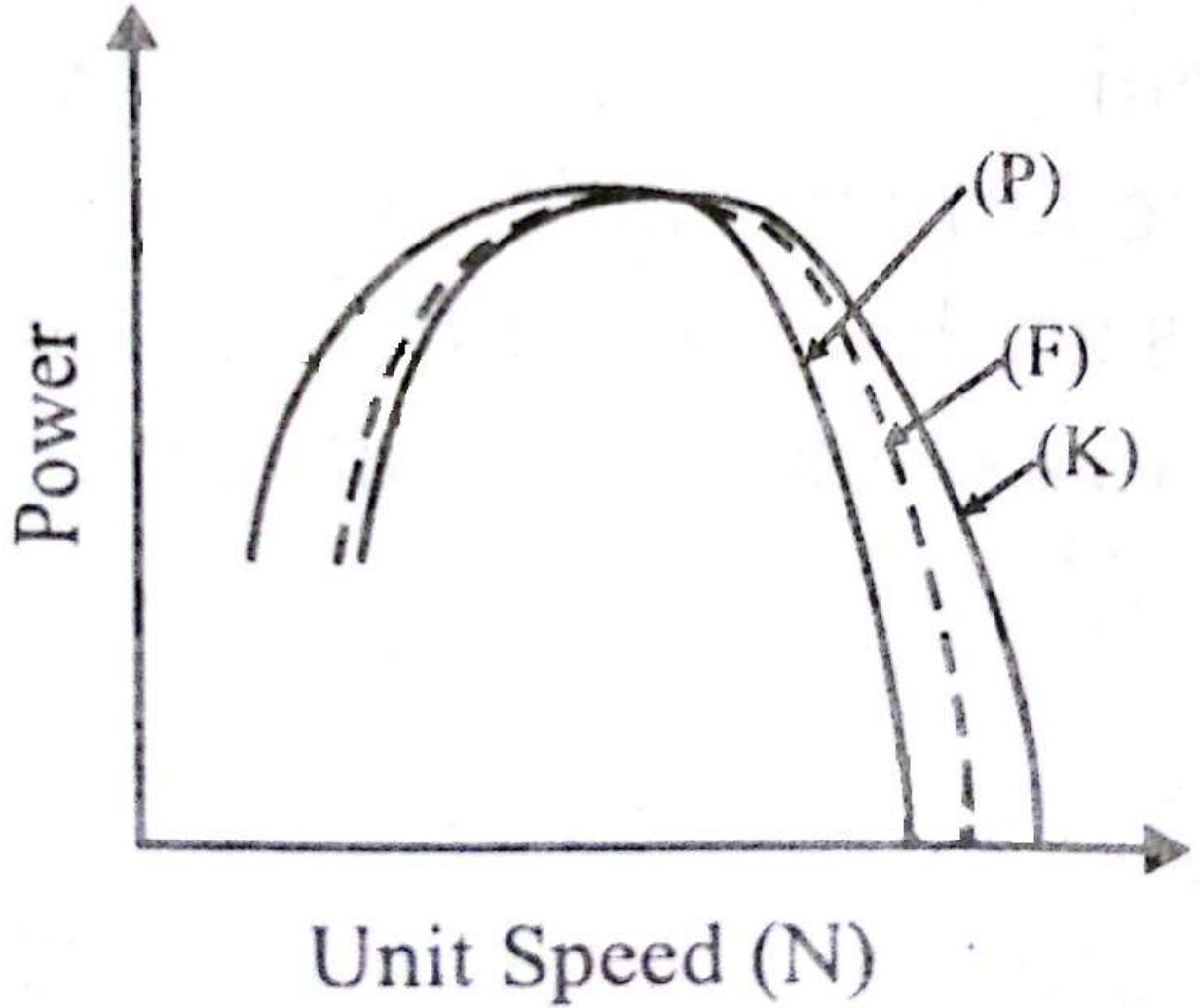
Comparison of turbine characteristic curves at varying speed (N)

