Lecture 2.20

Combustion System: Furnaces and Pulverized Fuel Firing

Agenda

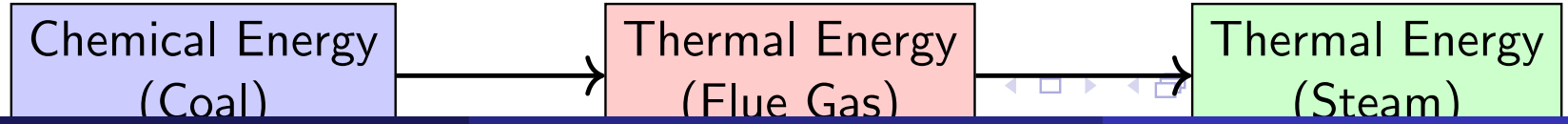
- Introduction to Combustion Systems
- Furnace Design and Requirements
- Types of Furnaces (Dry vs. Slag Tap)
- Pulverized Fuel (PF) Firing Overview
- Direct and Indirect Firing Systems
- Coal Pulverization Mills
- Burner Design and Aerodynamics
- Emissions Control in Furnaces

Introduction to Combustion Systems

Overview

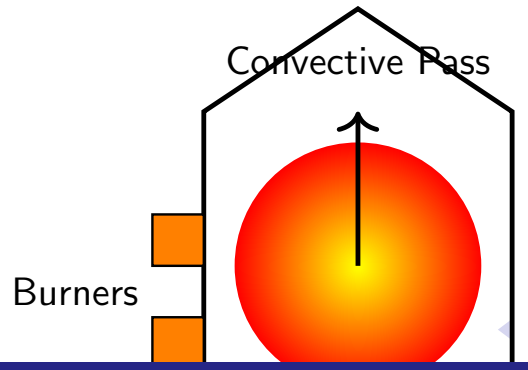
The combustion system acts as the primary energy conversion unit in a thermal power plant, converting chemical energy into thermal energy.

- Primary components include the furnace, burners, fuel preparation equipment (pulverizers), and draft systems (FD/ID fans).
- Key goals: Maximize combustion efficiency (complete oxidation of carbon and hydrogen), maintain stable flame ignition, and optimize heat transfer to water wall tubes.
- Requires precise control of the air-fuel ratio, typically defined by the stoichiometry of the coal composition (Ultimate Analysis).



Furnace Design Considerations

- **Furnace Volume & Heat Release Rate:** Designed to provide adequate residence time (typically 1–2 seconds) for complete combustion before flue gases enter the convective pass.
- **Water Wall Construction:** Modern furnaces use membrane water walls to absorb radiant heat, lower the gas temperature below the ash fusion point, and prevent slagging.
- **Burner Placement:** Configurations include front-wall, opposed-wall, and tangential (corner) firing. Tangential firing creates a central fireball for uniform heat distribution.
- **Aerodynamics:** Proper mixing of primary air (carrying coal) and secondary air is crucial for flame stability and reducing unburnt carbon.



Types of Furnaces: Dry Bottom vs. Slag Tap

- **Dry Bottom Furnace:** Designed for coal with high ash fusion temperatures ($> 1200^{\circ}C$). Ash falls as dry powder into the bottom hopper. Most common in modern utilities.
- **Slag Tap (Wet Bottom) Furnace:** Designed for low ash fusion temperature coals. Furnace temperatures are kept high enough to melt the ash into liquid slag, which drains continuously.
- **Cyclone Furnace:** A specific type of wet-bottom furnace that uses crushed coal (not fully pulverized) burned in a high-velocity cyclonic air stream, capturing ash as molten slag.
- **Selection Criteria:** Based almost entirely on the ash fusion characteristics and slagging potential of the primary coal source.

