

Power Plant Engineering (315374)

Model Question Paper — Set A · Model Answers

Q.1**a) Classification of power plants by source of energy.**

2 M

- **Conventional:** steam (coal / thermal) power plant, hydro-electric power plant, nuclear power plant, diesel power plant, gas turbine power plant.
- **Non-conventional:** solar, wind, geothermal, tidal, biomass and biogas power plants.

*(Conventional 1 M, non-conventional 1 M)***b) Calorific value; HCV and LCV.**

2 M

Calorific value (CV): It is the amount of heat released by complete combustion of unit mass (1 kg) of a solid/liquid fuel or unit volume (1 m³) of a gaseous fuel. Unit: kJ/kg (or kcal/kg) and kJ/m³.

- **HCV (gross CV):** heat released when the water vapour formed by combustion is condensed, so its latent heat is included.
- **LCV (net CV):** heat released when the water vapour escapes uncondensed; $LCV = HCV - \text{latent heat of the water vapour formed}$. $LCV < HCV$.

*(Definition 1 M, difference 1 M)***c) Components of gas turbine power plant.**

2 M

1. Compressor
2. Combustion chamber
3. Gas turbine
4. Generator (alternator)

(Also: starting motor, regenerator, intercooler, fuel system.)

*(Any four, ½ M each)***d) Regulatory agencies for nuclear power plants.**

2 M

- **AERB** — Atomic Energy Regulatory Board (India), the national nuclear safety regulator (formed 1983 under the Atomic Energy Act, 1962).
- **DAE / AEC** — Department of Atomic Energy and Atomic Energy Commission (policy).
- **IAEA** — International Atomic Energy Agency, Vienna (international safety standards and safeguards).

*(Indian agency 1 M, international agency 1 M)***e) Load factor and diversity factor.**

2 M

Load factor: Ratio of average load to maximum demand during a given period. It is always less than 1.

$$\text{Load factor} = \text{Average load} / \text{Maximum demand}$$

Diversity factor: Ratio of the sum of individual maximum demands of consumers to the maximum demand of the whole system (power station). It is greater than 1, because individual peaks do not occur at the same time.

$$\text{Diversity factor} = \Sigma \text{Individual maximum demands} / \text{Maximum demand on station}$$

(1 M each)

f) Commercial uses of fly ash.

2 M

1. Manufacture of Portland Pozzolana Cement (PPC) and as part-replacement of cement in concrete.
2. Fly-ash bricks, blocks and tiles.
3. Road embankments and sub-base of roads / highways.
4. Filling of low-lying areas and abandoned mines.

(Any four, ½ M each)

g) Full forms under NMEEE.

2 M

Abbreviation	Full form
PAT	Perform, Achieve and Trade
MTEE	Market Transformation for Energy Efficiency
EEFP	Energy Efficiency Financing Platform
FEEED	Framework for Energy Efficient Economic Development

(½ M each)

Q.2

a) Site selection for steam power plant.

4 M

1. **Availability of fuel (coal):** Plant should be near coal mines (pit-head) or near a railway line so that transport cost of coal is low (a 500 MW unit burns about 6000–7000 t of coal per day).
2. **Availability of water:** Large quantity of water is needed for condenser cooling and boiler feed make-up, so the site should be near a river, lake or sea.
3. **Transport facilities:** Rail and road connections are needed for coal, heavy machinery and staff.
4. **Nature of land / soil:** Land should be cheap, level and have good bearing capacity to carry heavy foundations of boiler and turbo-generator.
5. **Ash disposal:** Enough space should be available for ash pond / ash dyke and for fly-ash utilisation units.
6. **Nearness to load centre:** Transmission cost and losses are less if the plant is near the load centre.
7. **Pollution and population:** Site should be away from thickly populated areas; wind direction should carry smoke and fly ash away from towns.
8. **Space for expansion:** Space for future extension of units and for staff colony should be available.

(Any four factors with explanation, 1 M each)

b) Electrostatic precipitator.

4 M

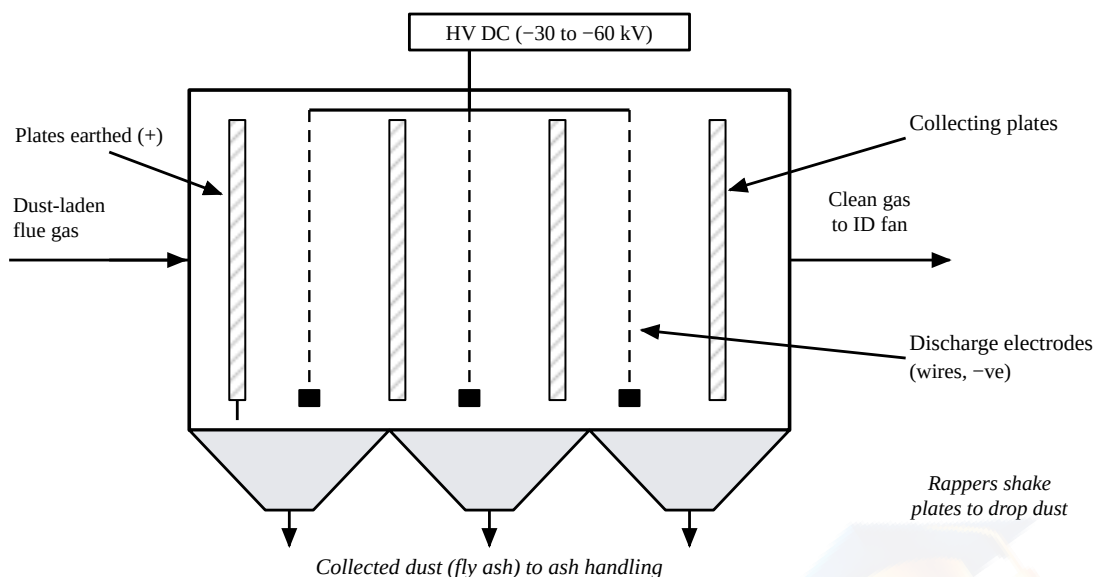


Fig.: Electrostatic precipitator (plate type)