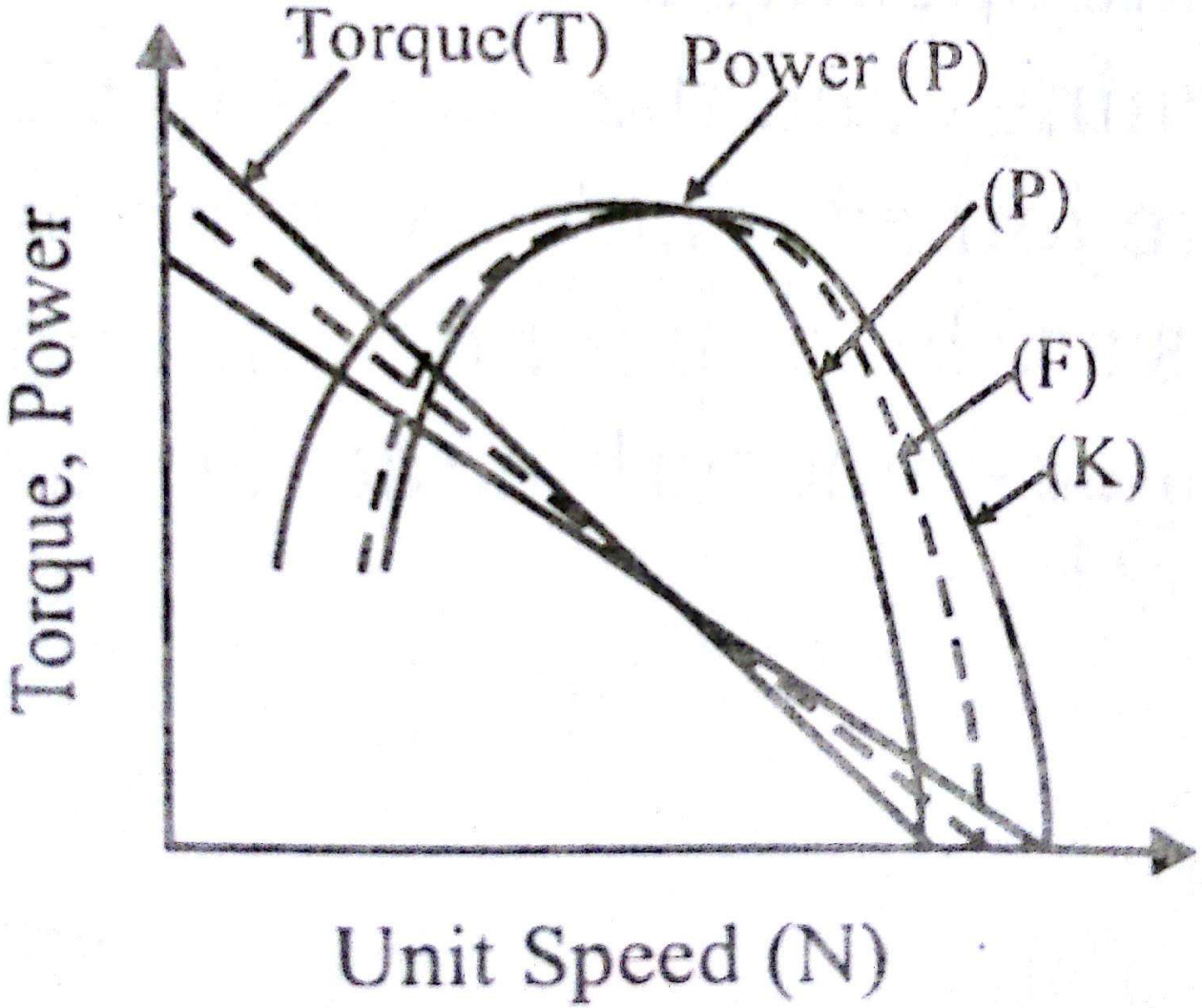
Pelton Wheel – P

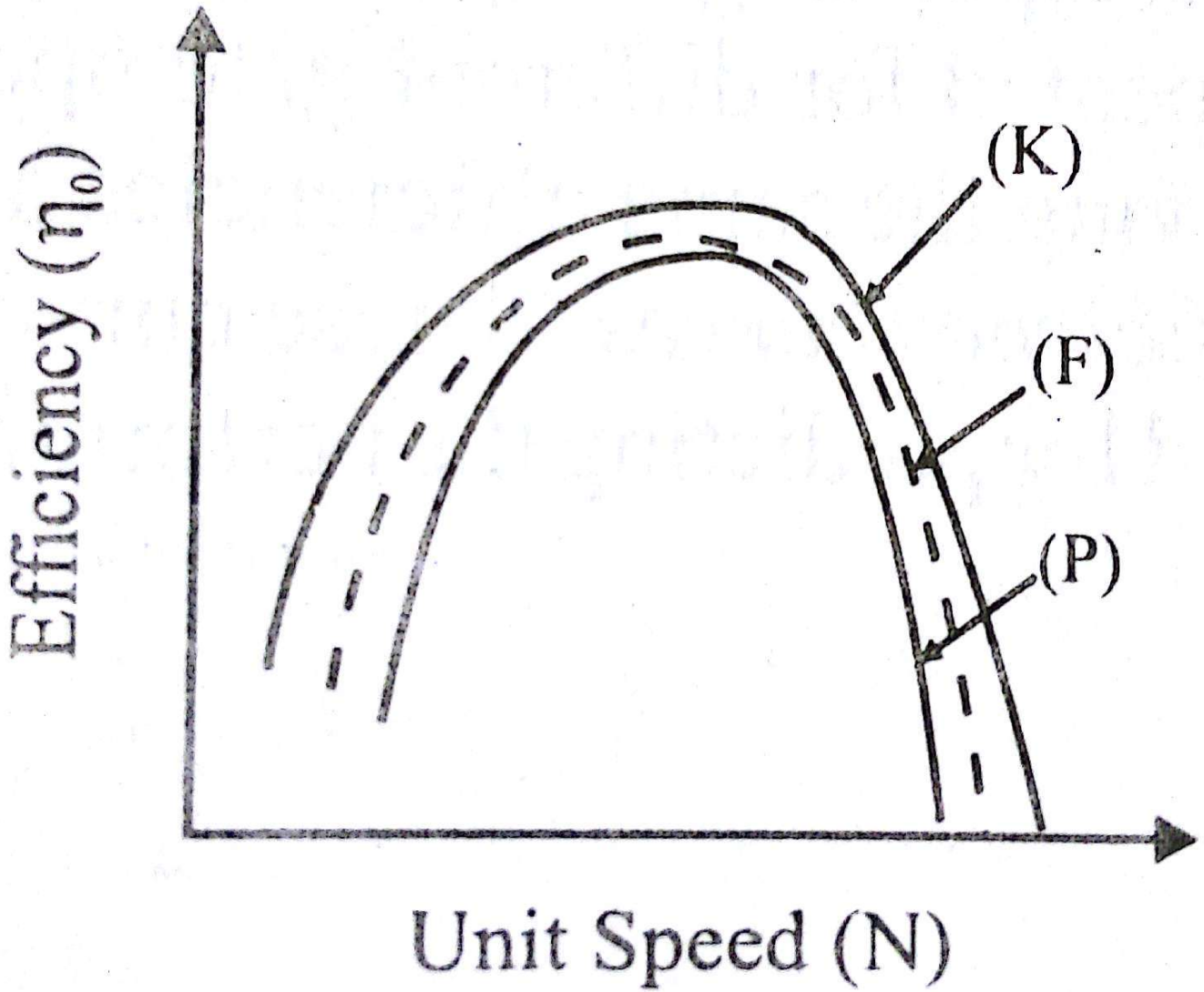
