Overview of Obra Thermal and Hydro Power Plant

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Introduction–

Obra Hydel Power Plant is one of the earliest large hydroelectric projects in eastern Uttar Pradesh, located near Obra town in Sonebhadra district, on the Son River. It works in coordination with the nearby Obra Thermal Power Plant, forming a classic hydro–thermal power complex.

Basic Overview

- **Type-** Hydroelectric Power Plant
- **Water source-** Son River
- **Commissioned-** 1960s (India’s early planned hydro projects, turbines in 1965)
- **Owner/Operator-** Uttar Pradesh Power Corporation Limited (UPPCL)

Importance–

- First major hydel project in UP
- Provides peak load support
- Stabilizes power supply for-
    - Obra Thermal Plant

    - Nearby industrial zones
- Helps in grid frequency control (fast START/STOP)

Installed Power Capacity–

- The Obra Hydel plant has a total installed capacity of about **99 MW.**
- It has **3 generating units** (all commissioned in the mid-1960s).

Working Principle–

Step 1– Water Storage

Water is stored at height in the Rihand reservoir behind the dam → this stores potential energy.

Step 2– Penstock Flow

At Obra, for each turbine 1 Penstocks of 8–9m diameters and length of 200–250m arranged as Dam integrated/ tunnel type steel-lined conduit with gentle slope are used. When Power is needed–

- Intake gates open
- Water flows through penstocks

Step 3– Turbine Action

High-head water strikes the turbine blades, converting–

Hydraulic energy → Mechanical energy

→ **Type–** Kaplan Vertical turbine

Step 4– Generator

- Turbine shaft rotates generator
- Mechanical energy → Electrical energy (AC)

Step 5– Power Transmission

- Voltage stepped up using transformers
- From generator 11kV → 33kV → 132kV → 220kV
- Power sent to grid

River, Reservoir and Level Terminology–

River system (Nature's view) – Son River→ tributary – Rihand River

Near Pipri, an artificial stream is created. This stream is an engineered waterway which feeds Obra Hydel turbines.

“Main Water body is Son River”.

River Bed– The river bed is the natural bottom of the river channel. It is irregular and variable due to erosion and siltation and is never used as a reference level in dam or hydropower design.

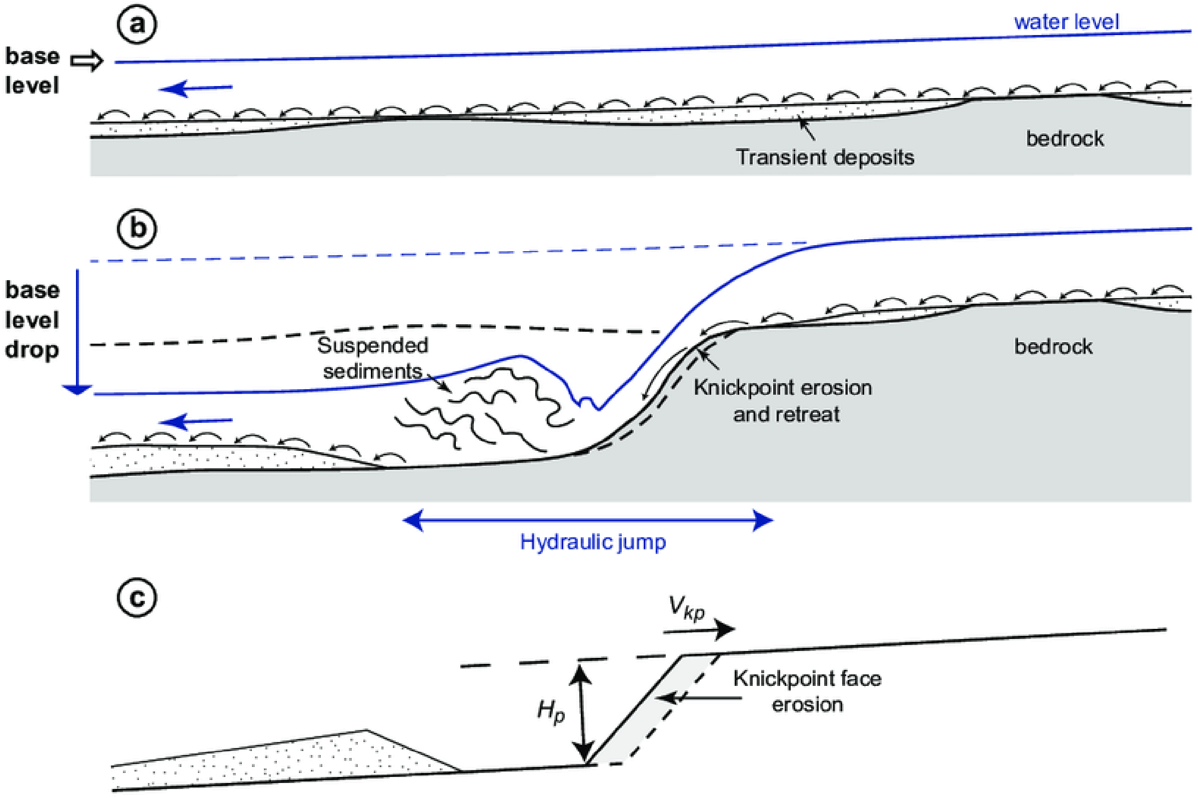
Datum and Reduced Levels (RL)–

All elevations are measured from a fixed survey datum, usually-

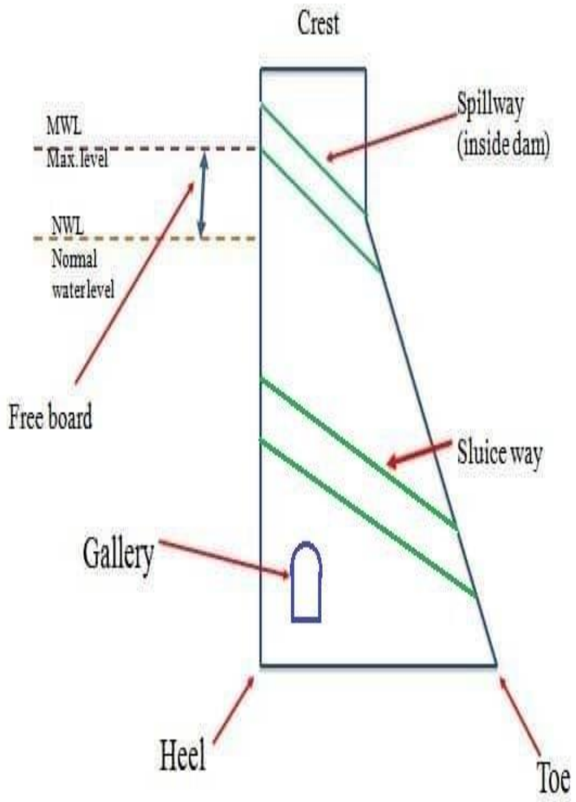
- Mean Sea Level (MSL), or
- A permanent benchmark tied to MSL
- Here, Reservoir water level, **RL = 192 ft**, this means the water surface elevation is 192 ft above datum, not above the river bed.

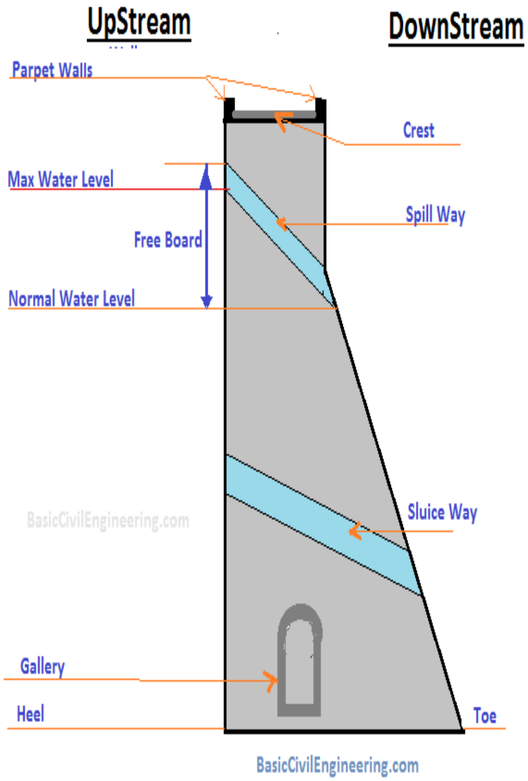
Full Reservoir Level (FRL) – FRL is the maximum normal operating water level

At Obra, **FRL ≈ 202 ft**, FRL is decided based on hydrology, flood studies, and storage requirements.



Schematic longitudinal section of a river-bed before (a) & during (b) the propagation





Dam–

→Dam Height–

$$\boxed{\text{Dam Height} = \text{Crest Level} - \text{Foundation Level}}$$

Dam Crest level = FRL + freeboard
Foundation level lies well below the river bed on hard rock

→ Dam height is a structural parameter, not related to power generation.

→ This is a gravity dam which resists water pressure by its own weight.

→ It has-

- Huge base width
- Massive concrete volume
- Internal galleries, drains, and conduits

→ During construction-

- The penstock passage is planned first
- Concrete is poured around it
- It becomes a monolithic part of the dam

→ Penstock diameter ≈ 8 m, length ≈ 200m

Since a typical gravity dam has base width of 60m – 100m and relative size of diameter is kept around 10%

→ Location-

- Near the neutral zone of the dam cross-section
- Not near upstream face
- Not near downstream toe

This zone has-

- Minimum bending stress
- Maximum concrete mass around

So stress distribution is hardly disturbed.

→ Concrete lining + steel liner-

Inside the conduit-

- Steel liner (20–25 mm) handles water pressure
- Surrounding concrete handles structural load
- Water pressure does not act on dam concrete directly, it is carried by steel liner

→ Internal galleries-

Gravity dams have-

- Inspection galleries
- Drainage galleries
- Grouting galleries

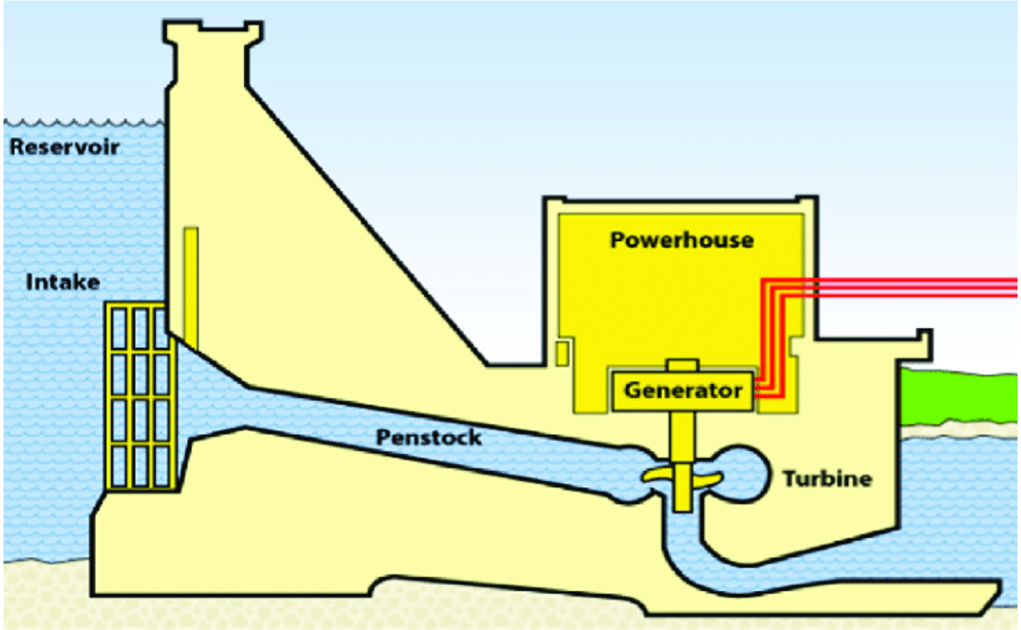
Penstock conduits are just like the bigger versions of these planned spaces.