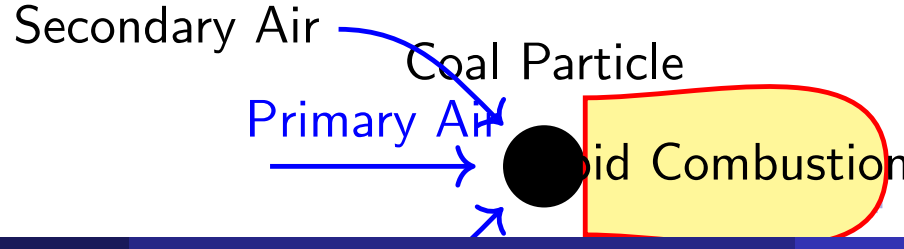
Dry Bottom Furnace **Slag Tap (Wet Bottom)**

Pulverized Fuel (PF) Firing System Overview

Overview

Pulverized Fuel (PF) firing is the standard for large-scale utility boilers (> 100 MW), replacing older stoker firing methods.

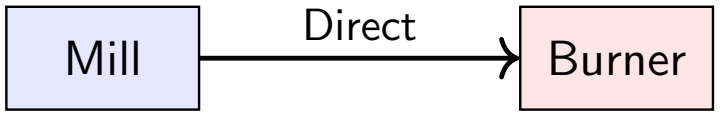
- **Mechanism:** Coal is ground to a fine powder (typically 70% passing through a 200-mesh/74-micron screen) to vastly increase its surface area.
- **Combustion Process:** The fine coal dust is entrained in primary air and injected into the furnace, burning rapidly in suspension, similar to a gas or liquid fuel.
- **Advantages:** High combustion efficiency, excellent load following capability (rapid response to load changes), and ability to utilize low-grade coals.



Direct vs. Indirect Pulverized Firing Systems

- **Direct Firing System (Unit System):** Coal is pulverized and directly transported to the burners by the primary air. There is no intermediate storage. Most common due to lower capital cost and safety.
- **Indirect Firing System (Bin System):** Pulverized coal is separated from the transport air via cyclones and stored in a bunker (bin) before being fed to the burners.
- **Advantages of Direct:** Simpler layout, lower fire/explosion risk, less equipment.
- **Advantages of Indirect:** Mill operation is independent of boiler load, allowing mills to operate at steady optimal efficiency; better for varying fuel moisture.

Direct Firing System

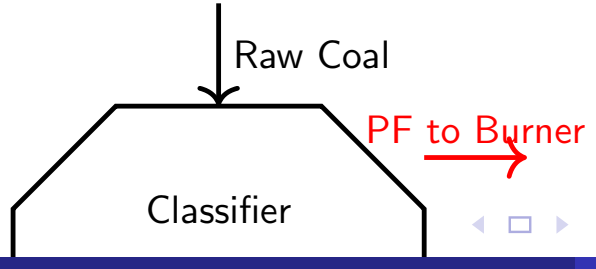


Coal Pulverization Mills

Function

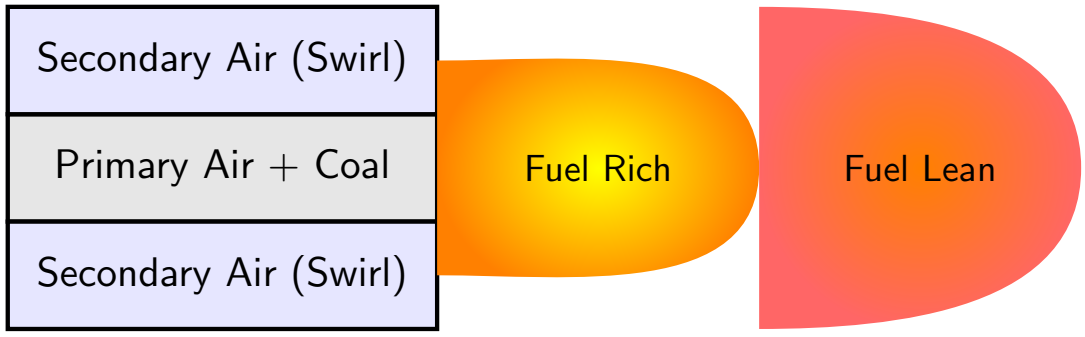
The primary function of a pulverizer is drying, grinding, and classifying the coal.

