Lecture 2.15

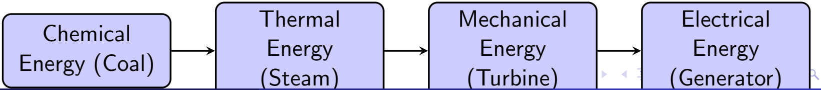
Configuration of Modern Thermal Power Plant - General Layout and Working

Agenda

- Overview of Plant Configuration
- The Four Primary Circuits
- 1. Coal and Ash Handling Circuit
- 2. Air and Flue Gas Circuit
- 3. Feedwater and Steam Circuit
- 4. Cooling Water Circuit
- Integrated General Layout
- Summary and Q&A

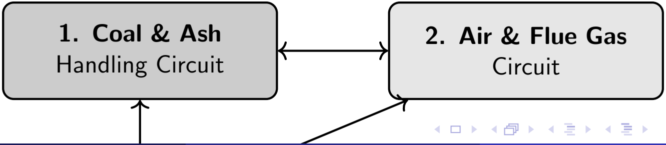
Overview of Modern Thermal Power Plant Configuration

- Fundamentally based on the modified Rankine Cycle utilizing water as the working fluid.
- Converts chemical energy of coal into thermal energy, then to mechanical work, and finally electrical energy.
- High-capacity plants (500 MW - 800 MW+) utilize supercritical and ultra-supercritical boiler technologies.
- Due to the complexity and scale, the plant layout is conceptually divided into four distinct but interdependent operational circuits.
- Efficient operation requires precise synchronization of material flow rates across all four circuits.



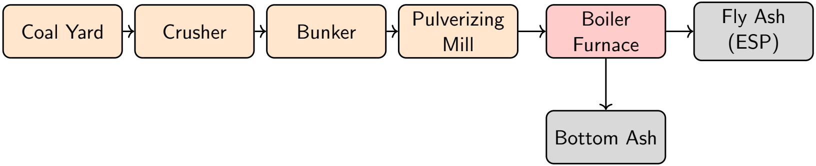
The Four Primary Circuits

- To understand the general layout, the power plant is divided into four main functional loops:
- **1. Coal and Ash Handling Circuit:** Manages the fuel input and combustion residue output.
- **2. Air and Flue Gas Circuit:** Supplies oxygen for combustion and safely handles the exhaust gases.
- **3. Feedwater and Steam Circuit:** The primary thermodynamic loop driving the turbine.
- **4. Cooling Water Circuit:** Rejects low-grade heat in the condenser to maintain turbine backpressure.
- Each circuit requires dedicated auxiliary machinery (pumps, fans, conveyors) that consume parasitic power.



1. Coal and Ash Handling Circuit

- **Coal Flow:** Coal Mines → Transport (Rail/Ship) → Unloading and Storage Yard → Crusher House → Magnetic Separator → Coal Bunkers → Pulverizing Mills → Boiler Furnace.
- **Ash Flow:** Boiler Furnace (Combustion) → Bottom Ash (Hopper) & Fly Ash (ESP) → Ash Handling System → Ash Storage Pond / Cement Industry Utilization.
- Modern plants use pulverized coal firing for higher combustion efficiency and rapid load response.
- Ash content in Indian coal can be 30-45%, making ash handling a massive logistical requirement in the plant layout.

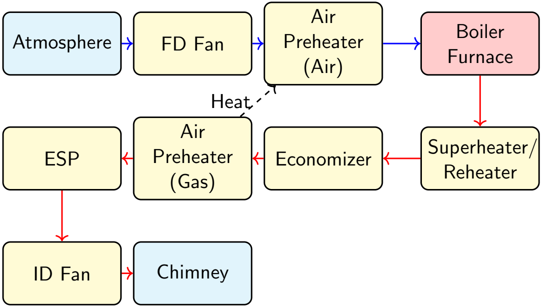


Working of Coal & Ash Handling System

- **Coal Preparation:** Raw coal is crushed to $\sim$20mm size, then pulverized to a fine powder (70% passing through 200 mesh) to maximize surface area for combustion.
- **Transportation:** Primary air carries the pulverized coal dust from the mill into the boiler burners.
- **Bottom Ash:** Coarse, heavy ash that falls to the bottom of the furnace. Usually quenched in a water impounded hopper and sluiced away.
- **Fly Ash:** Fine ash carried with the flue gases. Captured by Electrostatic Precipitators (ESPs) with up to 99.9% efficiency.
- Dry fly ash is typically pneumatically conveyed to silos for utilization in Portland Pozzolana Cement.

2. Air and Flue Gas Circuit

- **Air Flow:** Atmosphere → Forced Draft (FD) Fan → Air Preheater (APH) → Boiler Furnace.
- **Flue Gas Flow:** Boiler Furnace → Superheaters/Reheaters → Economizer → Air Preheater → Electrostatic Precipitator (ESP) → Induced Draft (ID) Fan → Chimney.
- **Primary Air (PA) Fan:** Supplies heated air to dry and transport pulverized coal from mills to burners.
- **Balanced Draft System:** Coordinated operation of FD and ID fans maintains the furnace pressure slightly below atmospheric (-5 to -10 mm of water gauge).