→ Structural design check

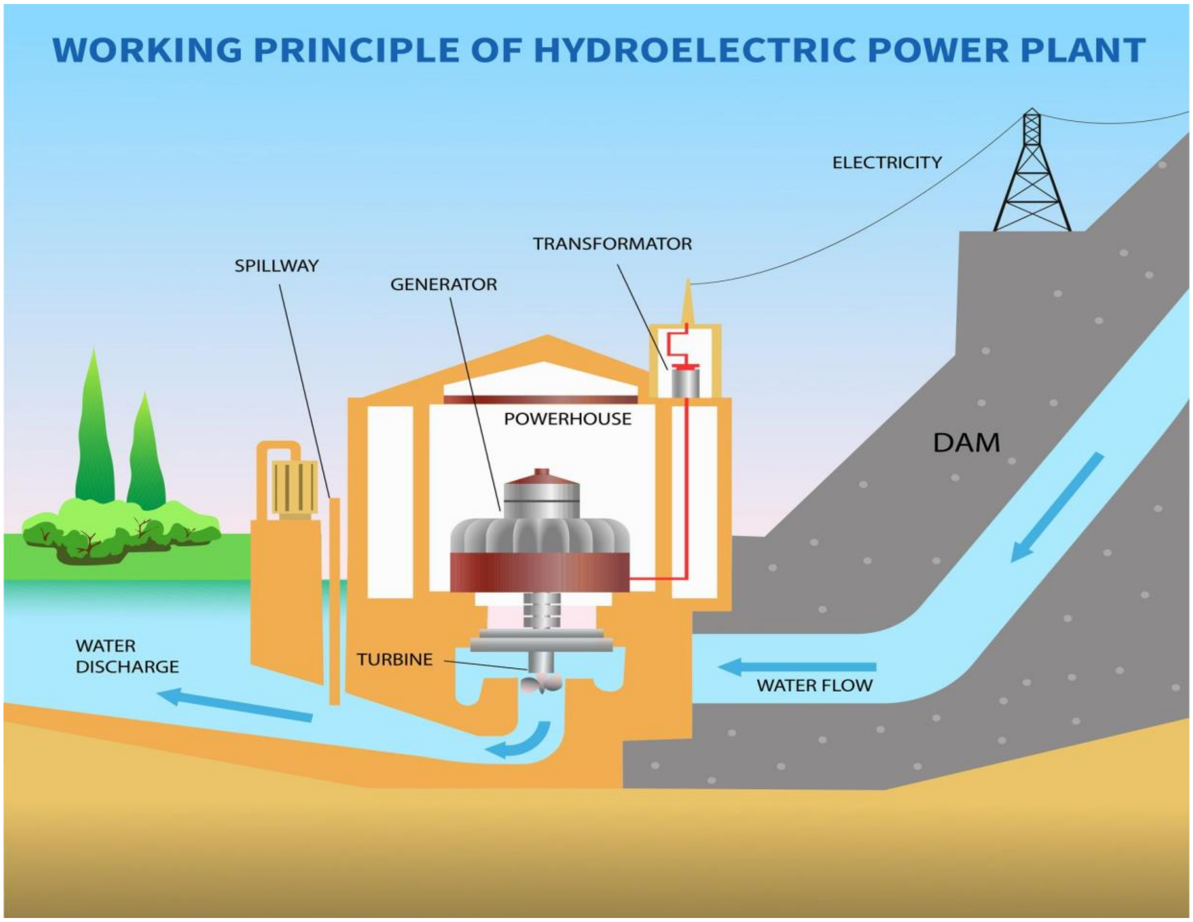
Engineers check-

- Sliding
- Overturning
- Shear stress
- Principal stresses

with conduits included in the model so the dam is designed assuming these voids exist.


Reservoir
Intake
Penstock
Powerhouse
Generator
Turbine

Low Head Dam


WORKING PRINCIPLE OF HYDROELECTRIC POWER PLANT
ELECTRICITY
TRANSFORMATOR
SPILLWAY
GENERATOR
POWERHOUSE
DAM
WATER DISCHARGE
TURBINE
WATER FLOW

Calculations–

Upstream water level (Reservoir side) – This is measured as- Reservoir Water Level (RWL), taken near intake opening.

Reservoir water level = 192 ft ≈ 58.5 m

This is gross available height or **Gross Head**

Downstream water level (Tail race) – This is water level after turbine in tail race / river

At Obra, Tail race level = 125 ft ≈ 38.1 m

Gross head – Gross Head is the vertical difference between the reservoir water surface level and the tail-race water surface level. It is denoted by Z_g.

$$\boxed{Z_{gross} = Z_{reservoir} - Z_{tail\ race}} = 58.5m - 38.1m$$

$$Z_g = 20.4\ m$$

Losses– Losses occur in Penstock due to friction, bends, turbulence. Typically in Hydel systems head losses are taken around 15% of Gross head.

Total losses ≈ 15% –20% of Z_g ≈ 3.4m

Net Head – Net Head is calculated between two water levels

$$\boxed{\text{Net Head} = \text{Gross Head} - \text{Head Loss}}$$

Net Head = 20.4m – 3.4m = 17 m **

****These Losses may slightly vary****

Discharge– Discharge per turbine is calculated by–

$$\boxed{P = \rho g Q H \eta}$$

Where, P = power = 33MW = 33×10^6 W
P = density = 1000kg/m^3
g = 9.81m/sec^2
H = Net Head = 17m
η = turbine efficiency = 90% = .9
then, Q = discharge = P ÷ ρgHη
= 220m^3/sec
Total Discharge = 3Q = 660 m^3/sec

Penstock velocity–

Discharge, Q = Area x velocity = $\pi D^2/4$ x velocity
220 = $\pi \times 8^2/4$ x velocity

Velocity, $V = 4.3767$ m/sec

Penstock thickness–

Max internal pressure inside penstock, $p = \rho g H = 1000 \times 9.81 \times 17.34 = 170105.4\ \text{N/m}^2$

$= 0.170$ MPa

For steel, FOS = 3, then, design pressure = $0.170 \times 3 = 0.510$ MPa = $0.510\ \text{N/mm}^2$

For structural steel, $\sigma_{\text{allowable}} = 120$MPa

$$\sigma_{\text{circumferential}} = \sigma_{\text{allowable}} = pd/2t$$

Then, thickness, $t = 0.510 \times 8000 / (2 \times 120) = 17$mm

Therefore, available thickness ≈ 20mm – 25mm

Friction loss– The loss of head (or energy) in pipes due to friction is calculated from Darcy-Weisbach equation

$$\text{Friction loss, } \boxed{h_f = 4\, f\, L\, V^2 / 2gD}$$

Where, L = length of pipe (or penstock) = 200 m

V = velocity of water inside pipe = 4.2882 m/sec

D = diameter of pipe = 8 m

$g = 9.81\ \text{m/sec}^2$

f = co-efficient of friction, which is a function of Reynold's number, R_e

$= 16/R_e$ for $R_e < 2000$ (viscous flow)

$= .079/ R_e^{1/4}$ for R_e varying from 4000 to 10^6

Reynold's number, $R_e = VxD / \nu$ where, ν = kinematic viscosity

$= 4.3767 \times 8 / (.01 \times 10^{-4})$ [for water $\nu = .01$ poise or cm^2/sec]

$= 35013600 = 35.0136 \times 10^6$

$f = 079/ R_e^{1/4} = .079/ (35.0136 \times 10^6)^{1/4}$

$= .00102699$

Now, $h_f = 4fLV^2/2gD$

$= .100267$ m

Spillways– They protect Reservoir level which indirectly ensures continuous hydel operations.

Purpose of spillway gates-

- To control excess reservoir water (Flood control)
- To protect the dam
- To maintain safe reservoir level

They operate-

- during monsoon
- during floods
- when reservoir exceeds Full Reservoir Level (FRL)

Spillway gates are meant for flood control and dam safety, they do not participate in power generation.

Intake Gate – It is large vertical steel gate which moves UP & DOWN housed in a concrete intake tower. It is located on the reservoir side at lower elevation than Spillway behind trash rack and before Penstock.

Reservoir → Trash rack → Intake gate → Penstock → Turbine

It is operated slowly to START / STOP water supply to the turbine and also act as Emergency shut- off.

Guide Vanes or Wicket Gates – Wicket gates are located **inside the turbine casing** and continuously control power output. These look like many curved blades arranged in a circle moving together connected to a governor ring.

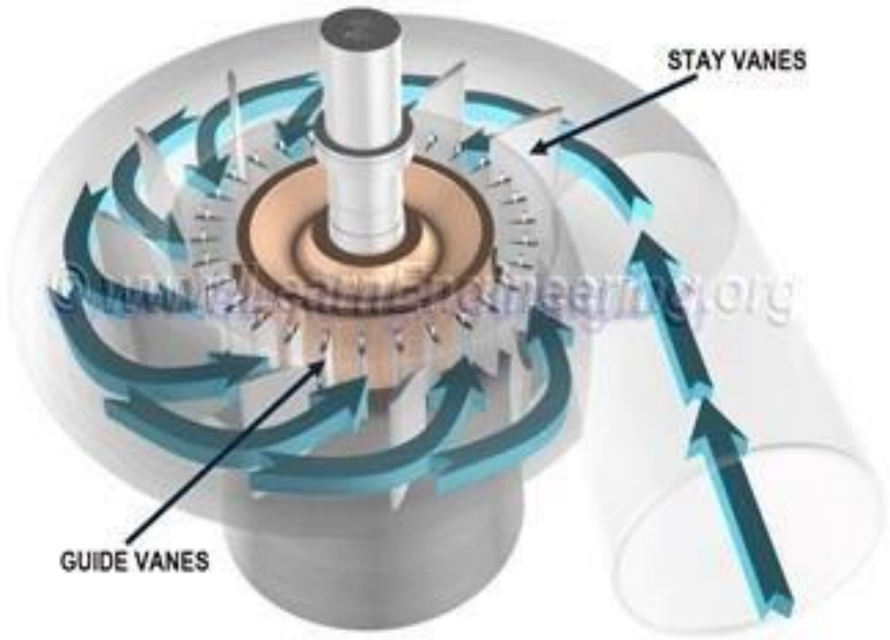
Penstock → Spiral casing → Wicket gates (guide vanes) → Turbine runner → Draft tube

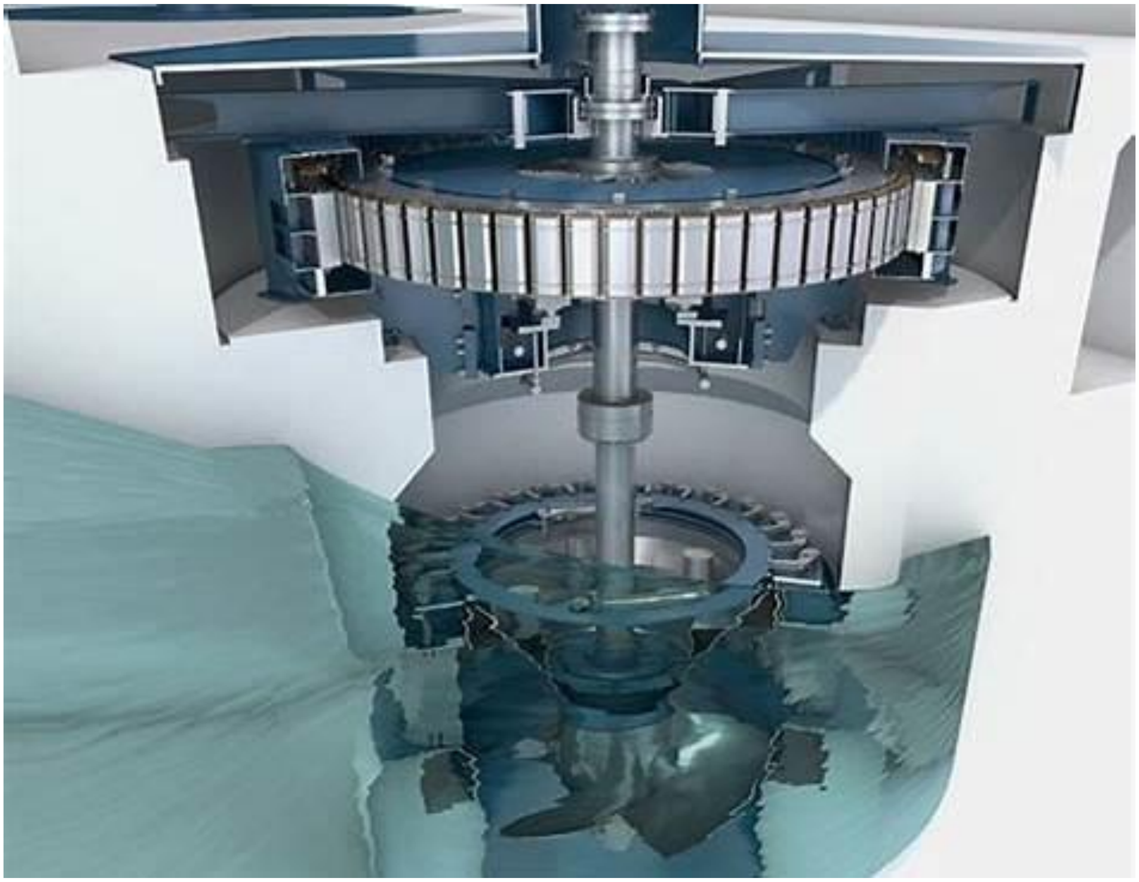
It act as real throttle of the turbine and has following purposes-

