

Power Plant Engineering (315374)

Model Question Paper — Set C · Model Answers

Q.1**a) Classification by nature of load.**

2 M

- **Base load plants:** run continuously at nearly constant load for long hours — large steam (coal), nuclear and run-of-river hydro plants.
- **Peak load plants:** run only during peak hours to supply the extra load — gas turbine, diesel, pumped-storage and storage-type hydro plants.

*(1 M each)***b) Fuels used in conventional power plants.**

2 M

- **Solid fuels:** coal (bituminous, sub-bituminous), lignite, coke, biomass / bagasse.
- **Liquid fuels:** diesel (HSD), light diesel oil, furnace oil (FO), naphtha — used in diesel plants, gas turbines and for boiler start-up.
- **Gaseous fuels:** natural gas, LNG, blast furnace gas, producer gas, biogas.
- **Nuclear fuels:** uranium-235, plutonium-239, uranium-233 (from thorium-232).

*(Any four types, ½ M each)***c) Out-plant coal handling equipment.**

2 M

1. Wagon tippler / rotary car dumper (unloading)
2. Coal crusher (preparation)
3. Magnetic separator and screens
4. Belt conveyor (transfer)
5. Stacker-reclaimer / bulldozer (outdoor storage)

*(Any four, ½ M each)***d) Function of compressor and combustion chamber.**

2 M

- **Compressor:** Compresses atmospheric air to high pressure (pressure ratio about 10–20, up to 30 in modern units); driven by the turbine.
- **Combustion chamber:** Fuel is burnt in the compressed air at constant pressure; temperature rises to about 1000–1400 °C.

*(1 M each)***e) Average load and peak load.**

2 M

Average load: The average of loads occurring on the station during a given period (day, month, year).

$$\text{Average load} = \text{Energy generated in the period (kWh)} / \text{Hours in the period}$$

Peak load: The maximum load (demand) on the power station during a given period (e.g. a day); it is the highest point of the load curve.

(1 M each)

f) Regulating 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).

(Any two, 1 M each)

g) Captive power plant.

2 M

Captive power plant (CPP): A power plant set up by an industry (any person / group) mainly to generate electricity for its **own use**. As per the Electricity Rules, 2005, the captive users must hold at least 26 % ownership and consume at least 51 % of the electricity generated annually.

Examples: coal-based CPPs of steel and aluminium plants, bagasse cogeneration plants of sugar factories, DG sets of hospitals.

(Definition 2 M)

Q.2

a) Advantages and disadvantages of steam power plant.

4 M

Advantages:

1. Can use cheap, low-grade coal available in India.
2. Large unit sizes (500–800 MW) — low cost per kW and per kWh.
3. Can be located near load centre or coal mine.
4. Initial cost lower than hydro and nuclear plants.

Disadvantages:

1. Pollution: fly ash, SO₂, NO_x, CO₂ (greenhouse gas).
2. Fuel transport and handling costly; ash disposal problem.
3. High running cost compared with hydro.
4. Needs large quantity of cooling water.

(½ M each)

b) Circulating FBC (CFBC) boiler.