Francis Turbine – F

Kaplan Turbine – K

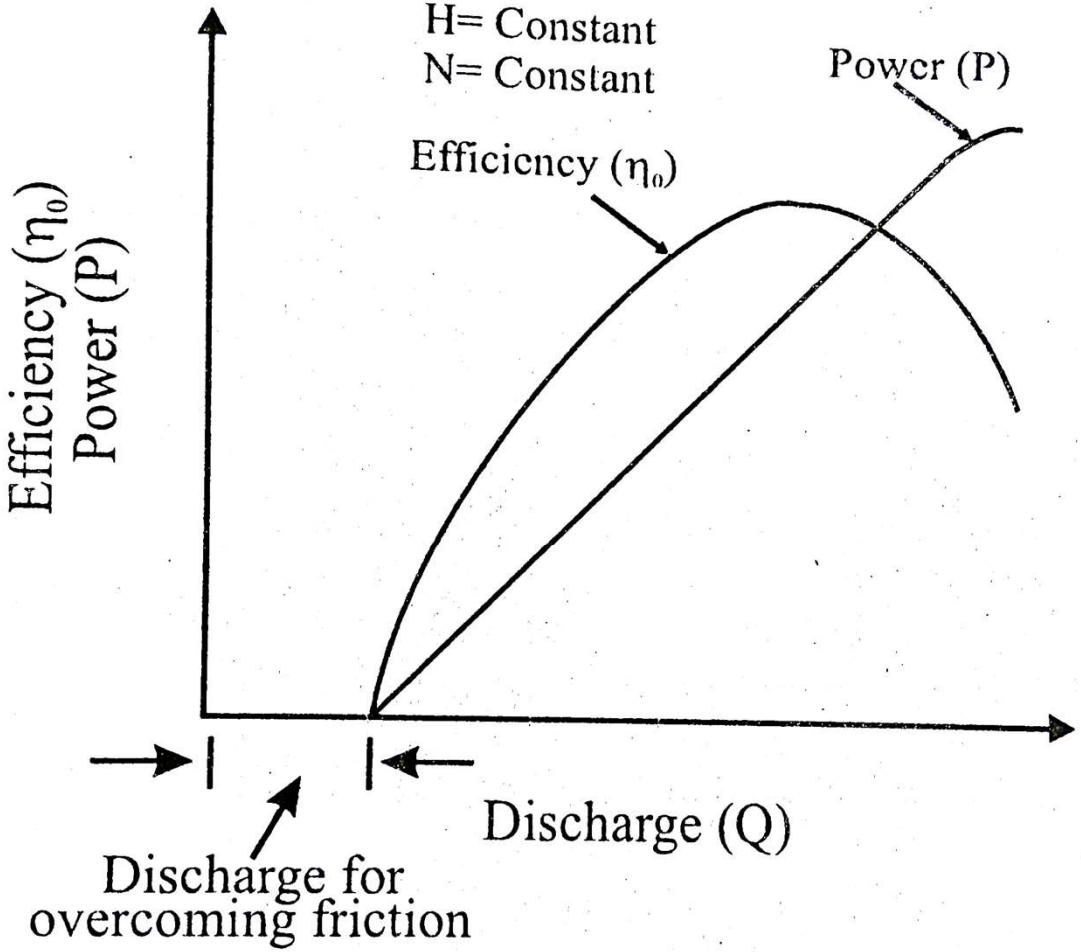

Discharge (Q)
(K)
(F)
(P)
Unit Speed (N)


Power
(P)
(F)
(K)
Unit Speed (N)


Torque(T)
Power (P)
(P)
(F)
(K)
Torque, Power
Unit Speed (N)