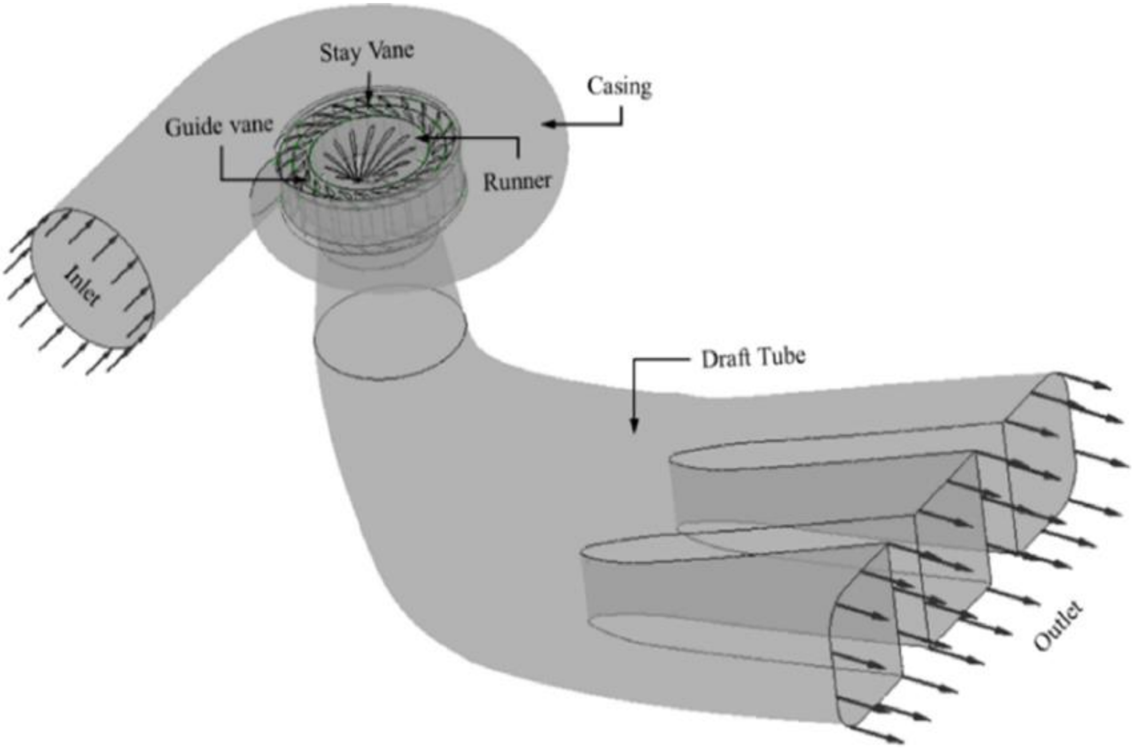
i. control how much water enters the runner
ii. control angle of attack
iii. maintain constant speed
iv. regulate power output

Simple Logic –

- **Reservoir** → fuel tank
- **Spillway gate** → overflow pipe
- **Intake gate** → fuel cock (ON / OFF)
- **Wicket gate** → accelerator
- **Turbine runner** → engine






Stay Vane
Casing
Guide vane
Runner
Inlet
Draft Tube
Outlet

Intake trash rack –

A **trash rack** is a steel bar screen installed **in front of the intake opening** to prevent debris from entering the penstock / turbine.

At Obra it protects against-

- tree branches
- floating vegetation
- plastic / debris
- fish (to some extent)

Trash rack is always submerged usually and not visible from the dam top.

Location at Obra- Intake is below FRL which is separated from spillway and Penstock is embedded inside dam

So the sequence is-

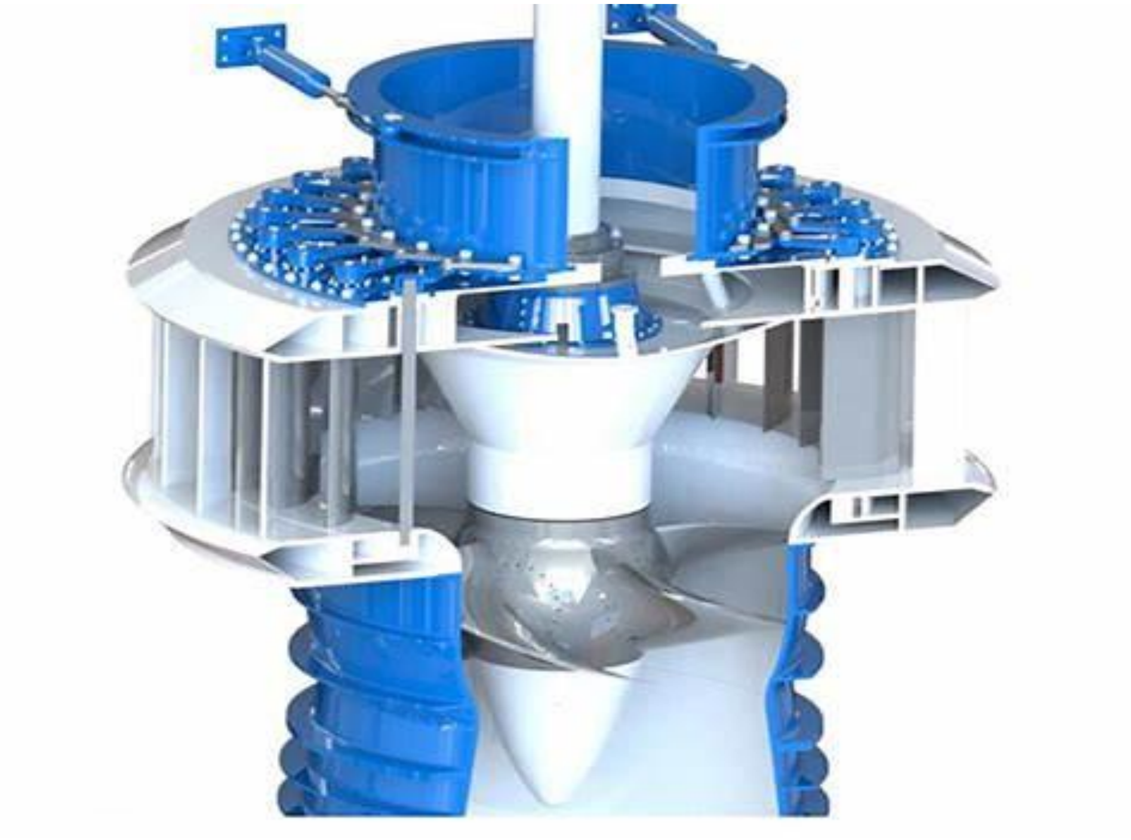
Reservoir
~~~~~~~~~~~~~~
| Trash rack | ← submerged, vertical
|------------|
| Intake gate|
|------------|
| Pressure conduit (penstock)

Discharge passing through ONE intake = 220m^3/sec

Total Discharge = 3 x 220 = 660m^3/sec

Turbines –
~~~~~~~~~~~~~~

Obra Hydel Power plant uses Reaction type Kaplan turbine.



Turbine dimensions (runner size)-

For Kaplan turbines, runner diameter depends mainly on head.

- Low head → large runner
- High head → small runner

For Head = **17 m**

and Power = **33 MW**

Size of intake openings

Intake opening velocity is kept low to avoid clogging, vibration, fish injury

Typical intake velocity, V = 1 m/sec – 1.5 m/sec ≈ 1.2 m/sec [remarkably less than penstock velocity]

Discharge per turbine, Q = 220 m^3/sec

Required intake flow area, A= Q ÷ V = 220 ÷ 1.2 = 183.33m^2

Overall Efficiency of the turbine, η_o = Shaft Power ÷ Water Power = Power developed ÷ ρgQH

Given, P = 33 MW

Water Power = 1000 x 9.81 x 220 x 17 = 36689400 watt = 36.68MW

$$\boxed{\eta_o = P \div \rho g Q H}$$

$\eta_o = 33 \div 36.68 = 0.89944 \approx \mathbf{90\%}$

at Obra, Runner diameter, $D_o = 5.17\text{m}$

Diameter of hub, $D_b = 35\% \text{ of } D_o = 1.8095 \text{ m}$

In Kaplan turbine,

Velocity of flow at inlet, V_{f1} = Velocity of flow at outlet, V_{f2}

$$\boxed{Q = \pi \left(D_o^2 - D_b^2\right) V_{f1} \div 4}$$

$$V_{f1} = 11.942756\text{m/sec} \approx 12\text{m/sec}$$

$$\text{Flow ratio} = V_{f1} \div \sqrt{(2gH)} = 11.942756 \div \sqrt{(2\text{x}9.81\text{x}17)}$$

$$= 0.65$$

Peripheral velocity at inlet, u_1 = Peripheral velocity at outlet, u_2

$$\boxed{u_1 = \pi D_o N \div 60}$$

for Kaplan turbine, peripheral velocity, $u_1 = \phi\sqrt{(2gH)}$

where, ϕ = speed ratio = 1.6 to 2.0 **[it is different from flow ratio]**

$u_1 = 1.7\text{x}\sqrt{(2\text{x}9.81\text{x}17)}$ **[taking $\phi \approx 1.7$]**

$= 31.047 \approx 31\text{m/sec}$

Speed of the Turbine, $N = u_1\text{x}60 \div \pi D_o = 31\text{x}60 \div 5.17\,\pi$

$= 114.5176 \approx 115\text{rpm}$

Specific speed of the turbine, $\boxed{N_s = N\sqrt{P} \div H^{5/4}}$

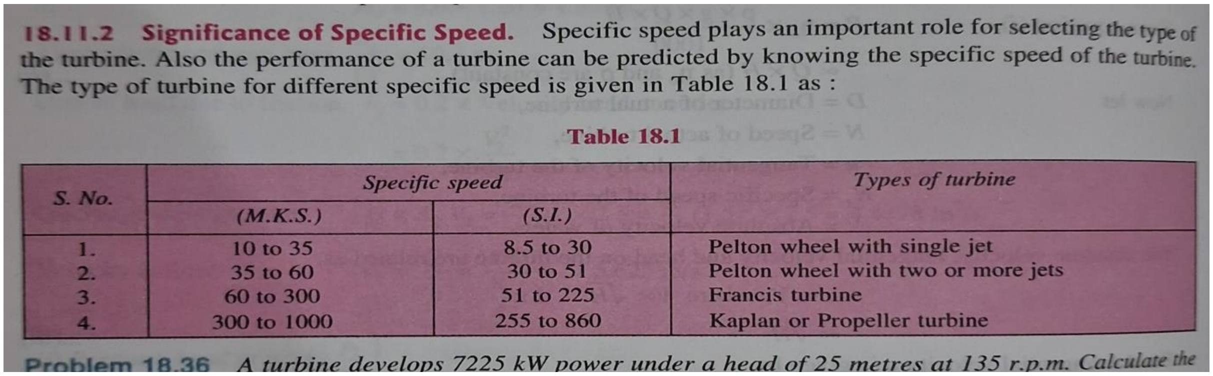
Where, N = turbine rpm / rotational speed (rpm)

P = power (kW)

H = net head (m)