4 M

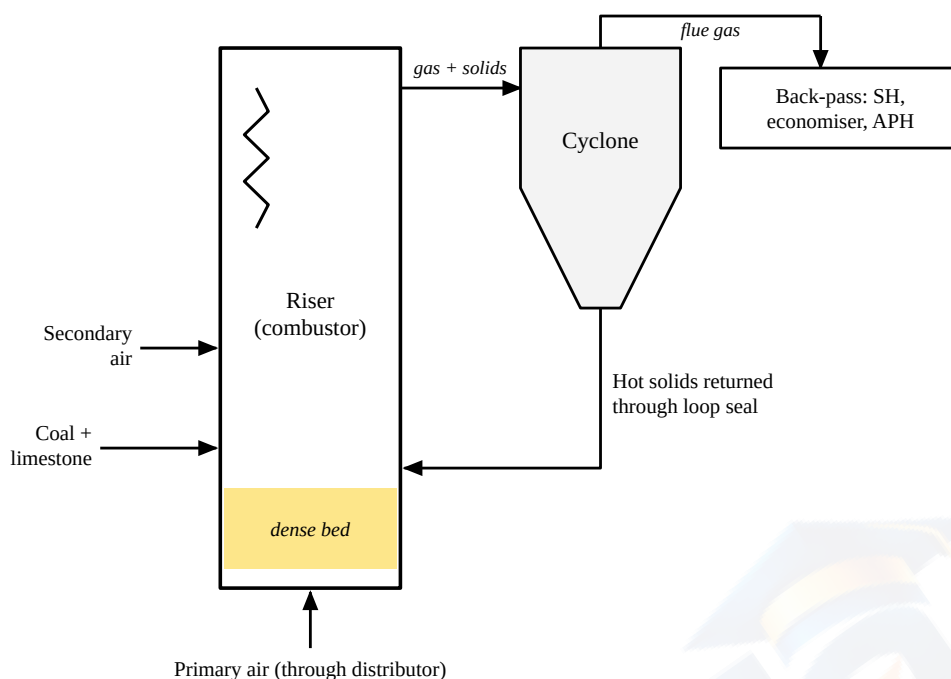


Fig.: Circulating fluidized bed combustion (CFBC) boiler — principle

1. Crushed coal and limestone are fed into the lower part of the tall **riser (combustor)**; primary air enters through the distributor and secondary air at higher levels.
2. Air velocity is high (about 4–6 m/s), so the bed particles are carried up through the riser; combustion takes place at about 850 °C all along the riser, whose walls are water-cooled tubes.
3. At the top, the gas–solid mixture enters a **cyclone**; the hot solids (unburnt coal, ash, limestone) are separated and returned to the bottom of the riser through a **loop seal** — the solids circulate many times, giving high combustion efficiency.
4. Hot flue gas from the cyclone passes through the back-pass (superheater, economiser, air preheater) and ESP to the chimney.

Advantages: burns low-grade coal efficiently (≈ 98 –99 % combustion efficiency), in-bed SO_2 capture with limestone, low NO_x , suitable for large units.

(Sketch 2 M, working 1 M, advantages 1 M)

c) Need of co-generation with example.

4 M

- **Cogeneration** (combined heat and power, CHP) is the simultaneous generation of electricity and useful heat (process steam) from the same fuel.
- A conventional plant rejects about 60 % of heat in the condenser; in cogeneration this heat is used for the process, so overall fuel utilisation becomes 70–85 %.
- Saves fuel and cost, reduces pollution and CO_2 per unit of useful energy.
- Gives reliable captive power to industry; surplus power can be exported to the grid.
- Suitable where both power and steam are required continuously: sugar, paper, textile, chemical, fertilizer, refinery, food processing.

Example — sugar factory: bagasse is burnt in a high-pressure boiler; steam runs a back-pressure turbine–generator for the factory's power, and the exhaust steam (≈ 2.5 bar) is used for juice

heating, evaporation and vacuum pans; surplus power is exported to the grid.

(Need 2 M, example 2 M)

d) NMEEE and its four initiatives.

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.

1. **PAT (Perform, Achieve and Trade):** market-based scheme; designated consumers get specific energy consumption reduction targets; over-achievers get tradable Energy Saving Certificates (ESCerts).
2. **MTEE** — accelerates the shift to energy-efficient appliances in designated sectors through innovative measures that make them affordable: e.g. Bachat Lamp Yojana (CFLs), UJALA LED bulb programme and Super-Efficient Equipment Programme (fans, ACs), standards & labelling (star rating) and demand-side management.
3. **EEFP** — a platform for financing energy-efficiency projects; BEE signs MoUs with banks / financial institutions and trains them to evaluate EE projects so that loans are easily available.
4. **FEEED** — develops fiscal instruments to promote energy efficiency: **Partial Risk Guarantee Fund for Energy Efficiency (PRGFEE)** that gives partial guarantee to banks lending to EE projects (ESCO projects), and **Venture Capital Fund for Energy Efficiency (VCFEE)** that gives equity support; also public procurement of efficient equipment.

(Introduction 1 M, four initiatives 3 M)

Q.3

a) Intercooling in open cycle gas turbine.

4 M

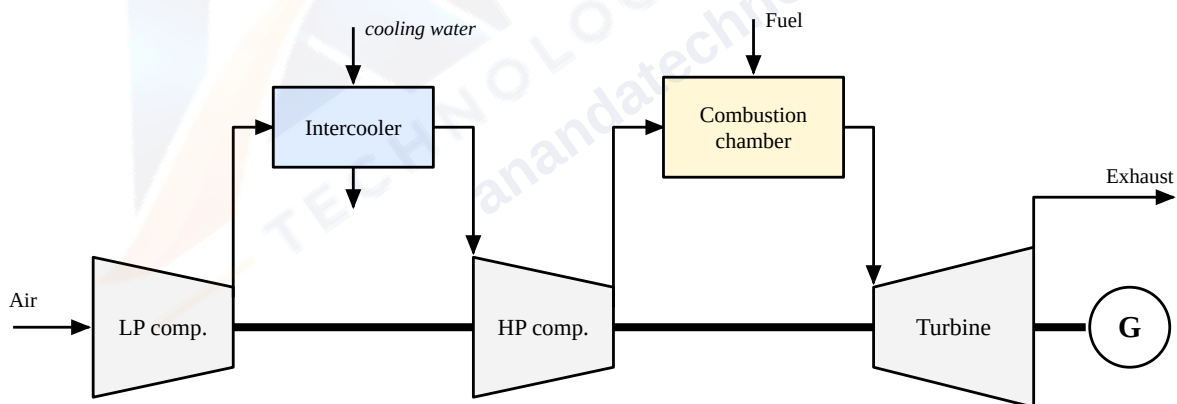


Fig.: Open cycle gas turbine with intercooling

1. Air is compressed in two stages: **LP compressor** and **HP compressor**.
2. Between the two stages air is cooled at constant pressure in an **intercooler** (by cooling water) nearly to the initial temperature.
3. Work needed to compress cooler (denser) air is less, so total compressor work decreases and **net work output increases**.
4. Air then goes to the combustion chamber and turbine as in a simple open cycle.