- Construction:** an ESP is a large chamber in which vertical earthed **collecting plates** are placed parallel to each other with **discharge electrodes** (wires) hung midway between them. The wires are connected to a high-voltage DC supply (about -30 to -60 kV) and the plates are earthed. Hoppers are provided at the bottom and rapping hammers on the plates.
- Ionisation (corona):** the high voltage produces a strong electric field near the wires; the gas around them ionises (corona discharge) and produces a large number of negative ions.
- Charging:** as the dust-laden flue gas passes slowly between the plates, the negative ions attach to the dust particles, which become negatively charged.
- Collection:** the charged particles are attracted to the positively (earthed) collecting plates and stick to them; clean gas leaves the ESP and goes to the ID fan and chimney.
- Removal:** the plates are periodically rapped (shaken); the dust layer falls into the hoppers and is removed by the fly-ash handling system.

(Sketch 2 M, working 2 M)

c) Need and opportunities of waste heat recovery.

4 M

Need:

- In a thermal power plant only 35–40 % of fuel energy becomes electricity; a large part is lost in flue gases, condenser cooling water, blow-down, etc.
- Recovering waste heat reduces fuel consumption and cost per kWh, i.e. improves overall efficiency.
- Reduces CO_2 and other emissions per kWh and thermal pollution.
- Helps meet PAT (net heat rate) targets under NEMEE and gives ESCerts.

Opportunities:

- Flue gases — economiser and air preheater (and HRSG behind gas turbines).
- Continuous blow-down water — flash tank and heat exchanger.
- Turbine extraction steam — regenerative feed-water heating.

- Condenser cooling water — low-temperature uses (district heating, fish farming).

(Need 2 M, opportunities 2 M)

d) Advantages and disadvantages of nuclear power plant.

4 M

Advantages:

1. Very small quantity of fuel needed (1 kg U-235 on complete fission gives energy equal to about 3000 t of coal); fuel transport cost negligible.
2. Requires less space than a coal plant of the same capacity.
3. No CO₂, SO₂ or fly ash emission — no air pollution in normal operation.
4. Suitable for large base-load units; can be located away from coal mines and near load centres.

Disadvantages:

1. Very high capital cost and long construction period.
2. Danger of radioactive leakage; elaborate shielding and safety systems needed.
3. Disposal of radioactive waste is a serious problem.
4. Not suitable for varying (peak) loads.

(½ M each)

Q.3

a) Closed cycle gas turbine power plant.

4 M

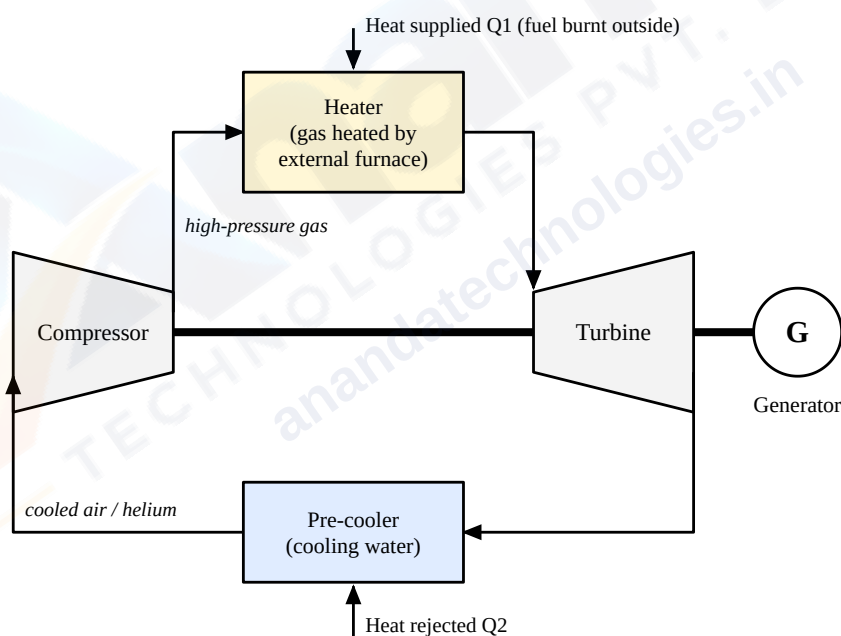


Fig.: Closed cycle gas turbine power plant

1. In a closed cycle the same working fluid (air, helium or CO₂) circulates again and again; it does not mix with the products of combustion.
2. The **compressor** compresses the cooled working fluid from the pre-cooler to high pressure.
3. The compressed fluid is heated at constant pressure in a **heater** (heat exchanger) by burning fuel **outside** in a separate furnace — external combustion.

- The hot high-pressure fluid expands in the **turbine** and produces work; the turbine drives the compressor and the generator.
- The exhaust from the turbine is cooled in the **pre-cooler** by cooling water and returned to the compressor inlet, completing the cycle.

(Sketch 2 M, working 2 M)

b) Coal pulverization by ball mill.