$N_s = 115\text{x}\sqrt{33000} \div 17^{1.25}$

$= 605.1926$

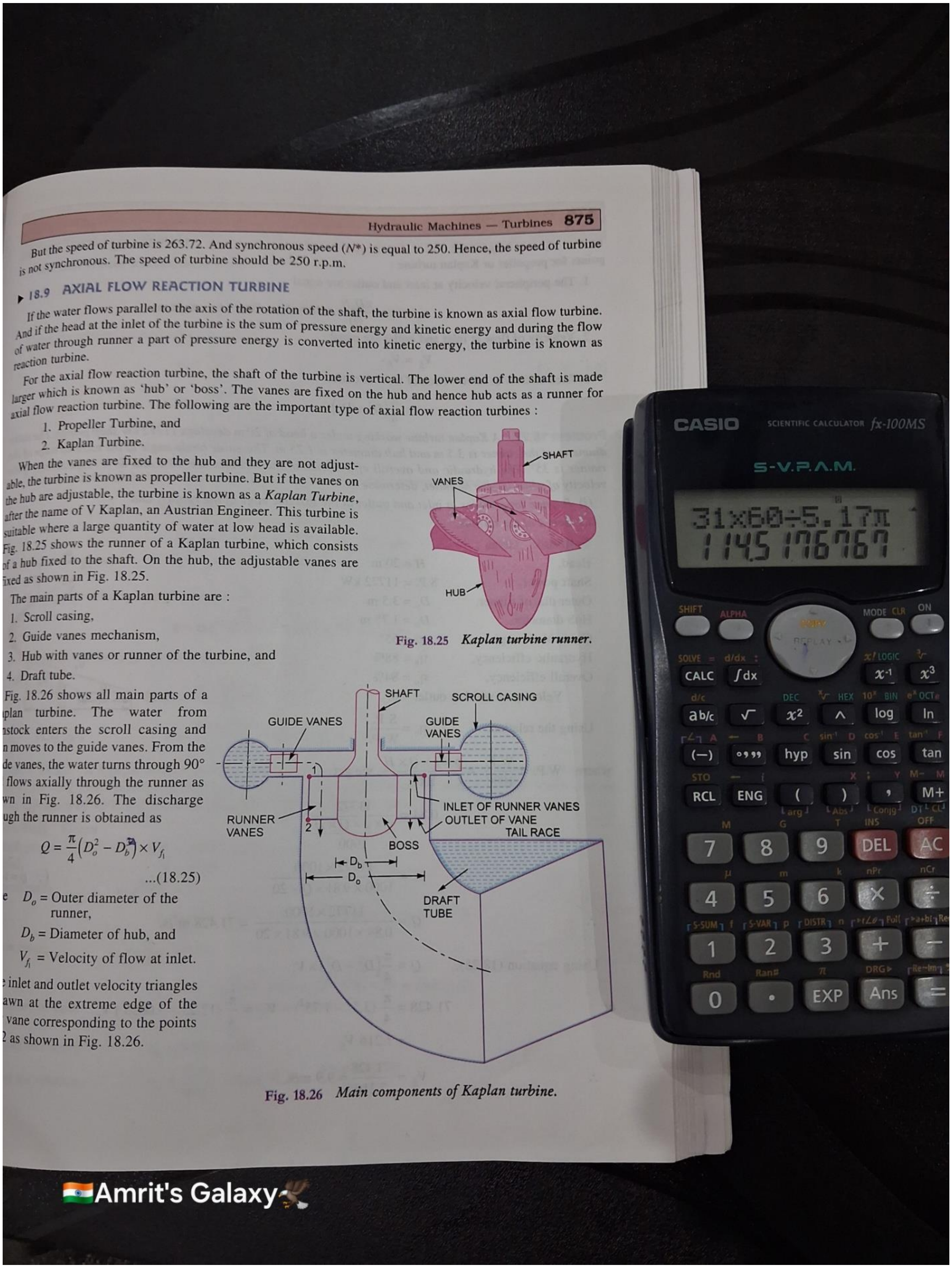


18.11.2 Significance of Specific Speed. Specific speed plays an important role for selecting the type of the turbine. Also the performance of a turbine can be predicted by knowing the specific speed of the turbine. The type of turbine for different specific speed is given in Table 18.1 as :

Table 18.1

S. No.	*Specific speed*		*Types of turbine*
	(M.K.S.)	*(S.I.)*	
1.	10 to 35	8.5 to 30	Pelton wheel with single jet
2.	35 to 60	30 to 51	Pelton wheel with two or more jets
3.	60 to 300	51 to 225	Francis turbine
4.	300 to 1000	255 to 860	Kaplan or Propeller turbine

Problem 18.36 *A turbine develops 7225 kW power under a head of 25 metres at 135 r.p.m. Calculate the*



But the speed of turbine is 263.72. And synchronous speed (N^*) is equal to 250. Hence, the speed of turbine is not synchronous. The speed of turbine should be 250 r.p.m.

18.9 AXIAL FLOW REACTION TURBINE

If the water flows parallel to the axis of the rotation of the shaft, the turbine is known as axial flow turbine. And if the head at the inlet of the turbine is the sum of pressure energy and kinetic energy and during the flow of water through runner a part of pressure energy is converted into kinetic energy, the turbine is known as reaction turbine.

For the axial flow reaction turbine, the shaft of the turbine is vertical. The lower end of the shaft is made larger which is known as 'hub' or 'boss'. The vanes are fixed on the hub and hence hub acts as a runner for axial flow reaction turbine. The following are the important type of axial flow reaction turbines :

1. Propeller Turbine, and
2. Kaplan Turbine.

When the vanes are fixed to the hub and they are not adjustable, the turbine is known as propeller turbine. But if the vanes on the hub are adjustable, the turbine is known as a *Kaplan Turbine*, after the name of V Kaplan, an Austrian Engineer. This turbine is suitable where a large quantity of water at low head is available. Fig. 18.25 shows the runner of a Kaplan turbine, which consists of a hub fixed to the shaft. On the hub, the adjustable vanes are fixed as shown in Fig. 18.25.

Fig. 18.25 *Kaplan turbine runner.*

The main parts of a Kaplan turbine are :

1. Scroll casing,
2. Guide vanes mechanism,
3. Hub with vanes or runner of the turbine, and
4. Draft tube.

Fig. 18.26 shows all main parts of a plan turbine. The water from nstock enters the scroll casing and n moves to the guide vanes. From the de vanes, the water turns through 90° flows axially through the runner as wn in Fig. 18.26. The discharge ugh the runner is obtained as

$$Q = \frac{\pi}{4}\left(D_o^2 - D_b^2\right) \times V_{f_1} \qquad \text{...(18.25)}$$

e D_o = Outer diameter of the runner,
D_b = Diameter of hub, and
V_{f_1} = Velocity of flow at inlet.

e inlet and outlet velocity triangles awn at the extreme edge of the vane corresponding to the points 2 as shown in Fig. 18.26.

Fig. 18.26 *Main components of Kaplan turbine.*

Switch Yard

POWER GENERATION –

99MW – it is the **maximum instantaneous output** when the plant is fully loaded.

Number of turbines = 3

3 hydro turbine–generator units

Each unit ≈ 33 MW

total = 3x33MW = 99MW (installed capacity)

Energy is calculated as:

$$\text{Energy (MWh)} = \text{Power (MW)} \times \text{Time (hours)}$$

If, **Case-1–** all 3 turbines ON- each at 33 MW- running for 1 hour

Energy generated = 99×1=99 MWh

That is 99,000 units (kWh) in 1 hour

Case-2– if run on full load for 10 hours

Energy generated = 99×10=990 MWh

That is 9.9 lakh units in 10 hours

Case-3– Typical real operation (not ideal)

Hydel plants rarely run full load all day.

If 2 turbines ON = 66 MW, running for 6 hours

Energy generated = 66×6=396 MWh

That is 3.96 lakh units

Why Obra Hydel does NOT run 24×7 at 99 MW?

Hydel plants are used mainly for-

- Peak load
- Morning & evening demand
- Grid frequency control

They depend on-

- reservoir level
- irrigation demand
- thermal plant coordination

So actual operation is-

- few hours at high load
- few hours at partial load
- sometimes shutdown

Actual electrical path at Obra Hydel-

Turbine (mechanical)

→ Generator output ≈ 11 kV

→ Step-up transformer

→ 33 kV (plant level)

→ Switchyard

→ Further step-up (132 / 220 kV) → Grid

Generator –

Each turbine has its own 11kV- hydro **umbrella shaped Vertical-shaft synchronous generator** connected via shaft

Generator power rating (per unit)

Since Turbine power = 33 MW, Generator is always rated slightly higher.

Typical margin– 5–10%

So generator rating ≈ 35–37 MW per unit

Generator voltage, Vg ≈11 kV

Why not higher?

- insulation limits
- rotor stress
- cooling constraints

Calculations–

Poles count– Since generator is directly coupled to turbine via shaft so formula-.

$$N = 120f \div p$$

Where, N = shaft rpm = turbine rpm

f = Grid frequency

p = .number of poles

$p = 120 \times 50 \div 115 = 52.1739$

$= 52$

Rotor Diameter– In umbrella type hydro generator, rotor diameter is usually larger than runner diameter**.**

$D_{rotor} \approx 1.5$ to 1.8 times runner diameter

$D_{rotor} = 1.6 \times 5.17 = 8.3m$

Pole Pitch–

$$T = \pi D_{rotor} \div p = 8.3\pi \div 52$$

$$= .50144m \approx 500mm$$

This value is comfortable, optimum for field coil placement and mechanically strong

Generator Torque–

Power, $P = T\omega$

Angular speed, $\omega = 2\pi N \div 60 = 2\pi \times 115 \div 60$

$= 12.04277$ rad/sec

Torque, $T = P \div \omega = 33 \times 10^6 \div 12.04277 = 2.74023 \times 10^6$ N-m

$= 2.74$ MN-m

→ This Torque is very high torque because speed is low (115 rpm)

Low speed → High torque

High speed → Lower torque

That’s why hydro generators (low rpm) have-

- Large shaft diameter
- Massive thrust bearing
- Huge rotor diameter
- Salient pole construction

Generator height (axial length)–

Generator height depends on-

i. Rotor rim + pole height
ii. Stator core height
iii. Air gap
iv. Thrust bearing arrangement
v. Top cover + spider
vi. Brake system
vii. Excitation system

In umbrella type-

- Thrust bearing is above the rotor
- Generator is compact vertically compared to conventional vertical type

Typical Proportions for Low-Speed Hydro Generators- For large low-speed salient pole machines

- Rotor diameter- 7–9 m
- Rotor axial length (stack height)- 1.2–1.8 m
- Pole height- 1–1.5 m
- Air gap- 20–40 mm
- Total generator height- usually **0.6 to 0.8 × rotor diameter**

Here, Rotor diameter = 8.3 m

Practical height ratio ≈ 0.7

Height = 0.7×8.3 = 5.8m

Height Reference–

Similar Kaplan unit of Obra was manufactured by H.E. (I) ltd [which is now BHEL] in 1965

Presently For 30–40 MW, 100–150 rpm turbine BHEL & NHPC (National Hydroelectric Power Corporation) keep the generator height around 5 m to 7 m, which matches the calculation.

Generator–turbine alignment–

Vertical stack (top to bottom):

Generator rotor

Generator stator

Thrust bearing ← carries weight of runner + shaft

Main shaft

Kaplan runner

Draft tube

This explains- very tall powerhouse, deep foundations, heavy crane capacity

Where the transformer is placed at Obra?

Physical location- Just outside the powerhouse, each generator has its **own step-up transformer c**alled **Generator Transformer (GT).**

Connection-

Turbine→ Generator (11 kV)→ Generator Transformer→ 33 kV bus→ Transmission lines

Voltage levels are staged-

11 kV → 33 kV → 132 / 220 kV

Why specifically 33 kV (and not directly 132 kV)? It is because 33 kV is used for- nearby substations, local/regional transmission, inter-connection with thermal plant network. Further step-up is done **at the switchyard**, not at the generator.

Technically we can but practically there are reasons.

Reason 1– Switchyard & Local Distribution

Often 33 kV is used for-

- 33 kV is used for local distribution
- Plant auxiliaries may operate at 6.6 kV / 11 kV / 33 kV
- Nearby industries use 33 kV

So 33 kV bus is useful.

If you directly go 132 kV:

- You still need a 33 kV transformer for local supply

- So intermediate voltage becomes necessary anyway

Reason 2– Transformer Rating & Flexibility

Instead of one large 11/132 kV transformer, Plants often use-

- 11/33 kV generator transformer
- Then 33/132 kV grid transformer

It provides- better protection coordination, easier maintenance, modular expansion, fault isolation

Reason 3 – Fault Level Control

In direct 11/132 kV transformer

- High short circuit
- Higher fault currents on 132 kV side
- Protection complexity increases

Intermediate 33 kV bus helps in system segmentation.

Reason 4– Insulation Stress

11 kV → 132 kV is large ratio (1:12), such transformer requires-

- Larger insulation requirement
- More expensive
- Bigger bushings
- Higher impulse stress

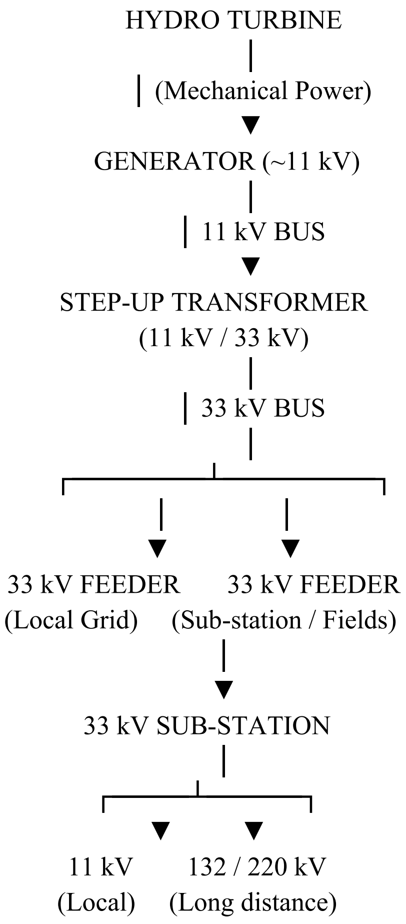
Two-step transformation reduces insulation gradient per stage.

One clean diagram–

Kaplan Turbine
↓
Generator (11 kV)
↓
Generator Transformer (11/33 kV)
↓
33 kV switchyard
↓
Power Transformer (33/132 kV)
↓
Grid

Final Summary–

RIHAND RESERVOIR
|
| (Water)
▼



OBRA THERMAL POWER PLANT

Introduction–

Obra Thermal Power Plant (OTPP) is a coal-based thermal power station located in Obra, Sonbhadra district, Uttar Pradesh. It is one of the major power-generating stations of UP and plays a crucial role in supplying electricity to the state.