5. Intercooling alone lowers the temperature of air entering the combustion chamber, so more fuel is needed; it gives best improvement in efficiency when used with a **regenerator**.

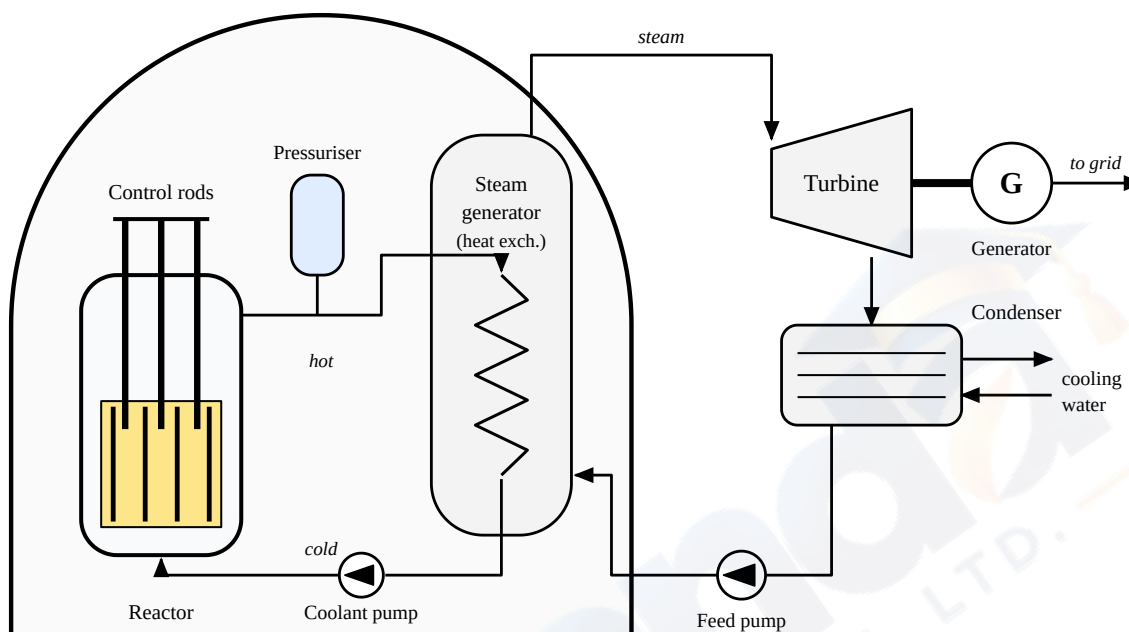
Advantages: more net work (specific output) and better efficiency with regeneration.

Disadvantages: extra cost, size and cooling-water requirement.

(Sketch 2 M, explanation 2 M)

b) General arrangement of nuclear power plant.

4 M



Reactor core: fuel + moderator + control rods; containment = concrete biological shield

Fig.: General arrangement (layout) of a nuclear power plant

1. **Reactor:** fission of U-235 nuclei by slow neutrons releases heat (about 200 MeV per fission) and 2–3 new neutrons, which sustain a controlled **chain reaction**.
2. **Main parts of reactor:** fuel rods (core), moderator (heavy/light water or graphite — slows down neutrons), control rods (cadmium / boron — absorb neutrons to control power), reflector, coolant and biological shield (thick concrete).
3. **Coolant** (water, heavy water, CO₂ or liquid sodium) removes heat from the core and gives it to water in the **heat exchanger (steam generator)**.
4. Steam produced drives the **turbine-generator**; exhaust steam is condensed in the condenser and the feed pump returns it to the steam generator — same as a steam power plant.
5. The reactor and primary circuit are housed in a **containment** building; radioactive waste is handled and stored safely.

(Sketch 2 M, explanation 2 M)

c) Cooling water circuit and cooling towers.

4 M

1. Exhaust steam from the turbine is condensed in the **condenser** by circulating cooling water; the water gets heated by about 8–10 °C.
2. The hot water is pumped to the **cooling tower**, where it is sprayed over the fill (packing) and cooled by a counter-flow of atmospheric air, mainly by evaporation of a small part of the water.

- Cooled water collects in the basin and the **circulating water (CW) pump** sends it back to the condenser. Make-up water replaces evaporation, drift and blow-down losses.
- Natural draught** (hyperbolic) towers produce air flow by the chimney effect of the tall shell (used for large units); **induced draught** towers use a fan at the top to suck the air (compact, used in medium plants).