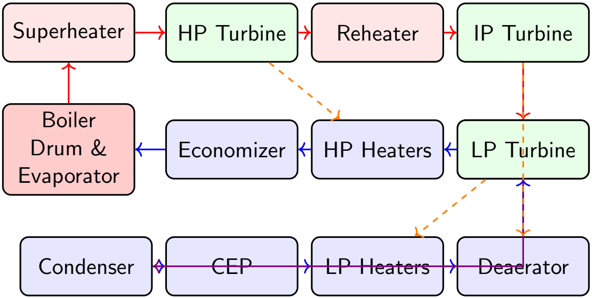


Working of Air and Gas System

- **Air Preheater (APH):** Recovers heat from outgoing flue gas to preheat incoming combustion air, improving boiler efficiency by 1% for every 20°C drop in flue gas temp.
- **Economizer:** Further recovers flue gas heat to preheat boiler feedwater.
- **Draft Fans:** FD fans push air in, ID fans pull gas out. ID fans handle hot, dusty corrosive gases and have higher power ratings than FD fans.
- **Chimney/Stack:** Disperses remaining flue gases high into the atmosphere to minimize ground-level concentration of pollutants (SO_x, NO_x, Particulates).
- Modern plants often include Flue Gas Desulfurization (FGD) units before the stack to remove SO_2.

3. Feedwater and Steam Circuit

- The closed-loop thermodynamic cycle (Rankine Cycle).
- **Water Path:** Condenser Hotwell → Condensate Extraction Pump (CEP) → Low Pressure Heaters → Deaerator → Boiler Feed Pump (BFP) → High Pressure Heaters → Economizer → Boiler Drum.
- **Steam Path:** Boiler Drum → Evaporator tubes (Water wall) → Superheater → High Pressure (HP) Turbine → Reheater → Intermediate Pressure (IP) Turbine → Low Pressure (LP) Turbine → Condenser.
- Involves phase changes: Subcooled liquid → Saturated mixture → Superheated steam → Wet steam → Saturated liquid.



Working of Feedwater and Steam System

- **Regenerative Feedwater Heating:** Steam is bled from turbine stages to heat feedwater. This increases the mean temperature of heat addition, boosting cycle efficiency.
- **Deaerator:** A crucial component that removes dissolved gases (Oxygen, CO_2) from feedwater to prevent internal boiler corrosion, while also acting as a direct-contact feedwater heater.
- **Boiler Feed Pump (BFP):** The largest auxiliary power consumer in the plant (often turbine-driven). Must pump water to a pressure higher than the boiler operating pressure (e.g., ¿170 bar for subcritical).
- **Reheating:** Steam expanding from the HP turbine is routed back to the boiler to be reheated before entering the IP turbine, increasing work output and preventing excessive moisture in LP turbine blades.

4. Cooling Water Circuit

- **Purpose:** To condense the low-pressure exhaust steam from the LP turbine back into liquid water, maintaining a high vacuum in the condenser.
- **Open Cycle (Once-through):** Water drawn from river/sea $\rightarrow$ Circulating Water (CW) Pumps $\rightarrow$ Condenser tubes $\rightarrow$ Discharged back downstream.
- **Closed Cycle:** Cooling Tower basin $\rightarrow$ CW Pumps $\rightarrow$ Condenser tubes $\rightarrow$ Hot water sprayed in Cooling Tower $\rightarrow$ Cooled by draft air $\rightarrow$ Returns to basin.
- Maintains turbine backpressure as low as 0.05 to 0.1 bar absolute, maximizing the enthalpy drop and work output.

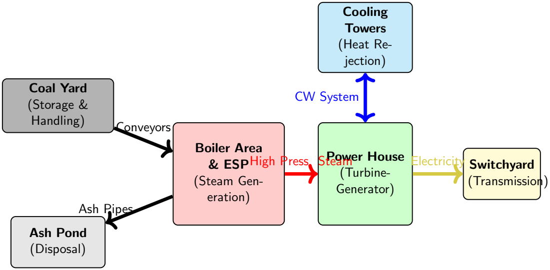
Open Cycle **Closed Cycle**

Working of Cooling Water System

- **Condenser:** A massive shell-and-tube heat exchanger. Steam flows over the outside of the tubes, while cooling water flows inside.
- **Cooling Towers (Natural Draft or Induced Draft):** Cool the warm water exiting the condenser primarily through evaporative cooling.
- **Make-up Water:** Required in closed cycles to compensate for evaporation losses, drift losses, and blowdown in the cooling tower.
- **Condenser Tube Fouling:** Bio-fouling and scaling inside tubes reduce heat transfer. Continuous mechanical cleaning (like sponge ball systems) or chemical dosing is required.

Integrated General Layout of a Thermal Power Plant

- The physical layout is optimized for minimal piping lengths, safe material handling, and future expansion.
- **Main Power House:** Contains the Turbine-Generator island and control room.
- **Boiler Area:** Located adjacent to the power house. Includes the furnace, milling plant, and draft fans.
- **Switchyard:** Located near the power house for stepping up voltage and transmitting power to the grid.
- **Balance of Plant (BOP):** Includes coal yard, ash pond, water treatment plant, and cooling towers, usually located peripherally based on wind direction and topography.



Summary

- A modern thermal power plant operates through the integration of four primary circuits: Coal/Ash, Air/Gas, Feedwater/Steam, and Cooling Water.
- The Coal and Ash circuit handles massive solid material flow and preparation for combustion.
- The Air and Gas circuit provides oxygen and extracts maximum sensible heat via the APH and Economizer.
- The Feedwater and Steam circuit is the primary thermodynamic loop utilizing regenerative heating and reheating.
- The Cooling Water circuit maintains condenser vacuum to maximize turbine efficiency.
- Optimal physical layout ensures safe, efficient operation and minimal transmission/transportation losses.

Next Lecture Preview

Topic: Boiler Types and Supercritical Technology

- Subcritical vs. Supercritical vs. Ultra-supercritical steam parameters.
- Once-through boilers and their operational dynamics.
- Advantages of supercritical technology in modern power generation.