- Owner & Operator– Uttar Pradesh Rajya Vidyut Utpadan Nigam Limited (UPRVUNL)
- Type– Coal-fired thermal power plant
- Boiler – Water tube boiler, firing by- pulverized coal
- Turbine – Steam turbine
- Primary fuel– Coal
- Cooling system– Water-based cooling

Installed Capacity–

The plant consists of multiple units developed in phases.

Obra – A → 5x200MW = 1000MW
+ 5x50 = 250 MW
+ 3x100 = 300 MW
Total Capacity = 1550 MW
Present Capacity = 1288MW

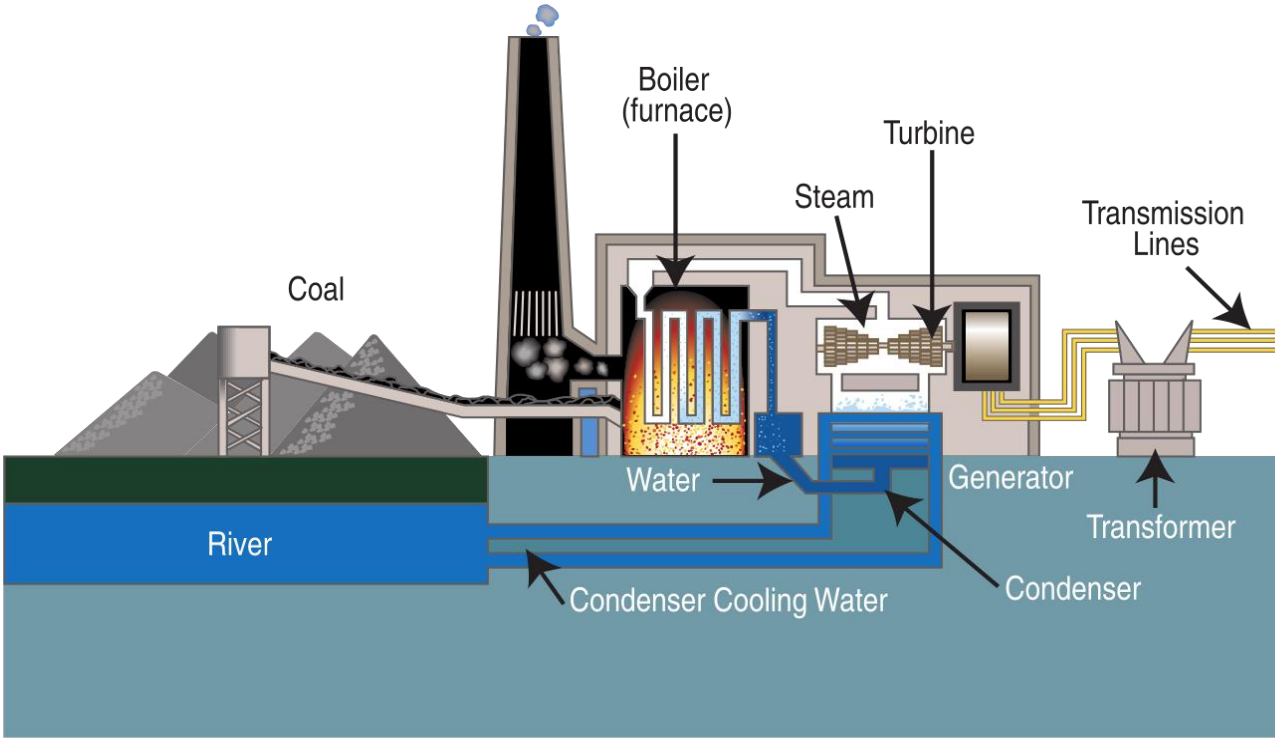
→ Obra–B units are **supercritical technology based**, making them **more efficient and environment-friendly** compared to older units

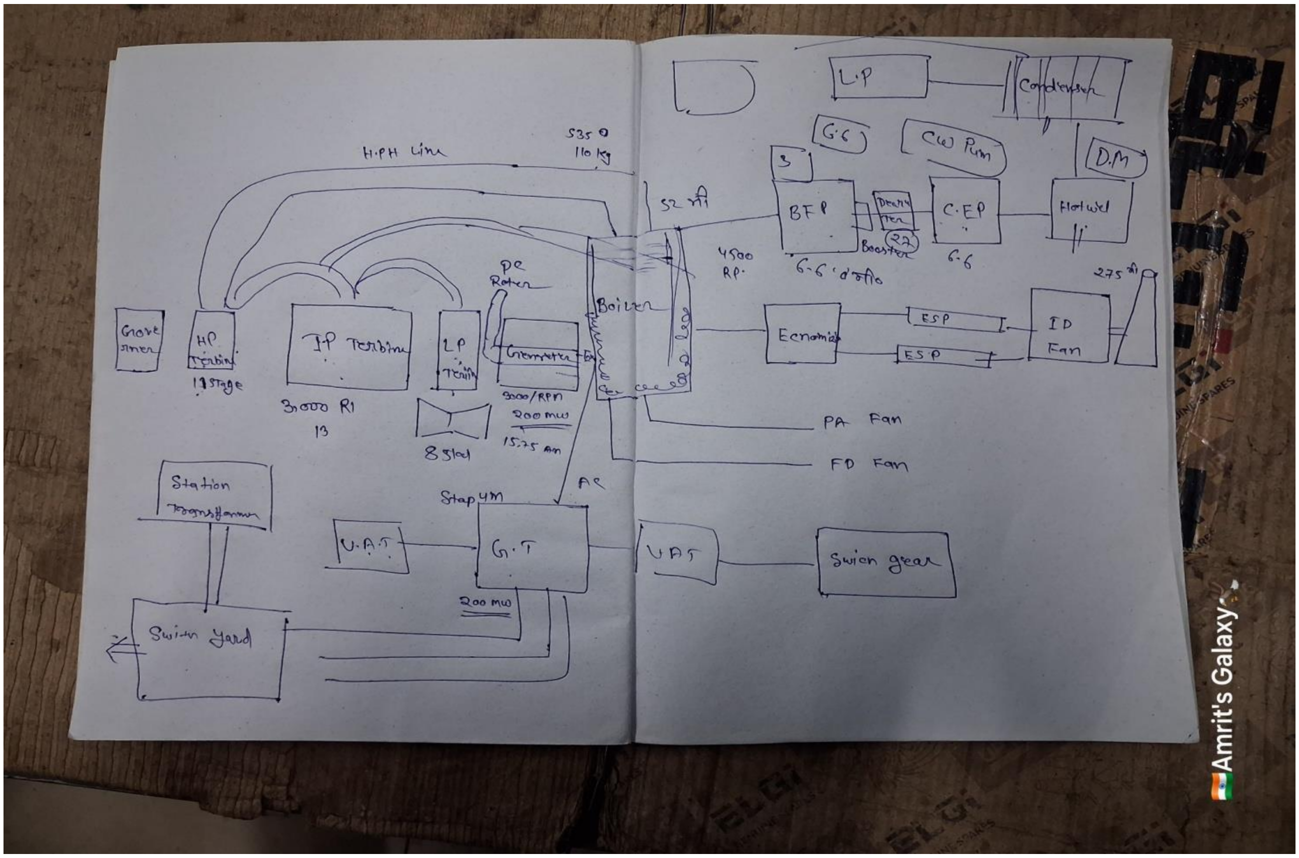
Location advantage–

- Located near coal belt of Eastern India
- close to railway (DHN Division, ECR) connectivity for coal transport
- availability of cooling water
- Sonbhadra is known as the **“Energy Capital of Uttar Pradesh”**

Working Principle–

1. Coal is burned in the boiler
2. Heat converts water into high-pressure steam
3. Steam rotates the steam turbine
4. Turbine drives the alternator (generator)
5. Electricity is stepped up by transformers
6. Power is sent to the grid





Major Systems in Obra TPS –

- Coal Handling Plant (CHP)
- Boiler (Pulverized coal fired)
- Steam Turbine
- Generator
- Condenser
- Cooling Tower
- Ash Handling Plant
- ESP (Electrostatic Precipitator) for pollution control

Environmental Control Measures –

- ESP to control fly ash
- Ash ponds for ash disposal
- High efficiency boilers
- Supercritical units to reduce coal consumption
- Plantation around plant premises

PLANT LAYOUT–

1. Boiler side (Right side of sketch)

Boiler (Water-tube, Pulverized coal fired)

- Coal is burnt in the furnace
- Water flows inside tubes
- Steam generated is high pressure + high temperature

Economiser (Before boiler)

- Feed water from pump → Economiser
- uses waste heat of flue gas
- raises water temperature before entering boiler

Purpose – Fuel saving + increasing efficiency

Superheater (After steam generation)

- Saturated steam → superheated steam
- Temperature raised to ~ **535°C**

Why needed? – Dry steam prevents turbine blade damage.

Reheater (Between HP & IP turbine)

- After HP turbine, steam pressure drops
- Steam sent back to boiler → reheater
- Temperature raised again
- Sent to IP turbine

Purpose – avoid moisture + increase turbine life

2. Turbine section (Upper middle of sketch)

The drawing shows three turbines in series-

HP Turbine – High Pressure Turbine

- Receives **superheated steam**
- High pressure, lower volume
- Produces first stage power

IP Turbine – Intermediate Pressure Turbine

- Steam comes from **reheater**
- Medium pressure → Further expansion

LP Turbine – Low Pressure Turbine

- Low pressure, very large volume steam
- Long blades
- Extracts last usable energy

→ All turbines are on the same shaft connected to Generator

3. Generator & Electrical side (Left / bottom)

Generator

- Turbine shaft → generator rotor
- Mechanical energy → electrical energy

Station Transformer

- Generator voltage ~ 11–15 kV
- Step-up to- 220 / 400 kV
- Power sent to- Switchyard
- Then to- Grid

→ one of the reasons why Switchyard is outside the plant boundary.

4. Condenser system (Right bottom of sketch)

Condenser

- Exhaust steam from LP turbine
- Cooled by circulating water
- Steam → water (condensate)

Why condenser is critical?

- Creates vacuum
- Increases turbine efficiency
- Allows reuse of water

Condensate Extraction Pump (CEP)

- Takes water from condenser
- Sends to LP heaters

5. Feed water heating system

LP (Low Pressure) Heaters

- Heated using **extraction steam from turbine**
- Raise water temperature gradually

Deaerator (DA)

- Removes **O_2 and CO_2**
- Prevents corrosion
- Also acts as **storage tank**

Boiler Feed Pump (BFP)

- Raises pressure to **boiler pressure**
- One of the **highest power-consuming pumps**

HP Heaters

- Final heating before economiser
- Uses turbine extraction steam

→ This whole process is called **Regenerative Feed Heating**

6. Cooling tower & circulating water (Left side)

Cooling Tower

- Hot water from condenser
- Cooled by air
- Sent back to condenser

→ This is a separate loop from boiler water.

7. Air & flue gas path (Lower middle of sketch)

FD Fan

- Pushes air into boiler
- Supports combustion

PA Fan

- Carries pulverized coal
- Primary air for combustion

ID Fan

- Pulls flue gas out
- Maintains negative pressure in furnace

ESP (Electrostatic Precipitator)