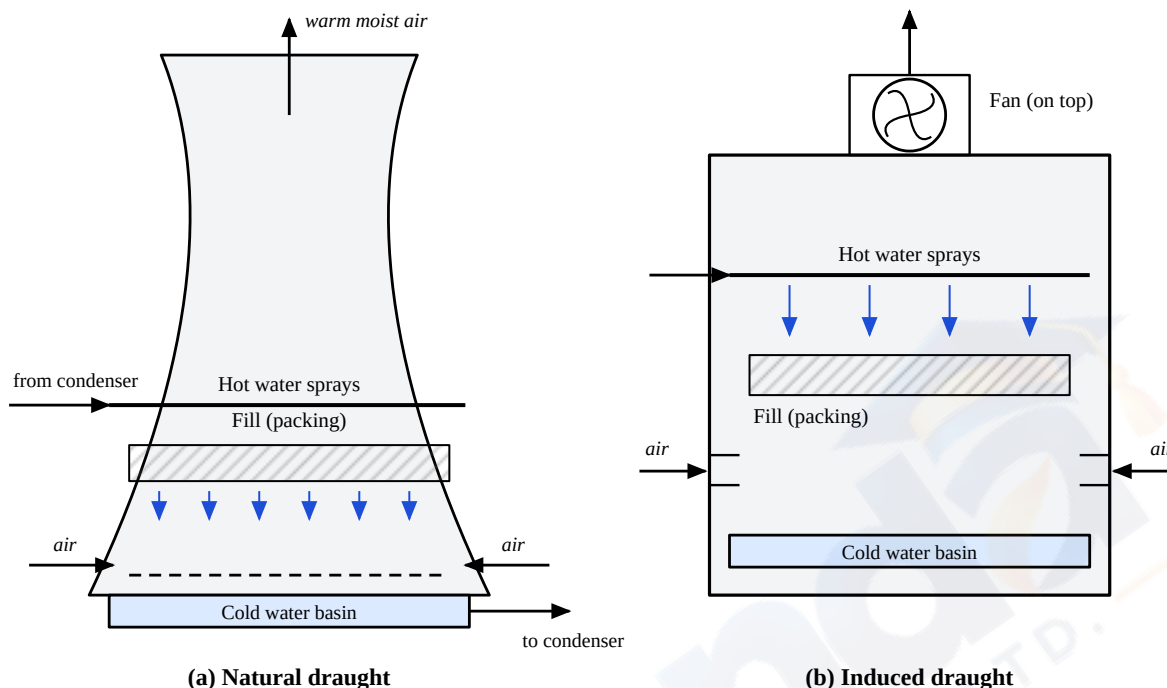


Fig.: (a) Natural draught (hyperbolic) and (b) induced draught cooling towers

(Explanation 2 M, sketches 2 M)

d) Nuclear waste and its disposal.

4 M

- Types of waste:** *Low-level* (gloves, clothing, filters, tools — little activity), *intermediate-level* (resins, sludges, reactor components) and *high-level* (spent fuel and fission products from reprocessing — highly radioactive and heat generating).
- Low-level waste:** compacted / incinerated, packed in drums and buried in engineered near-surface trenches at the site; very low-activity liquids and gases are diluted and released within limits after monitoring.
- Intermediate-level waste:** solidified in cement or bitumen, kept in shielded concrete vaults.
- High-level waste:** spent fuel is first cooled for years in water pools at the reactor; in India it is reprocessed (closed fuel cycle) to recover Pu and U; the remaining liquid HLW is **vitrified** (fixed in borosilicate glass), filled in stainless-steel canisters and stored in air-cooled vaults for interim storage.
- Final disposal:** deep geological repository in stable rock formations, using multiple barriers (glass, canister, buffer clay, rock).

(Types 1 M, disposal methods 3 M)

Q.4

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.

(Any four factors, 1 M each)

b) Boiler feed water (drum level) control.

