BURNING IN Boiler Furnaces
FURNACES
Boiler furnace tasks

The most important task of the boiler furnace is to provide conditions for proper combustion of fuel which is achieved by:

1. Fuel supply of the boiler furnace at the required rate and keeping it in the furnace by the time sufficient for burnt out.

2. Air supply of the boiler furnace at the required rate and proper mixing with the fuel.
Types of boiler furnaces

Coal-fired boilers can be classified regarding the type of a furnace:

- grate boilers (stoker),
- pulverized fuel-fired boilers (PF),
- fluidized-bed boilers.
TRAVELLING GRATE FURNACES
Cross-section of grate boiler
Burning on the travelling grate

Zones of combustion
1 - drying,
2 - devolatilization,
3 - burning,
4 - ash

Boilers of capacity up to 60 t/h usually are stokers.
Zones of combustion on grate

- Drying zone
- Combustion zone
- Agglomeration zone
- Moisture removal
- Vaporization
- Drying zone
Example of coal-fired stoker

WR 25
RAFAKO SA

Distribution of air under grate
Ignition vault of the grate furnace

Moving grate

Mechanism of coal layer ignition by the furnace vault
RETORT FURNACES
Principle of retort furnace operation

- Air box
- Worm-gear feeder
Burning in retort furnace
Boiler with retort furnace

- flue
- fuel reservoir
- heat exchanger
- retort
- screw feeder
- air box
- ash pan
- air fan
Retort furnace
PULVERIZED COAL FURNACES
Steam pulverized coal-fired boiler

Pulverized coal-fired boiler of capacity 650 t/h with tangential furnace
Modern pulverized coal-fired boilers

In modern power plants pulverized coal-fired boilers have mainly furnaces with membrane walls and major heat transfer is due to radiation.
Some technical data related to pulverized coal burning

Fuel burned in a furnace: pulverized coal (pc)
Delivery of pc to a furnace: by pulverized coal burners
Transport of pc to a burner: pneumatic, in flowing gas (hot air, flue gas)

Pulverized coal concentration on gas:
- hard coal: 0.5 kg/m\(^3\)
- lignite: 0.2-0.3 kg/m\(^3\)
Phases of pulverized coal burning

The time of pulverized coal-air mixture in a furnace can be divided into three periods:

1. drying, devolatilization and ignition of coal particles, which requires 0.2-0.3 s,

2. Intensive mixing and burning of pulverized coal-air jet during 0.5-1.5 s on a distance of 1-5 m with formation of flame kernel of the temperature 1500-1600 °C,

3. Burnout of larger coal particles and cooling of flue gas during 1-3 s on a distance 2/3 of the furnace.
Types of pulverized coal-fired furnaces

The main criteria is location of burners:

- wall-fired furnaces,
- roof-fired furnaces,
- corner-fired furnaces (tangentially fired).
Geometry of boiler furnaces

Pulverized coal-fired furnaces:
  a) wall-fired, b) roof-fired, c) corner-fired
Combustion systems of pulverized coal-fired boilers

- wall-fired furnaces with swirl burners (located at the front, back or side wall of the furnace)
- corner-fired furnaces with jet-burners (located mostly at corners, sometimes at walls of the furnace)
- corner-fired furnaces are often called tangential firing system.
Matching a burner type to the type of furnace

Pulverized coal-fired furnaces

- Wall-fired furnaces: swirl burners
- Roof-fired furnaces: jet burners
- Corner-fired furnaces: jet burners

Pulverized coal burners:

- swirl burners (located on the boiler walls);
- jet burners (located in the boiler corners or on the walls tangentially).
TANGENTIALLY FIRED FURNACES

1 – corner fired,
2 – corner and wall-fired,
3 – all-walls
Aerodynamics of tangentially-fired furnaces

Corner furnace
Scheme of tangentially fired furnace with corner location of burners

- Left wall
- Rear wall
- Right wall
- Front wall
- Burner
- Adjustment range of OFA
Burner box/corner fired furnace
Pulverized coal corner burner
Pulverized coal supply of corner-fired boilers