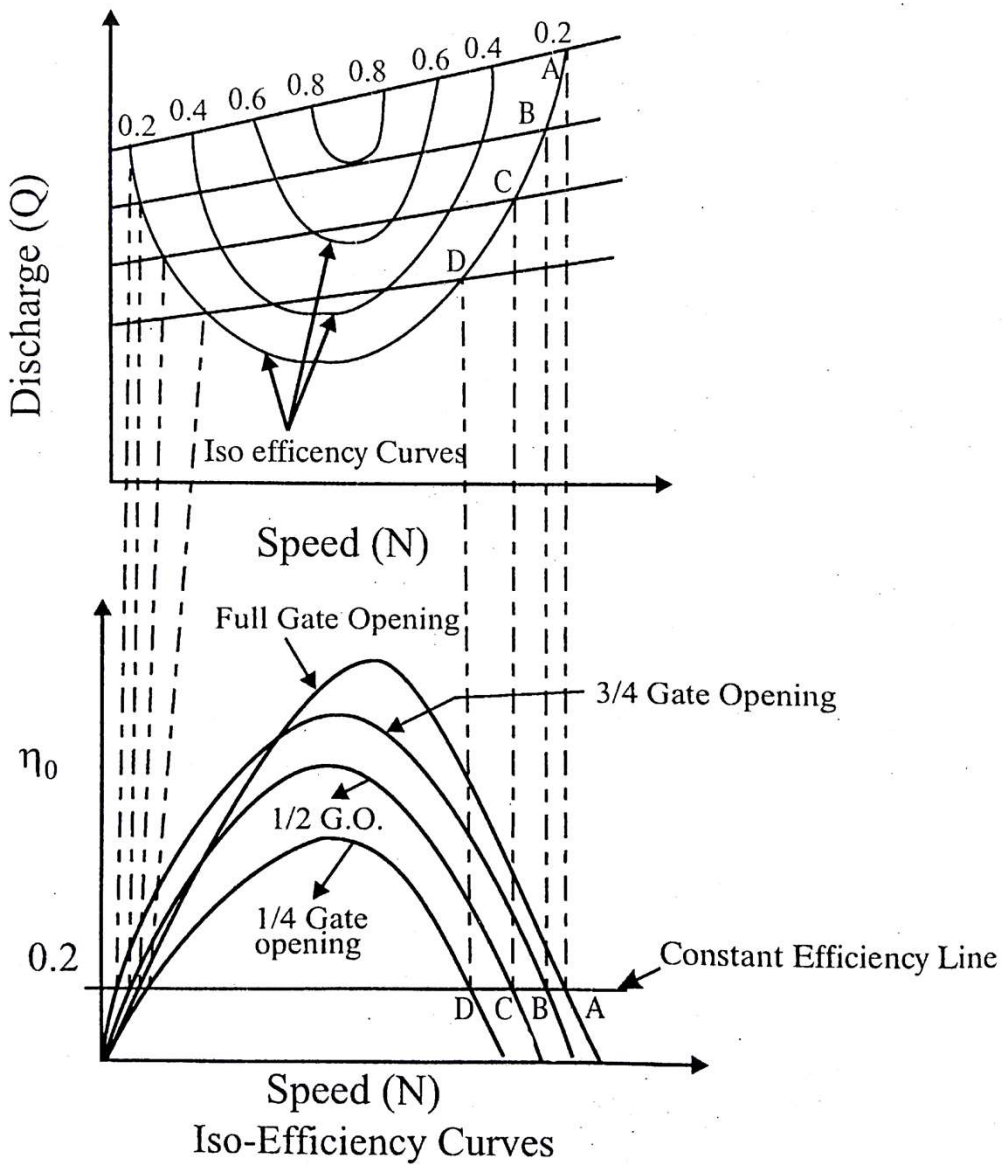

Efficiency (η_o)
(K)
(F)
(P)
Unit Speed (N)

Operating Characteristic curves



Operating Characteristic curves

Constant efficiency curves or Muschel Curves or Iso – efficiency curve



Iso-Efficiency Curves

Impulse turbine	*Reaction turbine*
1. Available energy is completely converted into kinetic energy before entry into the turbine.	1. Partially converted into kinetic energy before entry into the turbine.
2. Water directly strikes the runner.	2. First, water enters a row of fixed blades, then enters the runner vanes.
3. The pressure of the flowing water remains constant and equal to the atmospheric pressure.	3. The pressure of water reduces as it flows over the vanes. The pressure of water is usually less than the atmospheric pressure at the exit of the turbine.
4. No losses if flow is regulated depending upon the load.	4. Losses will be there during flow regulation.
5. Power developed by the change in the kinetic energy of the jet.	5. Power developed partly by the change in the kinetic energy and pressure energy.
6. Turbine can be installed above the tail race.	6. Turbine is submerged in water below the tail race level.

Impulse turbine	*Reaction turbine*
1. Available energy is completely converted into kinetic energy before entry into the turbine.	1. Partially converted into kinetic energy before entry into the turbine.
2. Water directly strikes the runner.	2. First, water enters a row of fixed blades, then enters the runner vanes.
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4. No losses if flow is regulated depending upon the load.	4. Losses will be there during flow regulation.
5. Power developed by the change in the kinetic energy of the jet.	5. Power developed partly by the change in the kinetic energy and pressure energy.
6. Draft tube is not necessary.	6. Draft tube is necessary.

Specific speed for different types of turbine

Type of turbine	*Specific speed, if P is in kW*
Pelton (single jet)	8 to 30
(two jets)	25 to 40
(multiple jets)	40 to 70
Francis (for heads below 370 m)	70 to 450
Kaplan (for head below 60 m)	360 to 910

Head for different types of turbines

Head of water in metres	*Type of turbine*
0 to 30	Either Kaplan or Francis
30 to 50	Either Kaplan or Francis
50 to 150	Francis
150 to 250	Either Kaplan or Pelton
250 to 300	Either Francis or Pelton
Above 300	Pelton