4 M

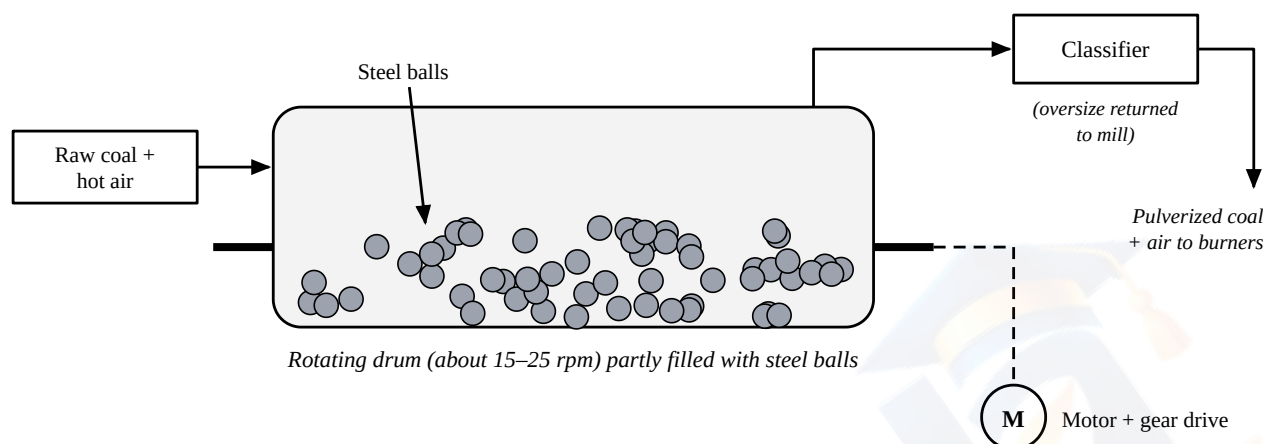


Fig.: Ball mill (tube mill) for coal pulverization

- Pulverization means grinding coal to a fine powder (about 70–80 % passing through a 200-mesh / 75-micron sieve) so that it burns quickly and completely like a gas, with less excess air.
- A ball mill is a horizontal rotating steel drum lined with wear-resistant plates and partly filled with hardened **steel balls** of different sizes.
- Crushed coal and hot primary air enter through the hollow trunnion at one end. As the drum rotates slowly, the balls are lifted and fall (cascade) on the coal; coal is ground by **impact and attrition**; hot air dries the coal.
- Fine coal is carried by the air stream to a **classifier**; oversize particles are returned to the mill and fine coal–air mixture goes to the burners.
- Advantages: simple, reliable, can grind hard and abrasive coal. Disadvantages: heavy, noisy, higher power consumption per tonne than bowl mills.

(Sketch 2 M, working 2 M)

c) Objectives of feed water treatment and parameters.

4 M

Objectives:

- To remove **hardness** (Ca and Mg salts) so that scale is not formed on boiler tubes (scale reduces heat transfer and causes overheating and tube failure).
- To prevent **corrosion** of boiler and feed system by removing dissolved O_2 and CO_2 and maintaining correct pH.
- To prevent **priming and foaming** (carry-over of water with steam) by controlling dissolved and suspended solids.
- To avoid **caustic embrittlement** of boiler plates and deposits on turbine blades (silica, salts).

Importance of parameters:

Parameter	Meaning	Requirement
Total hardness	Ca and Mg salts (as CaCO_3)	Practically nil (removed by softening / DM plant)
pH value	Acidity or alkalinity of water	Slightly alkaline, about 8.5–9.5 for feed water
Total dissolved solids (TDS)	All dissolved salts	As low as possible (DM water for high-pressure boilers); controlled by blow-down

(Objectives 2 M, parameters 2 M)

d) Fixed cost and operating cost.

4 M

1. **Fixed cost** (independent of energy generated — depends on installed capacity / maximum demand):

- Interest on capital investment (land, buildings, plant and equipment).
- Depreciation of plant and equipment.
- Taxes and insurance.
- Salaries of management and permanent staff, rent, etc.

2. **Running (operating / variable) cost** (proportional to energy generated, kWh):

- Cost of fuel (largest item for steam, gas and diesel plants).
- Cost of lubricating oil, water and chemicals.
- Wages of operating staff paid on the basis of generation.
- Repairs and maintenance depending on running hours.

3. **Total annual cost** = Fixed cost + Running cost; **Cost per kWh** = Total annual cost / kWh generated per year. Higher load factor spreads the fixed cost over more kWh and reduces cost per unit. (Some books also take a semi-fixed cost that depends on maximum demand.)

(Fixed cost 2 M, operating cost 2 M)

Q.4

a) Schematic of modern steam power plant and its circuits.