4 M

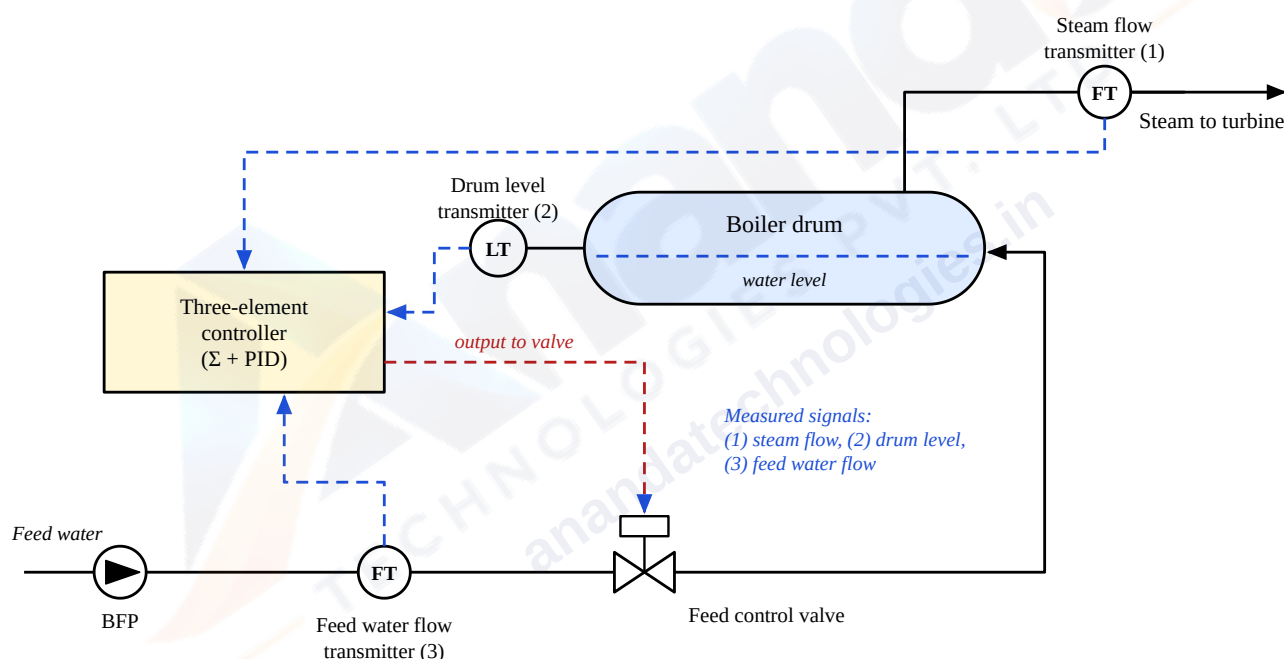


Fig.: Three-element boiler drum level (feed water) control

The feed water control system keeps the water level in the boiler drum constant at all loads. A **three-element control** uses drum level, steam flow and feed water flow signals to operate the feed control valve, so that feed water flow always matches steam flow.

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, importance 2 M)

c) Advantages and applications of gas turbine plants.

4 M

Advantages:

1. Simple, compact and light; less space and smaller foundations than steam plant.
2. Quick starting and loading (full load in a few minutes) — ideal as peak-load plant.
3. No boiler, condenser or ash handling; very little cooling water required.
4. Low capital cost per kW and short erection time.

Applications:

1. Peak-load and standby power plants in the grid.
2. Combined-cycle power plants (GT + waste-heat boiler + steam turbine) for base load.
3. Captive and cogeneration plants in refineries, fertilizer and petrochemical industries.
4. Aircraft propulsion (turbojet, turboprop) and marine propulsion.

(½ M each)

d) Compare BWR and PWR.

4 M

Point	BWR	PWR
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
Indian example	Tarapur 1 & 2	Kudankulam 1 & 2 (VVER)

(Any four points, 1 M each)

e) Demand factor and diversity factor.

4 M

Demand factor: Ratio of maximum demand of a system to its connected load. It is always less than 1.

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

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.

$$\text{Diversity factor} = \frac{\sum \text{Individual maximum demands}}{\text{Maximum demand on station}}$$

Why diversity factor > 1: different consumers (domestic, commercial, industrial, agricultural) reach their maximum demands at different times of the day. Hence the maximum demand on the station is less than the arithmetic sum of individual maximum demands, so the ratio is more than 1. A high diversity factor means a smaller plant can serve the same consumers, reducing the cost per kWh.

(Definitions with expressions 2 M, explanation 2 M)

Q.5

a) Coal handling line diagram and equipment.

6 M

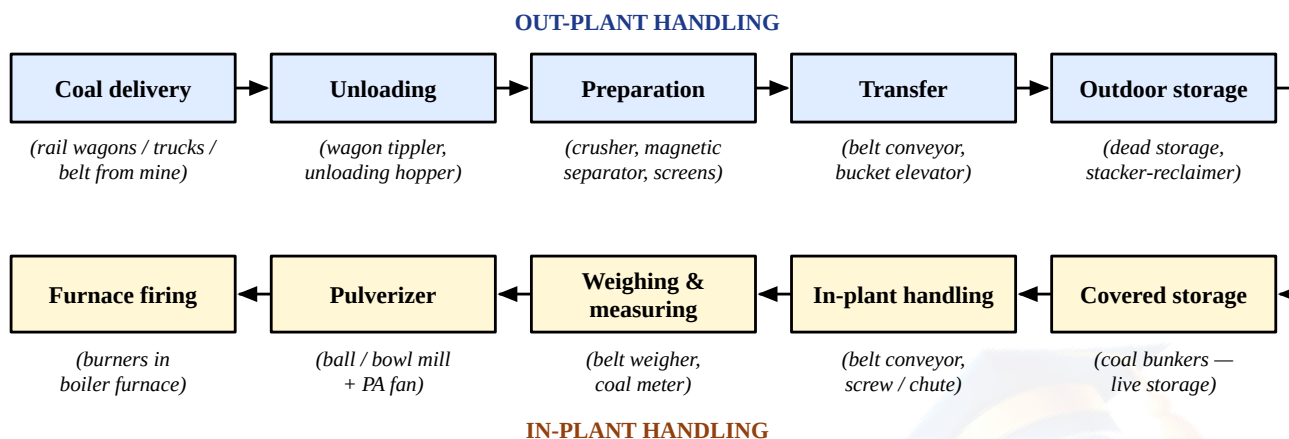


Fig.: Line diagram of coal handling (out-plant and in-plant)