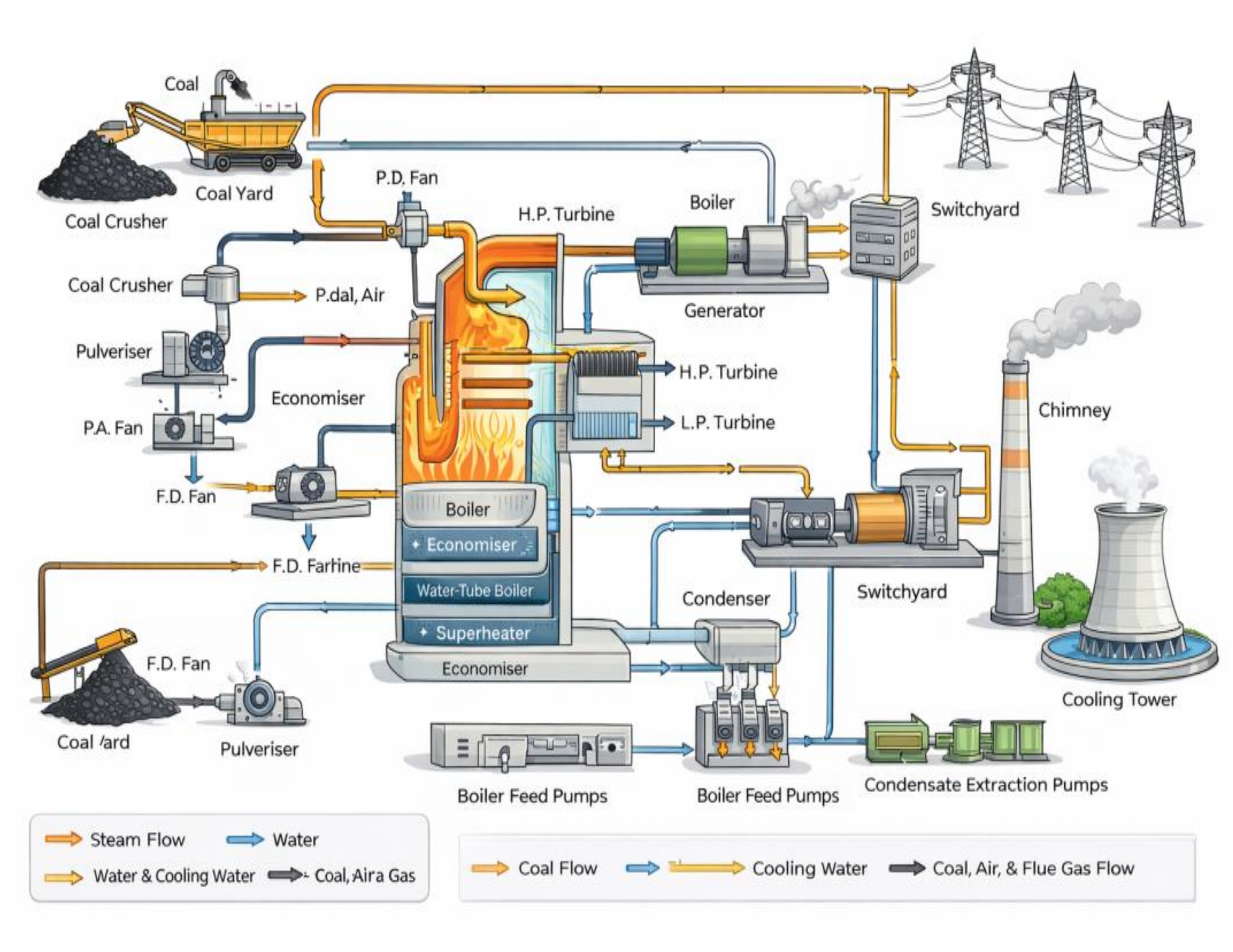
- Removes fly ash
- Protects environment
- Gas exits through chimney

8. Coal handling path

Coal yard → Crusher → Pulveriser → PA fan carries coal-air mixture → Boiler furnace

Complete cycle summary

Coal heats water
→ steam runs turbines
→ power generated
→ steam condensed
→ water reheated
→ reused
→ cycle continues


Coal
Coal Yard
Coal Crusher
Coal Crusher
P.dal, Air
Pulveriser
P.A. Fan
F.D. Fan
Economiser
P.D. Fan
H.P. Turbine
Boiler
Generator
Switchyard
H.P. Turbine
L.P. Turbine
Chimney
Boiler
Economiser
Water-Tube Boiler
Superheater
Economiser
F.D. Fartine
F.D. Fan
Coal Yard
Pulveriser
Condenser
Switchyard
Cooling Tower
Boiler Feed Pumps
Boiler Feed Pumps
Condensate Extraction Pumps
Steam Flow
Water
Water & Cooling Water
Coal, Aira Gas
Coal Flow
Cooling Water
Coal, Air, & Flue Gas Flow


UNIT No-12 (200 M.W.)
TSI-JB-07

PLANT WALKTHROUGH –

A thermal power plant can be considered as a very advanced steam engine running in a loop. The plant layout lies in 4 parts-

1. How do we make steam**?**
2. How do we use steam to make electricity**?**
3. How do we convert steam back into water**?**
4. How do we reuse that water safely and efficiently**?**

STEP 1– Making fire and heat (Coal → Boiler)

- Coal of size **250-300mm** is brought from the coal yard via Conveyor belt
- It is crushed to **20mm** → bowl mill which makes it upto **70-75µ**
- This fine powdered coal is blown into the boiler furnace
- Coal burns → huge heat is produced

STEP 2– Raw Water System

Reservoir / River Intake– It is the source of water for-

- Cooling tower
- DM plant
- Service water

Working-

- Pumps lift water from reservoir
- Sent to raw water treatment plant

Raw Water Treatment Plant (Clarifier + Filters) – Its main function is to remove mud, suspended solids, organic matters

Working-

- Alum dosing → particles settle
- Clarifier removes sludge

- Sand filters polish water

Now water is clean but still contains dissolved salts.

DM (Demineralization) PLANT – DM Plant (RO + Ion Exchange)

Working-

- **RO system**- removes 95–98% dissolved salts
- **Cation exchanger**- removes positive ions (Ca^{2+}, Mg^{2+})
- **Anion exchanger**- removes negative ions (Cl^-, SO_4^{2-})
- **This prevents-** Scale formation, Turbine blade deposits

Output– Ultra pure water (conductivity < 0.2 µS/cm) goes to boiler system.

STEP 3– Feed water System

Deaerator (DA) – Remove dissolved oxygen and CO_2

Working-

- Steam sprayed over water
- Heating drives out gases
- Vent removes oxygen

Why? Because oxygen causes:

$$4Fe + 2H_2O + O_2 \rightarrow 4Fe(OH)_2 \qquad \text{Rust formation}$$

→Even **5–10 ppb oxygen** can cause pitting in high-pressure boilers, deaerator reduces oxygen to less than 7 ppb

Chemical Dosing (Final Protection) – After DM + Deaeration, chemicals are added

Hydrazine or oxygen scavengers – Removes trace oxygen

NH_3 – maintains pH around 9–9.5

Why alkaline? Because steel is stable in alkaline conditions**,** Acidic water causes corrosion.

Why doesn't the boiler corrode continuously? Because inside the boiler-

- High temperature
- High pressure
- Controlled pH
- Very low oxygen
- Protective magnetite (Fe_3O_4) layer forms – This thin oxide layer protects tubes.

→ If minerals are present → scale forms → overheating → tube burst

→ If oxygen present → pitting corrosion

→Between these two – Oxygen is far more dangerous than pure water.

Real Corrosion Scenario in Plants – Corrosion usually happens due to-

- Oxygen ingress during shutdown
- Improper layup
- Condenser tube leakage
- Low pH excursion
- Poor deaerator performance

Boiler Feed Pump (BFP) – Raise pressure of water to boiler pressure (~130–170 bar)

Working-

- Multi-stage centrifugal pump
- Motor or turbine driven
- Pushes water through heaters to boiler

Very high power consumption.

Low Pressure (LP) Heaters – Preheat feedwater using extracted turbine steam

Working-

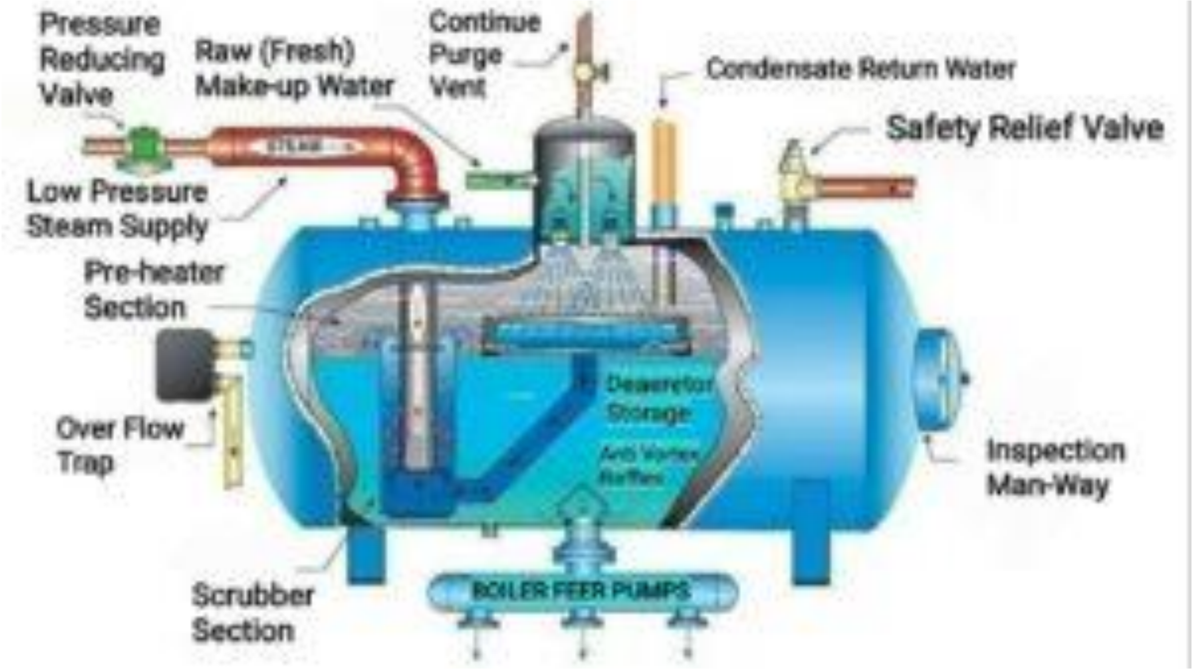
- Steam from LP turbine heats water
- Improves efficiency

High Pressure (HP) Heaters– Final heating before boiler

Working-

- Steam extracted from IP turbine
- Raises water temperature further

This process is called **Regenerative Heating**.



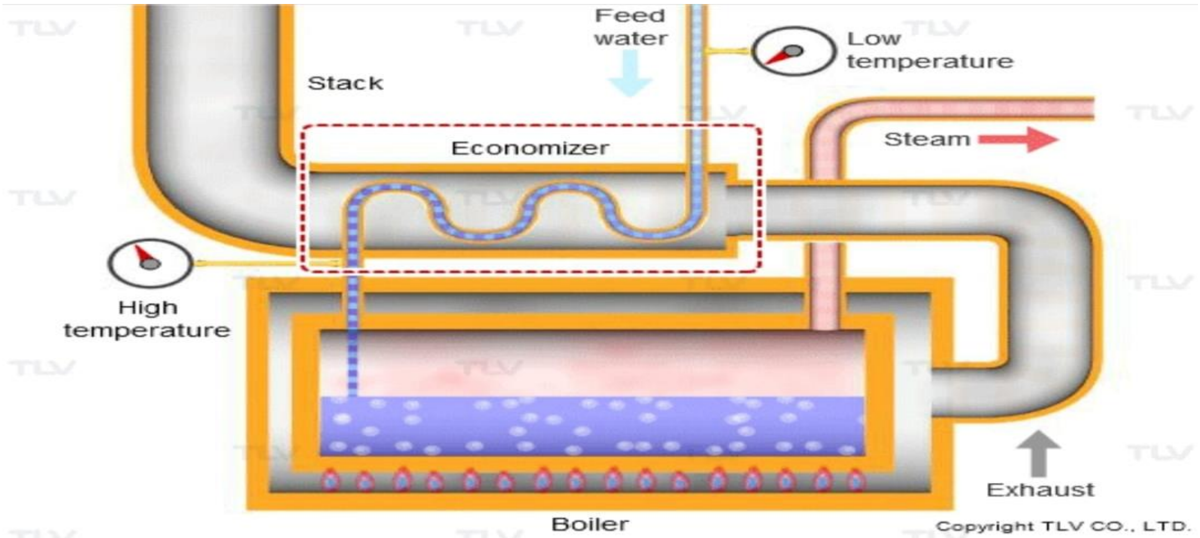
STEP 4– Turning water into very powerful steam (Inside the Boiler)

Inside and around the boiler, three important things happen-

1. Economiser– Preheat feedwater using flue gas heat

Working-

- Flue gases pass over tubes
- Water temperature increases
- Fuel saving



2. Boiler furnace – convert water into steam

Working-

- Pulverized coal burns
- Water flows inside tubes
- Heat transfer occurs
- Steam forms

3. Superheater – Increase steam temperature above saturation

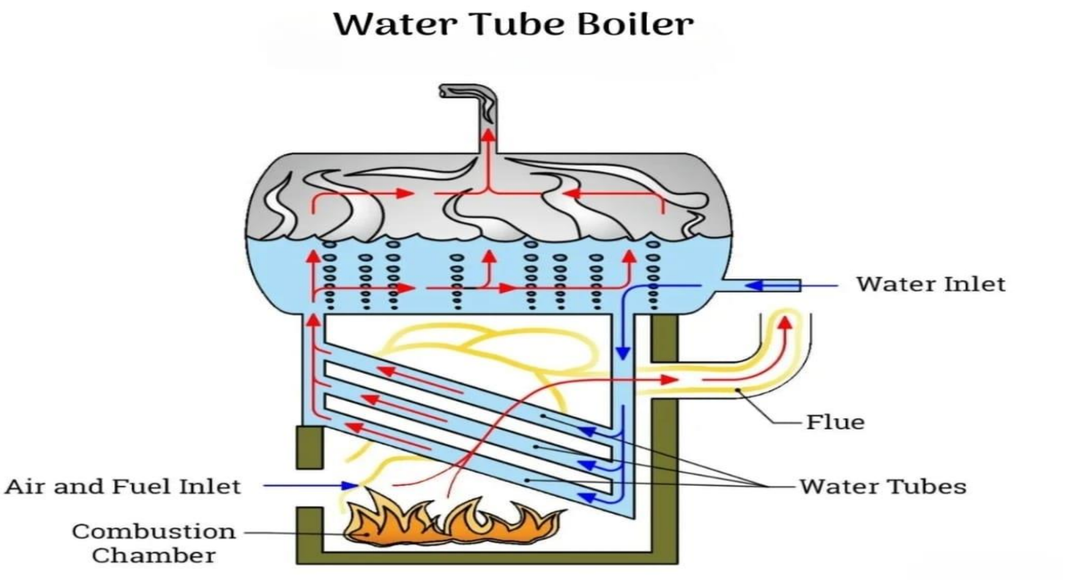
Working-

- Steam passes through hot gas path
- Temperature raised to ~535°C
- Prevents moisture in turbine

4. Reheater – Reheat steam after HP turbine

Working-

- Steam returns from HP turbine
- Heated again
- Sent to IP turbine
- Improves turbine life.