4 M

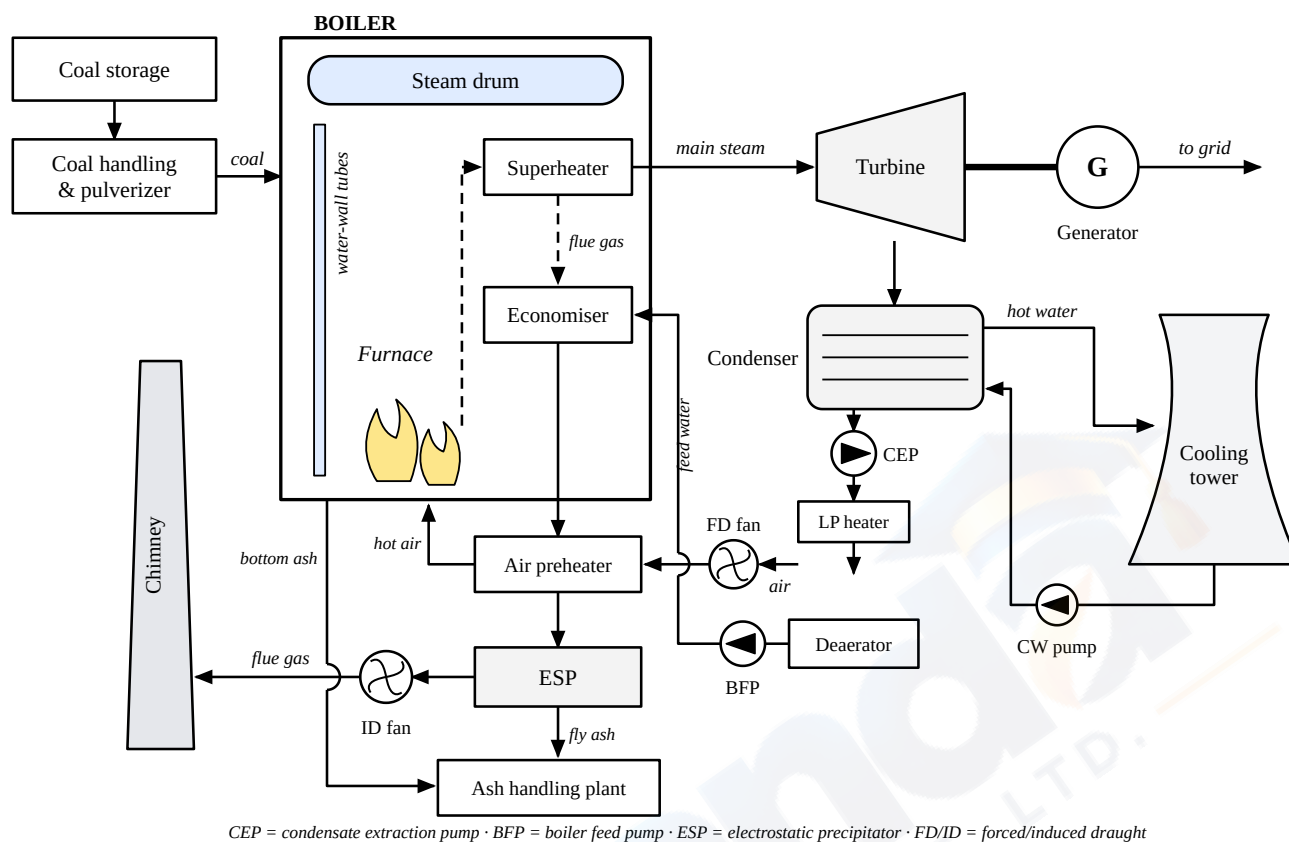


Fig.: Schematic layout of a modern coal-fired steam (thermal) power plant

- Coal and ash circuit:** coal storage → coal handling → pulverizer → boiler furnace; ash → ash handling plant → ash pond / silo.
- Air and flue gas circuit:** FD fan → air preheater → furnace; flue gas → superheater → economiser → air preheater → ESP → ID fan → chimney.
- Feed water and steam circuit:** condenser → CEP → LP heater → deaerator → BFP → HP heater → economiser → drum → superheater → turbine → condenser.
- Cooling water circuit:** condenser → hot water to cooling tower → cold water basin → CW pump → condenser.

The plant works on the **Rankine cycle**. For example, with steam at 160 bar, 540 °C and condenser pressure 0.1 bar (values from steam tables, computed): $h_1 = 3412$ kJ/kg, $h_2 = 2042$ kJ/kg (dryness 0.773), $h_3 = 191.8$ kJ/kg, pump work = 16.1 kJ/kg; $\eta_{\text{Rankine}} = [(h_1 - h_2) - W_p] / (h_1 - h_4) = (1370 - 16.1) / 3204 = 42.3 \%$ (ideal cycle; actual plant overall efficiency is about 35–40 %).

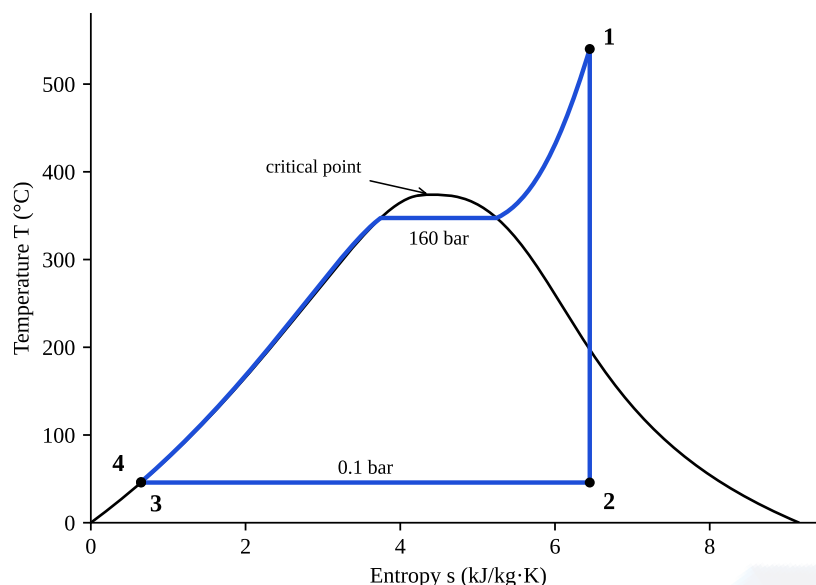


Fig.: Ideal Rankine cycle on T-s diagram (160 bar, 540 °C → 0.1 bar; computed with steam property data)

(Schematic 2 M, four circuits 2 M (T-s diagram for reference))

b) Compare BWR and PWR.

4 M

Point	BWR	PWR
Coolant boiling	Water boils inside the reactor vessel	Water does not boil (kept at ≈155 bar)
Circuits	Single circuit — steam goes directly to turbine	Two circuits — primary and secondary
Steam generator / pressuriser	Not required	Required
Reactor pressure	About 70 bar	About 155 bar
Radioactivity in turbine	Turbine steam is radioactive — shielding needed	Turbine steam is not radioactive
Control rods	Inserted from bottom	Inserted from top

(Any four points, 1 M each)

c) PAT scheme under NMEEE.

4 M

NMEEE (National Mission for Enhanced Energy Efficiency) is one of the eight missions of the National Action Plan on Climate Change (NAPCC, 2008); it is implemented by the Bureau of Energy Efficiency (BEE) under the Energy Conservation Act, 2001.

- PAT is a market-based mechanism under NMEEE to improve energy efficiency of large energy-intensive industries, called **Designated Consumers (DCs)**, e.g. thermal power plants, cement, iron & steel, aluminium, fertilizer, pulp & paper, textile, chlor-alkali, refineries, railways, DISCOMs.
- Perform:** each DC is given a target to reduce its Specific Energy Consumption (SEC) — for a thermal power plant the target is a reduction in **net heat rate** (kcal/kWh) — over a 3-year cycle from its baseline.