Stage	Equipment used
Coal delivery	Rail wagons (merry-go-round), trucks, ropeways, ships, belt conveyor from pit-head
Unloading	Wagon tippler, rotary car dumper, car shaker, unloading hopper
Preparation	Crushers (ring granulator / hammer mill), magnetic separator, screens
Transfer	Belt conveyor, screw conveyor, bucket elevator, skip hoist
Outdoor (dead) storage	Stacker-reclaimer, bulldozer, scraper (compacted piles for 30–60 days)
Covered (live) storage	Coal bunkers / silos above mills (about one day's requirement)
In-plant handling	Conveyors, chutes, feeders
Weighing and measuring	Belt weigher, coal meter, weigh bridge
Furnace firing	Pulverizer (ball / bowl mill), PA fan, burners

(Line diagram 3 M, equipment at each stage 3 M)

b) Compare gas turbine, steam and hydro plants; hydro layout.

6 M

Point	Gas turbine plant	Steam power plant	Hydro-electric plant
Fuel / energy source	Natural gas, naphtha, diesel	Coal, lignite, oil	Potential energy of stored water — no fuel
Initial (capital) cost	Lowest	Medium	Highest (dam, tunnel, penstock)
Running cost	High (costly fuel)	Medium	Very low
Thermal / overall efficiency	25–35 % (open cycle); 55–60 % combined cycle	33–40 %	80–90 % (water to wire)

Starting time	Few minutes	Several hours from cold	Few minutes
Type of load	Peak load / standby	Base load	Base or peak load
Space required	Least	Large (coal and ash yards)	Very large (reservoir), but power house is small
Pollution	Low (no ash, some NO _x)	High (ash, SO ₂ , NO _x , CO ₂)	Nil

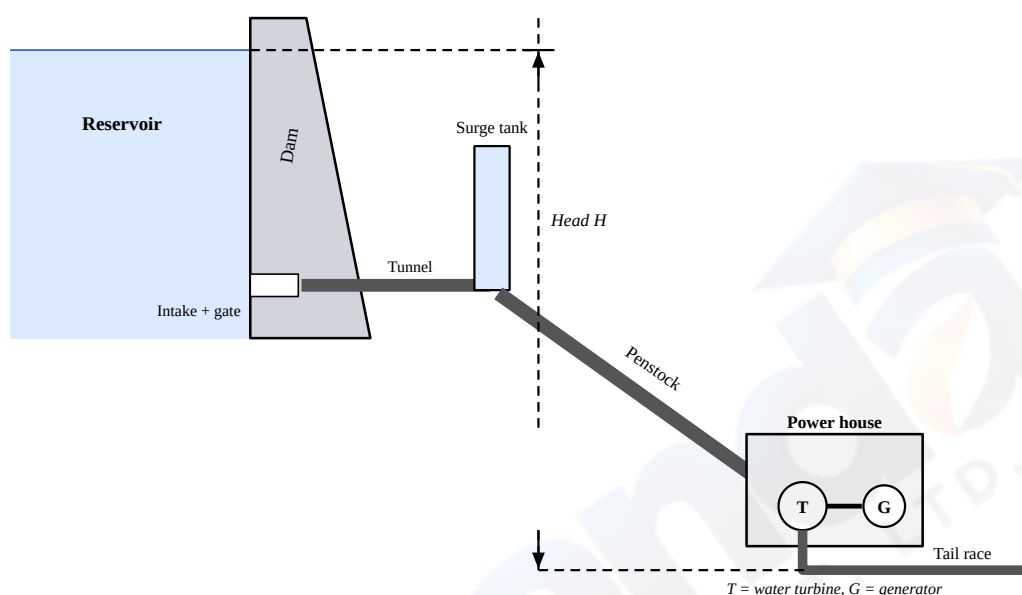


Fig.: Layout of a hydro-electric power plant

Hydro plant working: water stored in the reservoir behind the dam flows through the intake and tunnel/penstock to the turbine in the power house; the potential energy of the head H is converted to mechanical energy in the turbine and then to electricity in the generator; water leaves through the tail race. The surge tank protects the penstock from water hammer.

(Comparison 4 M, layout 2 M)

c) Closed cycle gas turbine and its advantages.