STEP 5– Turbine System

HP Turbine – High Pressure turbine, First stage energy extraction

Working-

- High-pressure steam enters
- Rotates blades
- Pressure drops

IP Turbine – Intermediate expansion

Working-

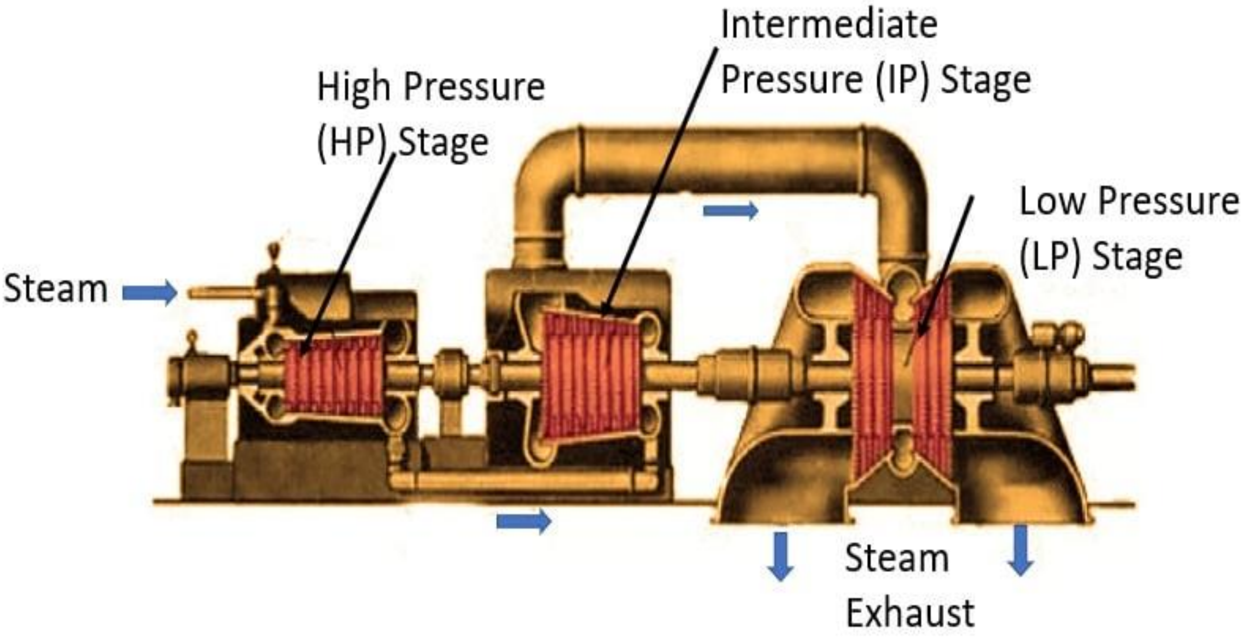
- Reheated steam expands
- More energy extracted

LP Turbine – Low Pressure turbine, Final expansion stage

Working-

- Low-pressure high-volume steam
- Long blades
- Maximum energy extraction

→ All turbines connected to same shaft



STEP 6– Generator & Electrical

Generator (Alternator) – converts mechanical energy → electrical energy

Working-

- Shaft rotates rotor
- Magnetic field rotates
- Electricity induced in stator

Output ≈ 11–15 kV

Step-up Transformer – increase voltage to transmission level

Working-

- 11 kV → 220/400 kV
- Reduces transmission losses

Switchyard – Send electricity to grid

Working-

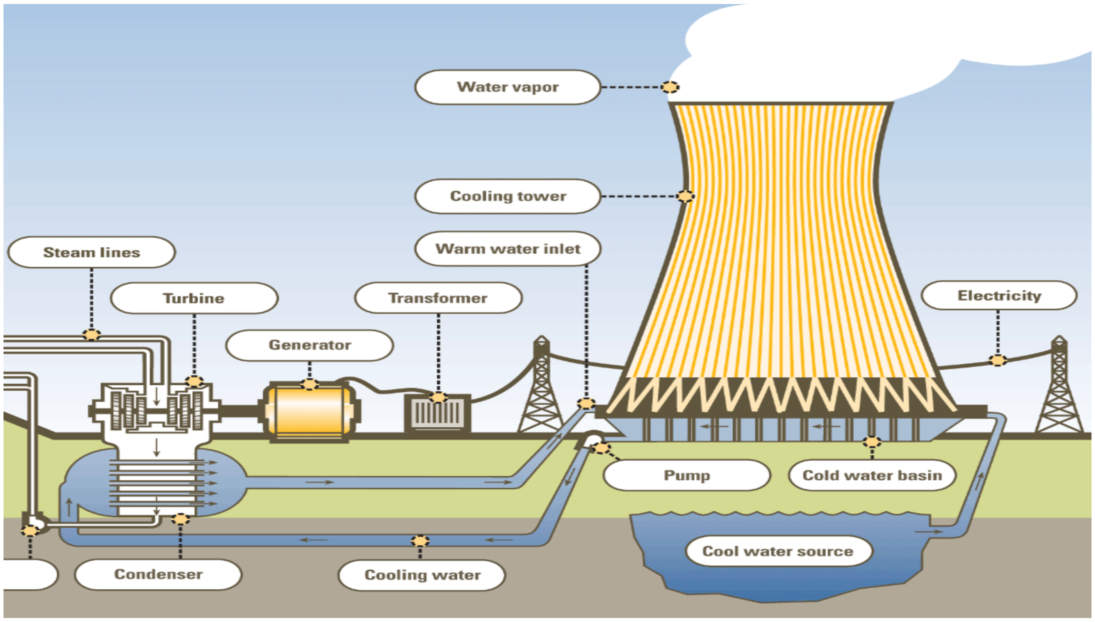
- Circuit breakers
- Isolators
- Busbars → Transmission lines

STEP 6– Condensing & Cooling

Condenser – convert steam back to water

Working-

- Steam contacts cold tubes
- Condenses
- Vacuum maintained
- Improves efficiency.



<u>Circulating Water Pump (CWP) –</u> Pump cooling water through condenser

<u>Cooling Tower–</u> Cool hot water from condenser

Working-

- Hot water sprayed
- Air flows upward
- Some water evaporates
- Remaining water cools
- Recycled back

<u>STEP 7–</u> Air & Flue Gas System

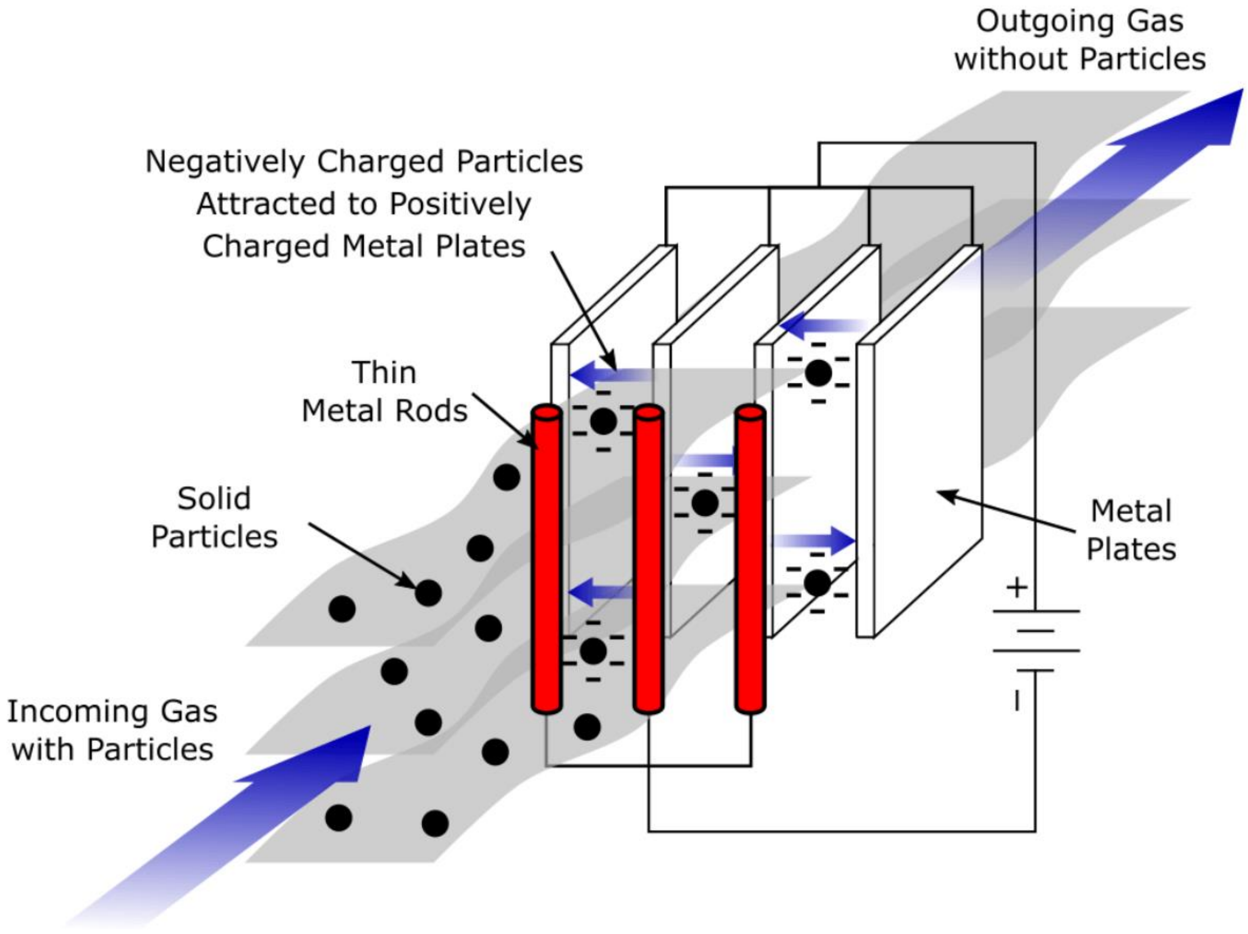
<u>FD Fan (Forced Draft) –</u> Pushes air into boiler

<u>PA Fan (Primary Air) –</u> Carries pulverized coal

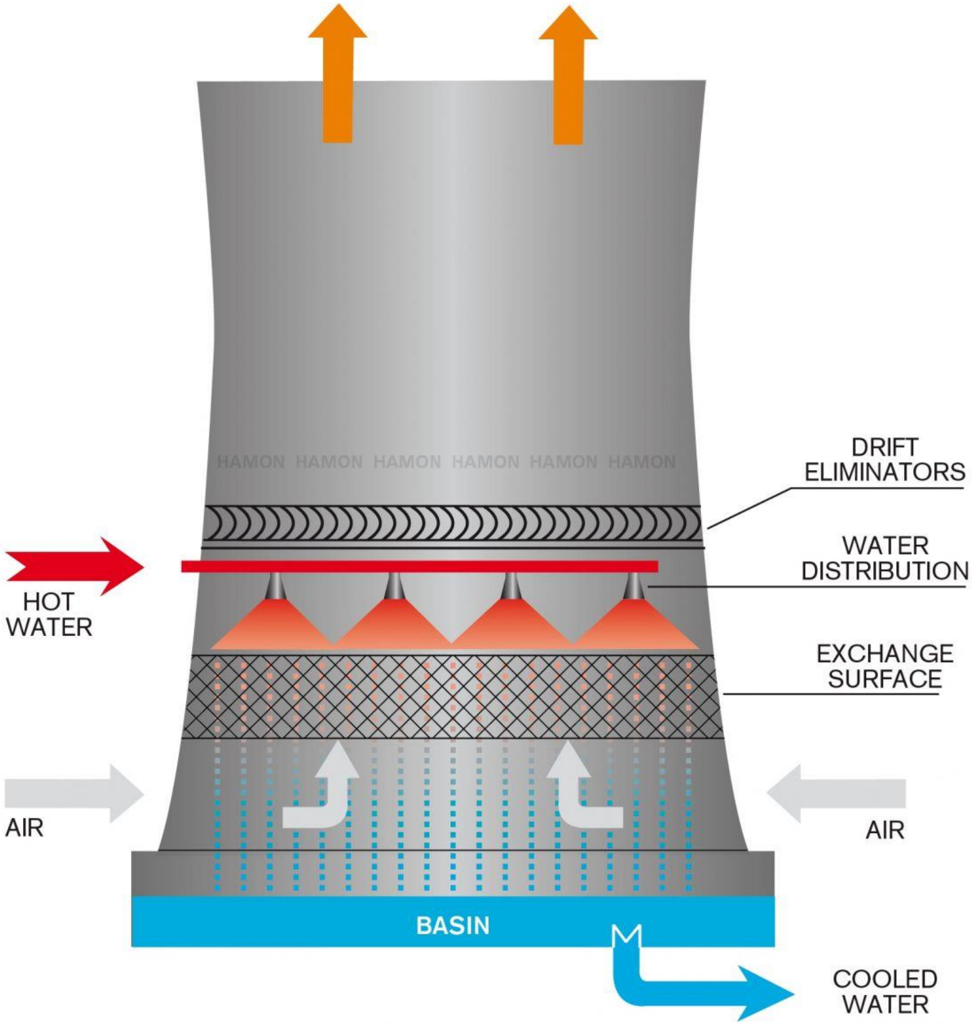
<u>ID Fan (Induced Draft) –</u> Pulls flue gas out and maintains negative pressure