3. **Achieve:** DCs implement energy-saving measures; achievement is verified by accredited energy auditors.
 4. **Trade:** DCs that do better than the target get **Energy Saving Certificates (ESCerts)** (1 ESCert = 1 tonne of oil equivalent saved). DCs that fail must buy ESCerts or pay a penalty. ESCerts are traded on power exchanges (IEX, PXIL).
 5. PAT Cycle-I (2012–15) covered 478 DCs in 8 sectors; later cycles added more sectors and DCs.
- (Concept 1 M, perform–achieve–trade 3 M)

d) Three-element boiler feed water control.

4 M

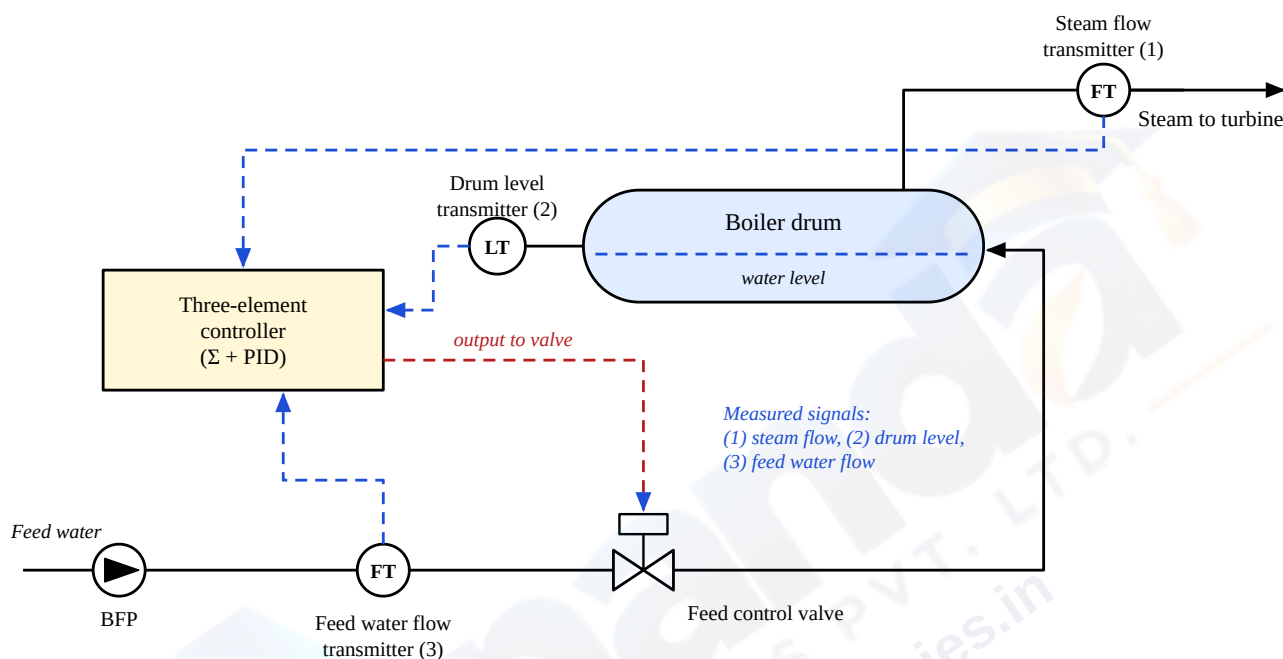


Fig.: Three-element boiler drum level (feed water) control

1. **Element 1 – Drum level:** the level transmitter (LT) measures the water level in the drum and sends it to the controller; this is the main controlled variable.
2. **Element 2 – Steam flow:** the steam-flow transmitter measures the steam drawn by the turbine. A change in load is sensed immediately, so feed water is changed in advance (feed-forward).
3. **Element 3 – Feed water flow:** measures actual feed water entering; the controller compares feed flow with steam flow and corrects the mismatch.
4. The controller combines the three signals and adjusts the **feed control valve** (or feed pump speed) so that feed flow = steam flow and the drum level remains at its set value even during sudden load change (no error due to "swell and shrink").

Importance:

- Low drum level may expose water-wall tubes → overheating and tube burst.
- High level causes carry-over of water with steam → damage to superheater and turbine blades.
- Maintains continuous steam supply at changing loads; allows safe automatic operation of large boilers.

(Diagram 2 M, explanation 1 M, importance 1 M)

e) Numerical: load factor, capacity factor, use factor, reserve.

4 M

Given: Installed capacity = 120 MW, maximum demand = 90 MW, energy = 480×10^6 kWh = 4,80,000 MWh per year, hours of operation = 8000 h.

Quantity	Formula and substitution	Result
Average load	Energy / hours in year = $4,80,000 / 8760$	54.79 MW
(i) Load factor	Average load / Max. demand = $54.79 / 90$	$0.6088 = 60.88 \%$
(ii) Plant capacity factor	Energy / (Capacity $\times$ 8760) = $4,80,000 / (120 \times 8760)$	$0.4566 = 45.66 \%$
(iii) Plant use factor	Energy / (Capacity $\times$ hours operated) = $4,80,000 / (120 \times 8000)$	$0.5000 = 50.00 \%$
(iv) Reserve capacity	Installed capacity – Max. demand = $120 - 90$	30 MW

(1 M each)

Q.5

a) Bubbling FBC boiler and types of FBC.