- **Ball and Tube Mills:** Low-speed mills using steel balls in a rotating cylinder. High reliability, high power consumption, excellent for very hard coals.
- **Vertical Spindle/Bowl Mills:** Medium-speed mills where coal is ground between a rotating bowl and stationary rollers. Most common in modern plants due to good efficiency and control.
- **Impact/Hammer Mills:** High-speed mills using rotating hammers. High wear rate, typically restricted to softer coals like lignite.



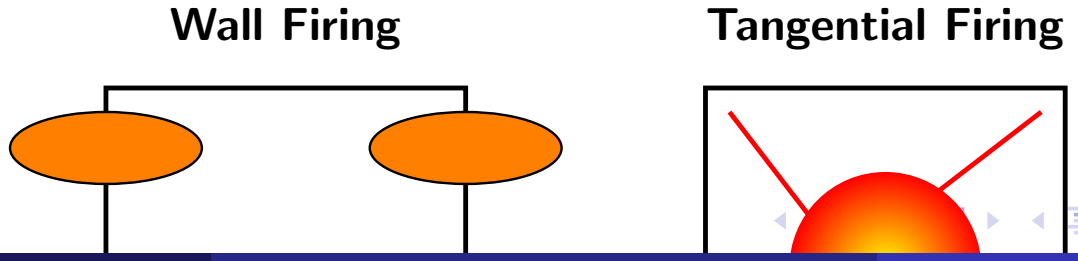
Burner Design and Aerodynamics

- Burners are responsible for introducing fuel and air into the furnace in a manner that ensures stable ignition, continuous combustion, and flame shaping.
- **Primary Air:** Carries the pulverized coal (about 15–20% of total combustion air). Must maintain a velocity high enough to prevent settling but low enough to ensure stable ignition at the burner tip.
- **Secondary Air:** Supplies the bulk of the oxygen for combustion (80–85%). Often introduced with a swirl to create a recirculation zone that stabilizes the flame.
- **Low-NOx Burners (LNB):** Modern burner designs that stage the introduction of air to create fuel-rich (reducing) and fuel-lean (oxidizing) zones, minimizing thermal NOx formation.



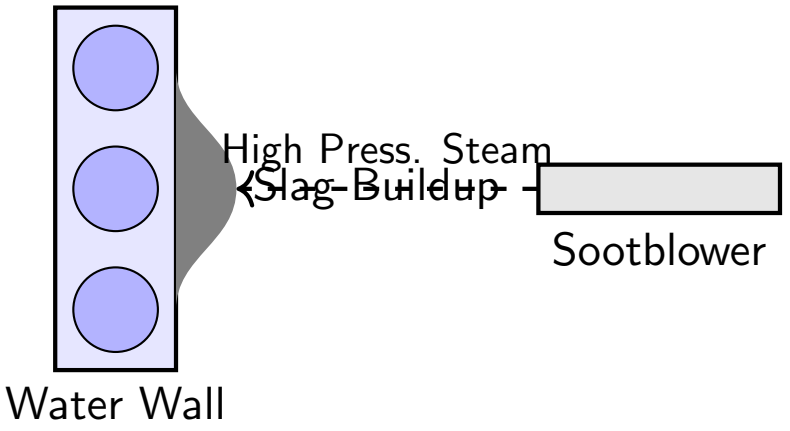
Tangential Firing vs. Wall Firing

- **Wall Firing:** Burners are mounted on the front wall (or opposed on front and rear walls). Each burner operates independently with its own flame envelope.
- **Tangential Firing:** Burners are located in the four corners of the furnace, aiming tangent to an imaginary circle in the center. Creates a single, massive rotating fireball.
- **Advantages of Tangential Firing:** Enhanced mixing of air and fuel due to the cyclonic motion, more uniform heat distribution to water walls, and inherently lower NOx emissions due to slightly staged combustion.
- **Control:** Tangential burners can tilt vertically to control the fireball position, adjusting steam temperatures in the convective pass.