Corners with jet burners

Coal-mills
Advantages of tangentially-fired furnaces

- self-stabilization of pulverized coal flames,
- delayed ignition of pulverized-coal/air mixture,
- staged mixing of pulverized coal/primary air mixture and secondary air,
- efficient heat transfer to the boiler walls,
- tolerance of the fuel variation.
Wall-fired furnaces with swirl burners:
1 – front-fired, 2 – opposite walls-fired,
3 – front- and back wall-fired, 4 – all walls-fired
Wall-fired PF boiler

Pulverized coal-fired boiler with front furnace
Wall-fired furnace with swirl burners

- Configuration of furnace
- Level of burners and OFA
- NO\textsubscript{X} reduction zone
- Burn-out zone
- Burner with low NO\textsubscript{X} emission
- Working burner with low NO\textsubscript{X} emission
Pulverized coal swirl burner
Swirl burners on the wall of a furnace
Pulverized coal supply of wall-fired boilers
Advantages of wall-fired furnaces

- stable flame in a single swirl burner,
- easy ignition of pulverized-coal/air mixture,
- fast mixing of pulverized coal/primary air mixture and secondary air,
- considerable burn-out of coal near the burner
- possibility of boiler operation with low load.
ROOF-FIRED FURNACES
Roof-fired furnaces - idea of operation

Figure 9-14. Down-shot flame furnace
Roof-fired furnaces

- Primary zone of combustion
  - early ignition and control of NO$_x$

- Secondary zone of combustion
  - Extended time of combustion
Position of burners in the furnace
CYCLONE FURNACES
Idea of operation of cyclone furnace
Cyclone furnaces in pulverized coal-fired boilers
A cyclone furnace boiler
Cyclone boiler furnace in Moszczenica

Boiler is fired with high-caloric hard coal and mine gas (50% methane + 50% air)
Comparison of selected parameters of PF and FB boilers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FB with circulating bed</th>
<th>PB with bubble bed</th>
<th>PF boilers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat load:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( q_A, \text{MW/m}^2 )</td>
<td>1.8-2.5</td>
<td>1.2-1.5</td>
<td>3,-5,5</td>
</tr>
<tr>
<td>( q_v, \text{MW/m}^3 )</td>
<td>0.2-0.4</td>
<td>0.1-0.2</td>
<td>0.08-0.2</td>
</tr>
<tr>
<td>Medium size of coal particle</td>
<td>3-30 mm</td>
<td>&lt; 25 mm</td>
<td>&lt; 300 ( \mu \text{m} )</td>
</tr>
</tbody>
</table>
HIGH-TEMPERATURE CORROSION IN PULVERIZED COAL-FIRED BOILERS
High-temperature corrosion hazard

The high-temperature corrosion in the coal-fired furnace is always present, however in recent decades hazard of corrosion increased considerably due to:

- application of low-\(\text{NO}_x\) combustion systems,
- intensive co-firing of biomass and coal, and waste fuels and coal,
- increase of steam parameters to supercritical values (600 °C, 26 MPa), and planned rise of the parameters to the ultra-supercritical values (700 °C, 30 MPa).
Corrosion hazard in PF boilers

1. The high-temperature corrosion is different in different parts of the boiler.

2. The greatest hazard of corrosion is in:
   - in the boiler furnace: evaporator (tubes)
   - over the furnace: superheater
Corrosion hazard due to application of low-NOx combustion systems

1. In the major part of the low-NO\textsubscript{x} boiler furnace there is reduction atmosphere, also near the furnace walls (tubes), which enhances corrosion of tubes.

2. Due to the reduction atmosphere in the boundary layer of the furnace walls the corrosion rate considerably increases:
   - from 10 nm/h in normal boiler operation,
   - to 600 nm/h in reduction atmosphere.
Effects of low-NOx corrosion

8 nm/h → 600 nm/h
Membrane walls damage due to low-NO$_x$ corrosion
Sulphur corrosion

Sulphur corrosion is connected with the presence of alkali metals in coal: potassium K and sodium Na, which combined with sulphur form alkali sulfides Na$_2$SO$_4$ and K$_2$SO$_4$ condensing on the tubes’ surface.