6 M

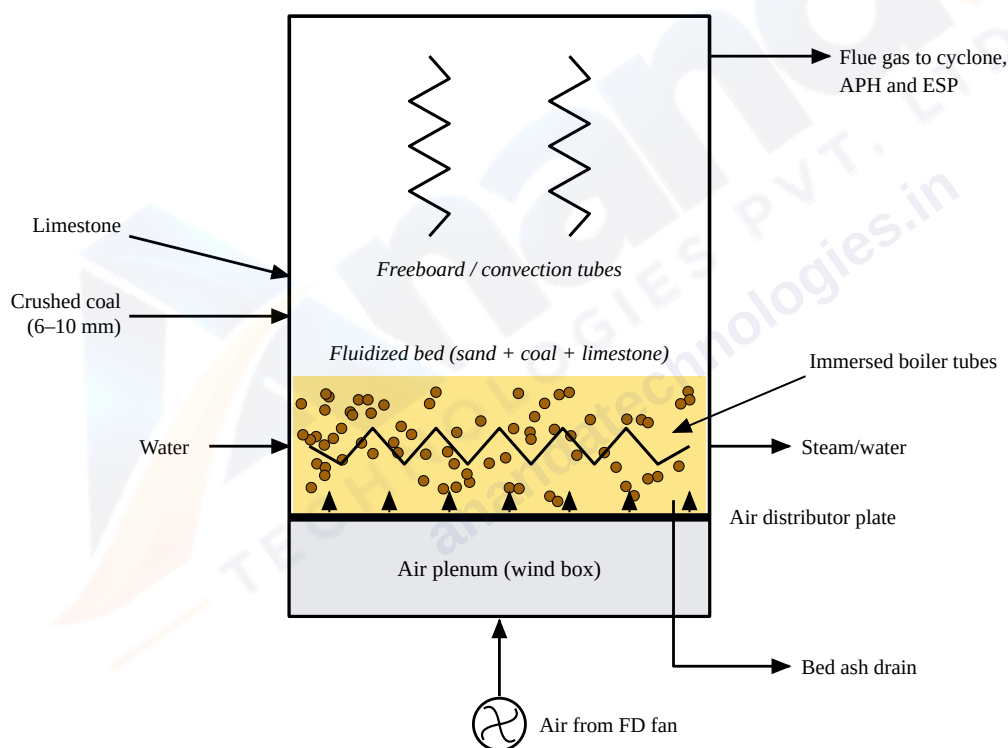


Fig.: Bubbling fluidized bed combustion (BFBC) boiler

- Principle:** when air is blown upward through a bed of fine solid particles at a suitable velocity, the particles are lifted and float, and the bed behaves like a boiling liquid. This is called **fluidization**. Fuel burnt in such a bed is called fluidized bed combustion.
- Construction:** the furnace has an **air distributor plate** (with nozzles) at the bottom, an **air plenum** below it, a bed of inert material (sand / ash) with crushed coal (6–10 mm) and limestone, and boiler tubes immersed in the bed and in the freeboard above.

3. **Working:** air from the FD fan enters the plenum and passes up through the distributor; the bed is fluidized. Coal is fed into the bed and burns at a low, uniform temperature of about **800–900 °C**. Heat is transferred to the water in the immersed tubes at a very high rate and steam is produced.
4. **SO₂ and NO_x control:** limestone (CaCO₃) added to the bed absorbs SO₂ (forms CaSO₄); the low bed temperature keeps NO_x formation low and prevents ash fusion (no clinker).
5. **Flue gases** pass through a cyclone (for unburnt particles), superheater, economiser, air preheater and ESP to the chimney; bed ash is drained from the bottom.

Types of FBC boilers:

- **Atmospheric FBC (AFBC):** (i) Bubbling FBC (BFBC) — low air velocity, dense bed; (ii) Circulating FBC (CFBC) — high velocity, solids carried up and returned by cyclone.
- **Pressurised FBC (PFBC):** bed works at 6–16 bar; hot pressurised flue gas also drives a gas turbine (combined cycle).

(Sketch 2 M, construction and working 3 M, types 1 M)

b) Types of nuclear reactors; BWR.

6 M

Types of nuclear reactors:

1. Pressurised Water Reactor (PWR / VVER)
2. Boiling Water Reactor (BWR)
3. Pressurised Heavy Water Reactor (PHWR / CANDU)
4. Gas-cooled reactor (Magnox, AGR, HTGR)
5. Fast Breeder Reactor (FBR, sodium cooled)
6. Liquid-metal / molten-salt reactors