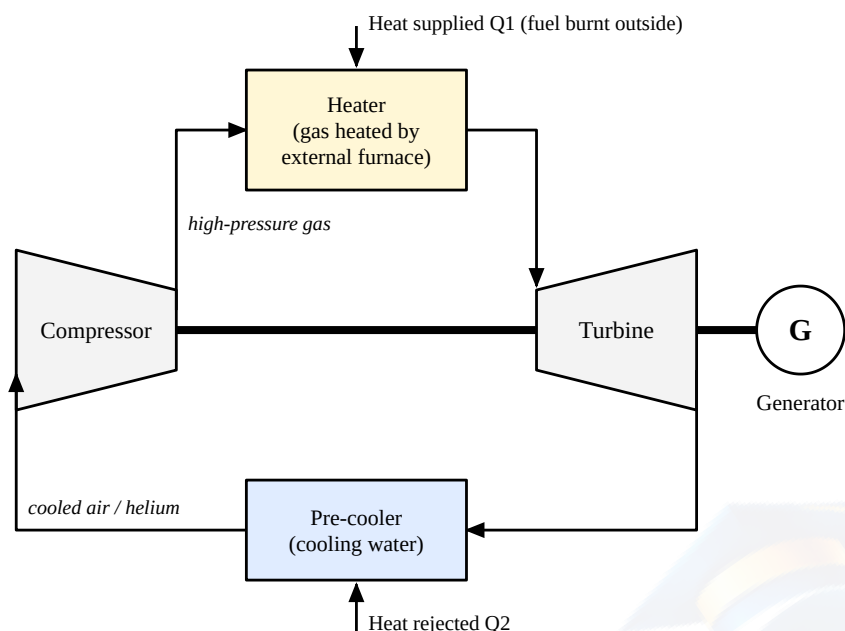


Fig.: Closed cycle gas turbine power plant

1. In a closed cycle the same working fluid (air, helium or CO_2) 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.
4. The hot high-pressure fluid expands in the **turbine** and produces work; the turbine drives the compressor and the generator.
5. The exhaust from the turbine is cooled in the **pre-cooler** by cooling water and returned to the compressor inlet, completing the cycle.

Advantages:

1. Working fluid is clean, so no erosion / corrosion of turbine blades.
2. Any cheap fuel (even coal or nuclear heat) can be used, as combustion is external.
3. Higher pressure in the circuit → smaller size for same output; part-load efficiency is high (load controlled by changing pressure level).
4. Gases with better properties (helium) can be used.

(Sketch 2 M, working 2 M, advantages 2 M)

Q.6

a) Electrostatic precipitator.

6 M

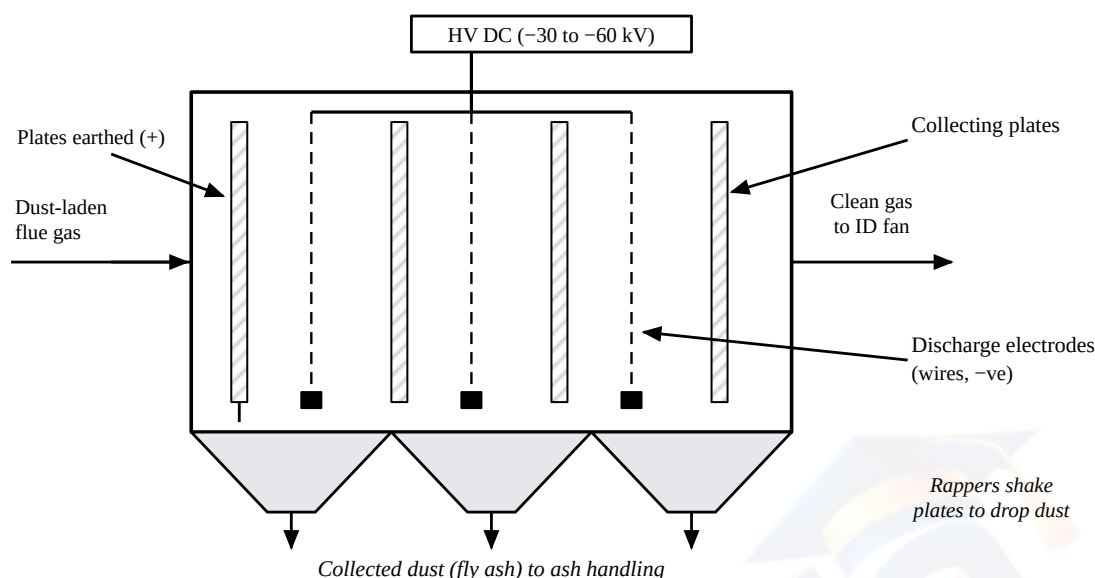


Fig.: Electrostatic precipitator (plate type)

- 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.

Advantages:

- Very high collection efficiency (99–99.9 %), even for fine particles below 1 micron.
- Low pressure drop, so low ID fan power.
- Can handle very large gas volumes at high temperature.
- Dry dust is collected, which can be sold for cement/brick making.
- Low running and maintenance cost.

(Sketch 2 M, working 2 M, advantages 2 M)

b) Numerical: load curve, load duration curve and factors.