They aren’t directly responsible for corrosion because of their melting high-temperature (Na$_2$SO$_4$ – 884 °C, K$_2$SO$_4$ – 1069 °C), however in the presence of SO$_3$ they form corrosive pirosulfides and trisulfides near the surface of the evaporator tubes.
Reactions of sulphur corrosion

I. Pirosulfides

\[ \text{Na}_2\text{SO}_4 + \text{SO}_3 \rightarrow \text{Na}_2\text{S}_2\text{O}_7 \quad (T_{\text{melt}} = 389 \, ^\circ\text{C}) \]
\[ \text{K}_2\text{SO}_4 + \text{SO}_3 \rightarrow \text{K}_2\text{S}_2\text{O}_7 \quad (T_{\text{melt}} = 404 \, ^\circ\text{C}) \]

II. Trisulfides: sodium- and potassium-iron:

\[ 3\text{Na}_2\text{SO}_4 + \text{Fe}_2\text{O}_3 + 3\text{SO}_3 \rightarrow 2\text{Na}_3\text{Fe}({\text{SO}_4})_3 \quad (T_{\text{topn}} = 624 \, ^\circ\text{C}) \]
\[ 3\text{K}_2\text{SO}_4 + \text{Fe}_2\text{O}_3 + 3\text{SO}_3 \rightarrow 2\text{K}_3\text{Fe}({\text{SO}_4})_3 \quad (T_{\text{topn}} = 618 \, ^\circ\text{C}) \]
Hazard of sulphur corrosion due to application of ultra-supercritical steam parameters
Corrosion hazard due to co-firing biomass and coal - chlorine corrosion

Chlorine (Cl$_2$) is particularly corrosive for steel at high temperature. It causes *active oxidation* of metal removing the protective layer of iron oxides, which are converted into porous, not protecting deposit.

Sources of molecular chlorine (Cl$_2$) near a tube surface are present in flue gas hydrogen chloride (HCl) and present in deposit alkali metals chlorides (KCl and NaCl).
Mechanism of chlorine corrosion

Chlorine diffuses through deposit to metal and reacts with it

\[ \text{Fe} + \text{Cl}_2 \rightarrow \text{FeCl}_2(s) \]

Metal chlorides formed on the metal surface have high pressure at the temperature of 500 °C, therefore they diffuse through the protecting magnetite layer (\(\text{Fe}_3\text{O}_4\)) and damage it. After this iron chloride meets oxygen and undergoes oxidation:

\[ 2\text{FeCl}_2(g) + \frac{3}{2}\text{O}_2 \rightarrow \text{Fe}_2\text{O}_3(s) + 2\text{Cl}_2 \]
\[ 3\text{FeCl}_2(g) + 2\text{O}_2 \rightarrow \text{Fe}_3\text{O}_4(s) + 3\text{Cl}_2 \]

As a result a new layer of iron oxides is formed, however porous and not protecting. Moreover released chlorine can return to metal.
Mechanism of chlorine corrosion

<table>
<thead>
<tr>
<th>Metal</th>
<th>Deposit</th>
<th>Gas phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>Cl₂</td>
<td>Fe₂O₃</td>
</tr>
<tr>
<td>Cr</td>
<td>CrCl₂</td>
<td>Cr₂O₃</td>
</tr>
</tbody>
</table>

Metals: Fe, Cr
Deposit: Cl₂, FeCl₂, Fe₂O₃, CrCl₂, Cr₂O₃
Gas phase: O₂
Anti-corrosion protecting measures in pulverized coal-fired boilers

1. Maintenance of oxidizing atmosphere in the boundary layer at the furnace walls.
2. Reduction of temperature of steam approximately to 537 °C.
3. Application of protecting coatings.
4. Additives to flue gas neutralizing some corrosive agents.
5. Reduction of sulphur, chlorine and alkali metals in fuels.
Spreading a membrane wall with INCONEL
Anti-corrosion protecting coating: INCONEL
Anti-corrosion protecting coating: ceramic-metallic coating