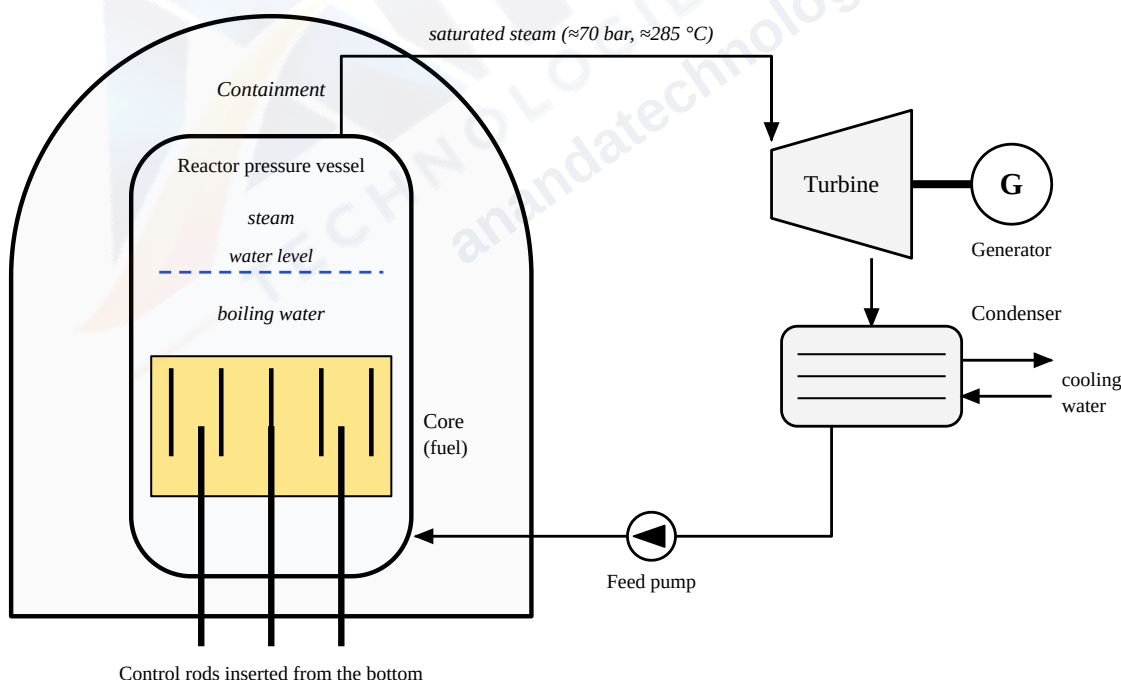


Fig.: Boiling Water Reactor (BWR) nuclear power plant

1. In a BWR, ordinary (light) water acts as **coolant and moderator**; it is allowed to **boil inside the reactor pressure vessel** at about 70 bar.
2. Fission heat from the fuel rods in the core converts water into a steam–water mixture; steam separators and dryers at the top of the vessel separate the steam.
3. Saturated steam (about 285 °C) goes **directly** to the turbine — no steam generator or separate secondary circuit is needed.
4. Exhaust steam is condensed in the condenser and the feed pump returns the water to the reactor vessel.
5. Control rods are inserted from the **bottom** of the vessel (the top is occupied by separators and dryers). Example: Tarapur units 1 & 2.

(Types 1 M, sketch 2 M, working 3 M)

c) Numerical: load curve, energy, load factor, capacity factor.

6 M

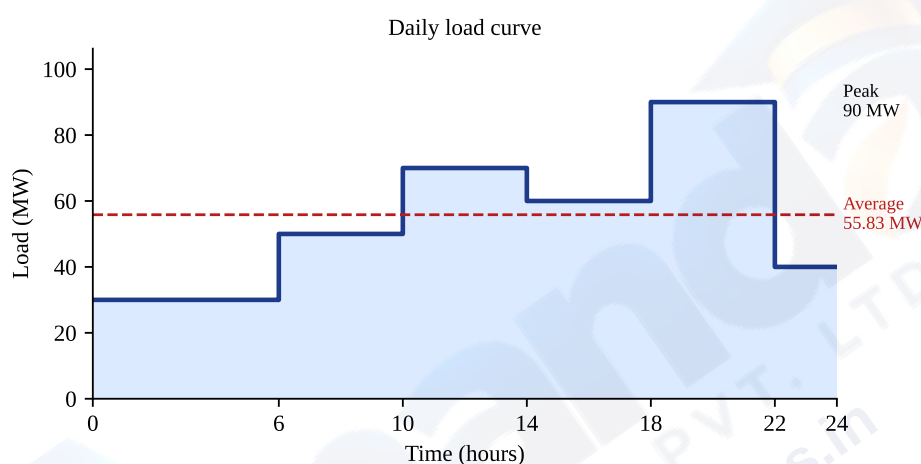


Fig.: Daily load curve (drawn from the given data)

Period	Load	Duration	Energy
0–6 h	30 MW	6 h	$30 \times 6 = 180 \text{ MWh}$
6–10 h	50 MW	4 h	$50 \times 4 = 200 \text{ MWh}$
10–14 h	70 MW	4 h	$70 \times 4 = 280 \text{ MWh}$
14–18 h	60 MW	4 h	$60 \times 4 = 240 \text{ MWh}$
18–22 h	90 MW	4 h	$90 \times 4 = 360 \text{ MWh}$
22–24 h	40 MW	2 h	$40 \times 2 = 80 \text{ MWh}$
		Total	1340 MWh

Quantity	Formula and substitution	Result
(i) Energy generated per day	Area under load curve = $\Sigma (\text{load} \times \text{duration})$	1340 MWh = 1,340,000 kWh
(ii) Average load	$\text{Energy} / 24 = 1340 / 24$	55.83 MW
Maximum demand	Highest point of load curve (18–22 h)	90 MW
(iii) Load factor	$\text{Average load} / \text{Max. demand} = 55.83 / 90$	62.04 %

Plant capacity factor	Energy / (Capacity × 24) = 1340 / (120 × 24)	46.53 %
Reserve capacity	Installed capacity – Max. demand = 120 – 90	30 MW

(Load curve 2 M, energy and average load 2 M, factors 2 M)

Q.6

a) Coal handling line diagram.

6 M

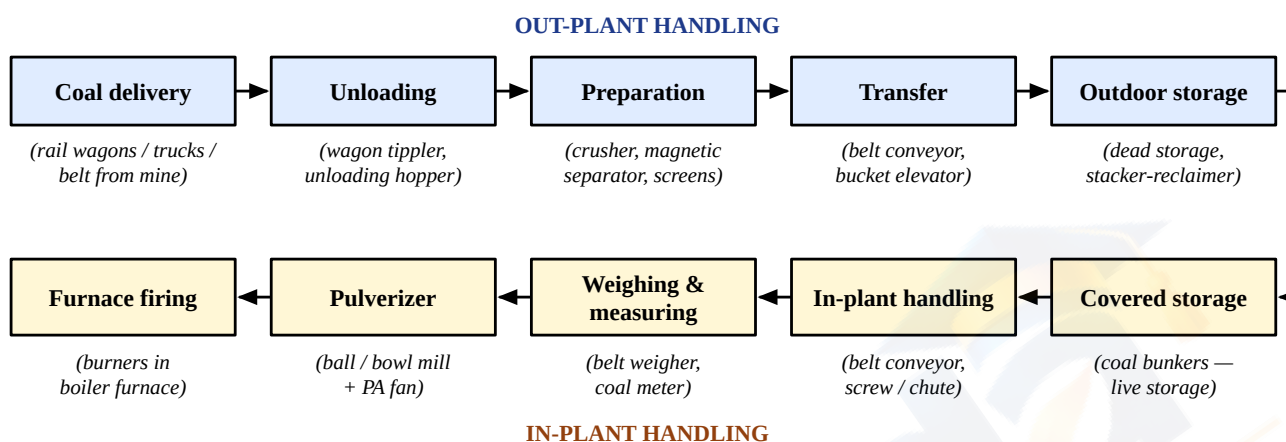


Fig.: Line diagram of coal handling (out-plant and in-plant)