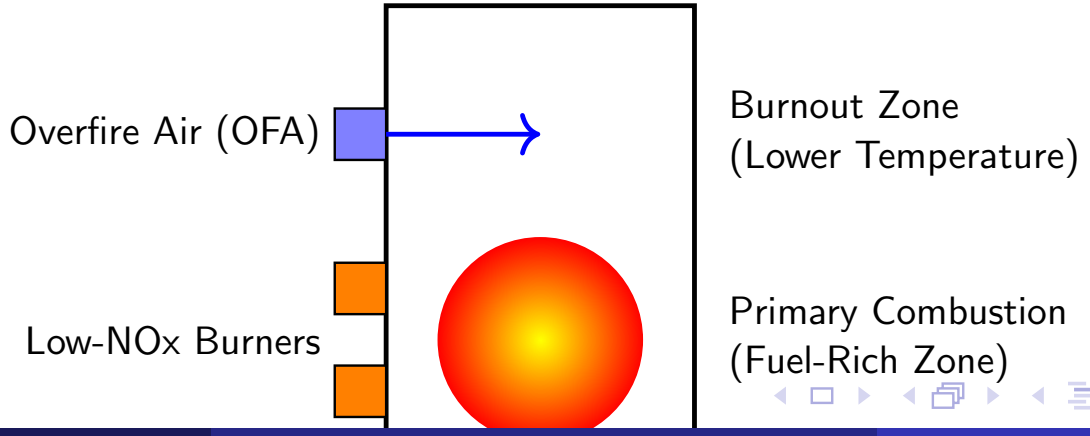
Combustion Optimization and Slagging Control

- **Slagging:** The accumulation of molten ash on the radiant water walls of the furnace. Severely degrades heat transfer and can cause structural damage if large chunks fall.
- **Fouling:** The accumulation of dry, sintered ash on the convective tubes (superheaters/reheaters).
- **Control Measures:** Managing excess air levels (typically 15–20% excess air required for PF firing) to ensure oxidizing conditions, as reducing atmospheres lower the ash fusion temperature.
- **Sootblowers:** Automated lances that inject high-pressure steam or air into the furnace and convective passes periodically to clean tube surfaces.



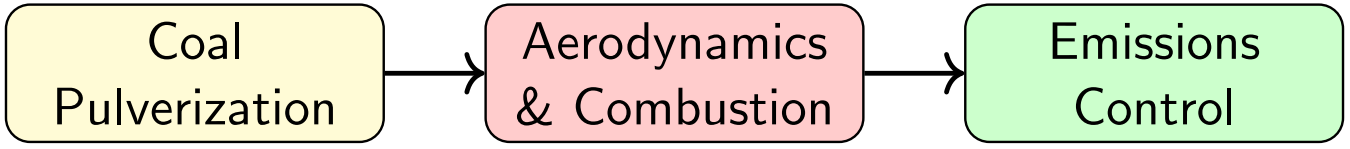
Emissions and NOx Control in Modern Furnaces

- Thermal NOx is generated by the high-temperature oxidation of atmospheric nitrogen. Fuel NOx comes from nitrogen bound in the coal.
- Primary control relies on in-furnace modifications: Overfire Air (OFA) and Low-NOx Burners (LNB).
- **Overfire Air (OFA):** Diverts 10–20% of combustion air above the main burner zone, completing combustion at a lower temperature to suppress thermal NOx.
- **Flue Gas Recirculation (FGR):** Recirculating a portion of the relatively cool flue gas back into the combustion zone to lower the peak flame temperature.



Summary

- The combustion system efficiently converts the chemical energy of coal into thermal energy using a carefully designed furnace and burner arrangement.
- Dry bottom furnaces are standard for utility boilers, sized to manage heat release and prevent slagging.
- Pulverized Fuel (PF) firing dominates modern plants by allowing rapid, efficient combustion of fine coal particles in suspension.
- Direct firing systems with bowl mills are the industry standard due to safety and operational simplicity.
- Advanced burner designs (Low-NOx, Tangential) and air staging (OFA) are critical for emission control and flame stability.



Next Lecture Preview

Next Topic: Steam Generators and Boiler Configurations

We will explore the water-steam circuit, subcritical vs. supercritical boilers, and the design of convective passes.

- Reading Assignment: Review chapters on boiler thermodynamics and heat transfer surfaces (superheaters, reheaters, economizers).