<u>ESP (Electrostatic Precipitator) –</u> Removes fly ash particles

<u>Chimney –</u> Releases cleaned gases to atmosphere



Working of ESP



Induced Draft Cooling Tower- work-diagram

STEP 8– Ash Handling

Bottom Ash System – Collects heavy ash from furnace

Fly Ash System – Collects fine ash from ESP → Ash pond → Cement industry

Final Simplified Flow –

Raw water → DM plant → Deaerator → Pump → Heaters → Boiler → Turbine → Generator → Transformer → Grid

Steam → Condenser → Cooling tower → Recycle

Calculations –

1. Water Requirement – Water requirement can be breakdown in 4 parts-

I. How much water is needed initially?
II. How much steam is produced?
III. Where losses happen?
IV. How much steam/water is actually lost?

I. How much water is needed for one 200 MW boiler?

A 200 MW subcritical coal unit typically requires-

Steam generation rate ≈ 650–750 tonnes per hour (TPH) = 700TPH

which means- 700 tonnes/hour = 700,000 kg/hour of water boiler converts into steam every hour

Initial filling requirement – Before starting from cold condition-

- Boiler drum + water walls + piping + economiser
- Condenser hotwell
- Deaerator storage tank
- Feedwater lines

Roughly, ≈ 1,500 – 2,000 tonnes of water initially

This is **one-time filling**, not continuous consumption. Initial filling depends on- Total internal water holding volume + Size of condenser hotwell + Deaerator storage capacity + Boiler circulation volume

→ It is not directly equal to steam generation rate**,** but proportional to plant size.

II. What happens to 700 TPH steam?

Steam path– Boiler → HP Turbine → Reheater → IP → LP → Condenser → back to boiler

In ideal condition, **a**lmost all 700 TPH is reused but there are losses (real plant ≠ ideal plant)

III. Where losses happen (step-by-step)

In the direction of flow –

A. Boiler losses – Blowdown loss

To remove dissolved solids typically 1–3% of steam generation ≈ 2% (assume)

$700 \times 0.02 = 14$ TPH

Loss = **14 tonnes/hour**

B. Steam leakages – From- Valve glands + Flanges + Start-up vents + Drains ≈ 0.5 – 1% = 1% (assume)

$700 \times 0.01 = 7$ TPH

Loss = **7 tonnes/hour**

C. <u>Turbine gland steam loss –</u> Steam used for sealing turbine shaft **≈ 0.5%**

$700 \times 0.005 = 3.5$ TPH

Loss = **3.5 tonnes/hour**

D. <u>Auxiliary system drains –</u> Sampling + Chemical dosing + Heater drains ≈ 1–2% = 1% (assume)

$700 \times 0.01 = 7$ TPH

Loss = **7 tonnes/hour**

E. <u>Cooling tower evaporation loss –</u> This steam is NOT loss directly from boiler, but cooling water evaporation**.**

For 200 MW unit, Cooling water circulation ≈ 25,000–30,000 m^3/hr

Evaporation loss formula, $\boxed{E = 0.00085 \times C \times \Delta T}$

Where, C = Circulating water (m^3/hr) =30000 m^3/hr (assuming)

ΔT = Temperature rise (°C) ≈ 10 °C (outlet water may rise by 8–10° C)

Evaporation loss, $E = 0.00085 \times 30000 \times 10 = 255\ m^3/hr$

≈ 1% ≈ 300m^3/hr water loss **<u>*this is makeup water requirement</u>**

Total steam/water loss per hour = 30.5 TPH ≈ 30 tonnes/hour ≈ 4%

Therefore, Steam reused ≈ 670 TPH ≈ 96%

& Makeup water requirement ≈ 30 tonnes per hour

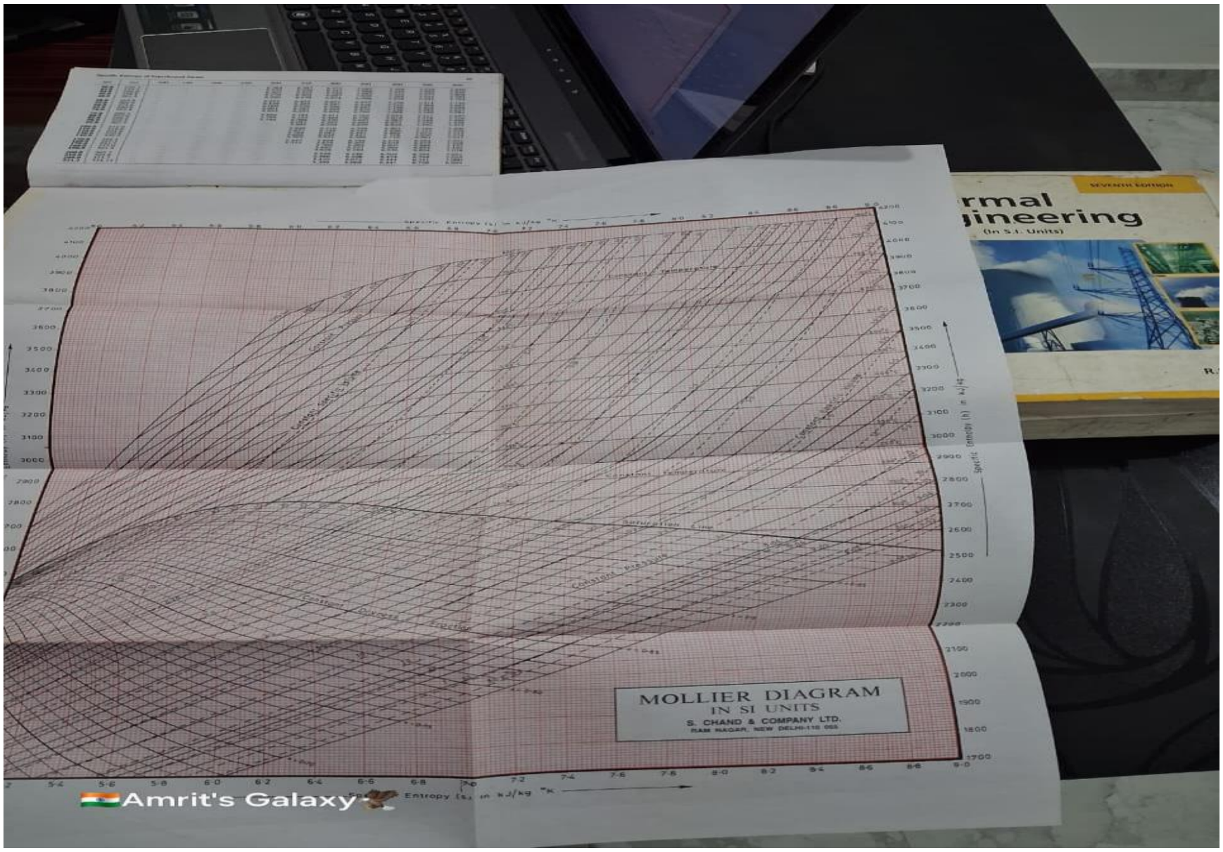
+ Cooling tower evaporation ≈ 300–400 m^3/hr

Therefore, totals plant water makeup = 300m^3/hr + 30TPH ≈ (300 + 30) m^3/hr

≈ 350 m^3/hr **<u>*for 200 MW unit</u>**

<u>Important Concept –</u> The boiler does NOT consume 700 tonnes of water every hour**,** it circulates 700 tonnes per hour in a loop. **Actual fresh water consumption is only ~4% of steam flow.**

2. Steam–



Steam turbine works on – **Rankine Cycle**

Main processes – Standard numbering:

1 → Turbine inlet (superheated steam)

2 → Turbine exit

3 → Condenser exit (saturated liquid)

4 → Pump exit (compressed liquid entering boiler)

STEP 1 — Realistic Steam Conditions

For 200 MW unit

Main Steam Pressure = 130 bar (safe for steel structures)

Temperature = 535°C

Condenser pressure= 0.1 bar (~45°C saturation)

STEP 2 — Steam Table & MOLLIER DIAGRAM

At Turbine Inlet 130 bar & 535°C

by **MOLLIER DIAGRAM,** Specific Enthalpy, h_1 = 3460 kJ/kg

Specific Entropy, s_1 = 6.58 kJ/kg K

At Condenser Pressure (0.1 bar)

According to **STEAM TABLE 1,** saturated water and steam (temperature) table

Absolute pressure, $p = 0.10080$ bar

Temperature = 46°C

Specific enthalpy of water, $h_f = 192.5$ kJ/kg

Specific enthalpy of steam, $h_g = 2585.1$ kJ/kg

Specific entropy of water, $s_f = 0.651$ kJ/kg K

Specific entropy of steam, $s_g = 8.148$ kJ/kg K

STEP 3 — Find Turbine Exit State (Isentropic Expansion)

Since ideal expansion, $s_2 = s_1 = 6.58$

Quality equation, $\boxed{s_2 = s_f + x(s_g - s_f)}$

$\Rightarrow 6.58 = .651 + x(8.148 - .651)$

Therefore, $x = 0.790849$

→ So steam at exit is 79% dry

For exit enthalpy, $\boxed{h_2 = h_f + x(h_g - h_f)}$

$\Rightarrow h_2 = 192.5 + .790849(2585.1 - 192.5)$

Therefore, $h_2 = 2084.685317$ kJ/kg

STEP 4 — Turbine Work

$W_t = h_1 - h_2 = 3460 - 2084.685317$

$= 1375.314683$ kJ/kg

STEP 5 — Pump Work

Pump work, $W_p \approx 10$ kJ/kg

Net work, $W_{net} = 1375.314683 - 10 = 1365.314683$

≈ 1365 kJ/kg

STEP 6 — Heat Supplied in Boiler

$Q_{in} = h_1 - h_4$

Where, h_1 = Enthalpy of water at turbine inlet = 3460 kJ/kg

h_4 = Enthalpy of water at pump outlet = $h_3 + W_p$

h_3 = Enthalpy of saturated water leaving the condenser

According to **STEAM TABLE 2,** saturated water & steam (pressure) table

At Absolute pressure, $p = 0.100$ bar

$h_3 = 191.8$ kJ/kg

Therefore, $h_4 = h_3 + W_p = 191.8 + 10 = 201.8$

≈ 200 kJ/kg

Finally $Q_{in} = h_1 - h_4 = 3460 - 200$

= 3260 kJ/kg

STEP 7 — Rankine Cycle Efficiency

Efficiency, $\boxed{\eta = W_{net} \div Q_{in}}$

$= 1365 \div 3260 = 41.8711\%$

Therefore, **$\eta \approx 41.87\%$**

→ This is **Ideal Rankine efficiency**

→ Now apply real-world losses –

- Turbine efficiency ≈ 85%
- Generator efficiency ≈ 98%
- Boiler efficiency ≈ 85–90%
- Mechanical losses

Actual overall plant efficiency = 41.87% × 0.85 × 0.9 = 32.03055%

Overall Plant efficiency = 32%

Conclusion –

Ideal thermodynamic efficiency ≈ **42%**

Actual plant efficiency ≈ **32 – 33%**

Loss difference ≈ 9–10% due to real-world irreversibility

→ A thermal plant is not inefficient because Engineering failed – it is limited by the **Second Law of Thermodynamics.**