- Coal delivery:** coal is brought from mines by rail wagons (merry-go-round rail), trucks, ropeways, ships or belt conveyors (pit-head plants).
- Unloading:** wagon tipplers, car shakers or rotary dumpers unload wagons into underground hoppers.
- Preparation:** coal is crushed to about 20–25 mm in crushers; magnetic separators remove iron pieces; screens separate fine coal.
- Transfer:** belt conveyors, screw conveyors, bucket elevators carry coal from unloading point to storage or bunkers.
- Outdoor (dead) storage:** about 30–60 days reserve stored in compacted piles (stacker-reclaimer) to protect against supply interruption; piles are compacted to prevent spontaneous combustion.
- Covered (live) storage:** coal bunkers / silos above the mills hold about one day's requirement.
- In-plant handling:** conveyors, chutes and feeders carry coal from bunkers to mills.
- Weighing and measuring:** belt weighers / coal meters record coal consumption for efficiency calculation.
- Furnace firing:** coal is pulverized in mills and blown with primary air into the burners.

(Line diagram 3 M, explanation 3 M)

b) Cogeneration in sugar industry.

6 M

Cogeneration (combined heat and power, CHP) is the simultaneous generation of electricity and useful heat (process steam) from the same fuel.

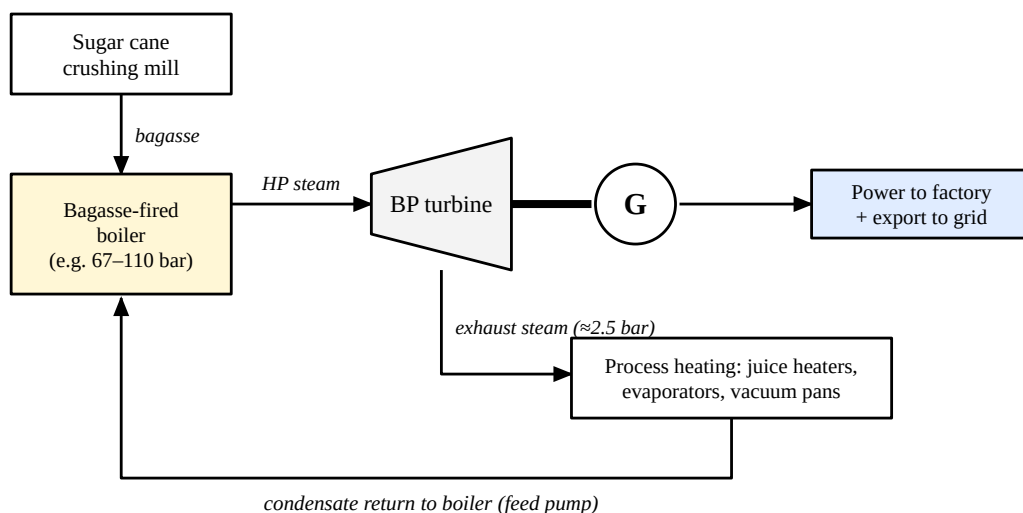


Fig.: Bagasse-based cogeneration in a sugar factory (back-pressure turbine)

1. Sugar cane is crushed in the mill; the fibrous residue **bagasse** is used as fuel in a **bagasse-fired boiler** (high-pressure boiler, e.g. 67–110 bar).
2. High-pressure steam drives a **back-pressure (or extraction-condensing) turbine** coupled to the generator; the power runs the factory and surplus is exported to the grid.
3. The low-pressure exhaust steam (about 2.5 bar) from the turbine is used for process heating — juice heaters, evaporators and vacuum pans.
4. Condensate is returned to the boiler as feed water. In the off-season, other biomass or coal may be fired.

Advantages:

- Bagasse (a waste) is used as fuel — very low fuel cost and carbon-neutral.
- Sugar mill becomes self-sufficient in power and earns by exporting surplus power.
- Overall efficiency 70–80 % compared with about 35 % for power-only plant.

(Sketch 2 M, explanation 3 M, advantages 1 M)

c) Numerical: cost of generation per kWh.

6 M

Given: Max. demand = 50 MW, load factor = 0.65, capital cost = ₹ 300 crore, interest + depreciation = 10 %, fixed O&M = ₹ 12 crore/year, fuel cost = ₹ 2.60/kWh. (1 crore = 10^7)

Quantity	Formula and substitution	Result
Average load	Load factor $\times$ Max. demand = 0.65×50	32.5 MW
Energy generated per year	$32.5 \times 1000 \text{ kW} \times 8760 \text{ h}$	284,700,000 kWh
Interest + depreciation	10 % of ₹ 300 crore	₹ 30 crore
Annual fixed cost	$30 + 12$	₹ 42 crore = ₹ 420,000,000
Fixed cost per kWh	$420,000,000 / 284,700,000$	₹ 1.4752
Running (fuel) cost per kWh	Given	₹ 2.60

Cost of generation	$1.4752 + 2.60$	₹ 4.08 per kWh (≈ 408 paise)
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Check: total annual cost = ₹ 42 crore + ₹ 74.02 crore (fuel) = ₹ 116.02 crore; divided by 284,700,000 kWh gives the same ₹ 4.08/kWh.

(Energy 1 M, fixed cost 2 M, cost per kWh 3 M)

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