6 M

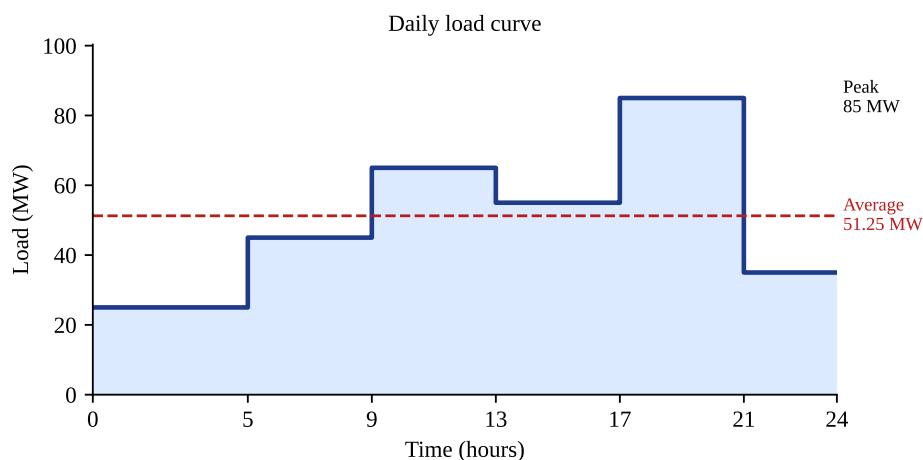


Fig.: Daily load curve (from given data)

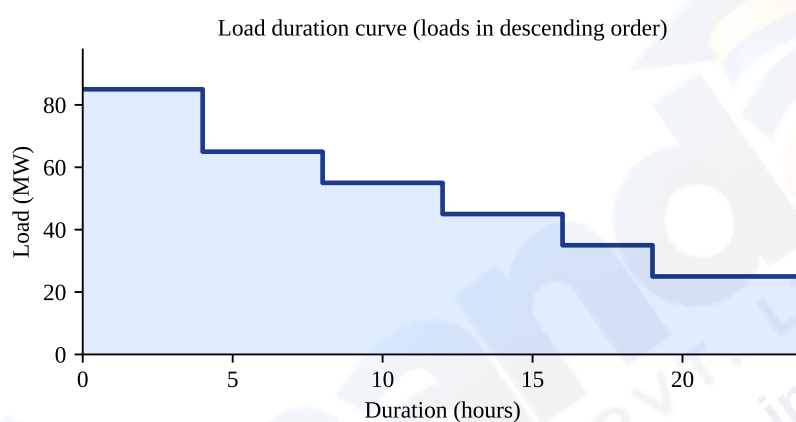


Fig.: Load duration curve (same loads arranged in descending order)

Period	Load	Duration	Energy
0–5 h	25 MW	5 h	$25 \times 5 = 125 \text{ MWh}$
5–9 h	45 MW	4 h	$45 \times 4 = 180 \text{ MWh}$
9–13 h	65 MW	4 h	$65 \times 4 = 260 \text{ MWh}$
13–17 h	55 MW	4 h	$55 \times 4 = 220 \text{ MWh}$
17–21 h	85 MW	4 h	$85 \times 4 = 340 \text{ MWh}$
21–24 h	35 MW	3 h	$35 \times 3 = 105 \text{ MWh}$
		Total	1230 MWh

Quantity	Formula and substitution	Result
(i) Energy per day	$\Sigma (\text{load} \times \text{duration}) = \text{area under load curve}$	1230 MWh
Average load	$1230 / 24$	51.25 MW
Maximum demand	Peak of load curve (17–21 h)	85 MW
(ii) Load factor	$51.25 / 85$	60.29 %

(iii) Plant capacity factor	Energy / (capacity × 24) = 1230 / (100 × 24)	51.25 %
(iv) Demand factor	Max. demand / Connected load = 85 / 150	0.567
(v) Reserve capacity	100 – 85	15 MW

(Curves 2 M, energy 1 M, factors 3 M)

c) Numerical: cost of generation at two load factors.

6 M

Given: MD = 40 MW; capital cost ₹ 240 crore; interest + depreciation 12 %; fixed O&M ₹ 8 crore/year; running cost = fuel ₹ 2.80 + variable O&M ₹ 0.20 = ₹ 3.00 per kWh.

Quantity	Formula and substitution	Result
Annual fixed cost	12 % of 240 + 8 = 28.8 + 8	₹ 36.8 crore
(i) Energy at LF 0.5	40,000 kW × 0.5 × 8760	175,200,000 kWh
Fixed cost per kWh	$36.8 \times 10^7 / 175,200,000$	₹ 2.1005
Cost of generation (LF 0.5)	2.1005 + 3.00	₹ 5.10 per kWh
(ii) Energy at LF 0.8	40,000 kW × 0.8 × 8760	280,320,000 kWh
Fixed cost per kWh	$36.8 \times 10^7 / 280,320,000$	₹ 1.3128
Cost of generation (LF 0.8)	1.3128 + 3.00	₹ 4.31 per kWh

Comment: when the load factor rises from 50 % to 80 %, the same fixed cost is spread over more units, so the fixed cost per kWh falls from ₹ 2.10 to ₹ 1.31 and the cost of generation falls by ₹ 0.79 per kWh (15.4 %). Hence a high load factor reduces the cost of generation.

(Fixed cost 1 M, each case 2 M, comment 1 M)

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