Boiler – Process Description

On a conventional thermal power plant, the boiler is responsible for converting the chemical energy stored in the fuel (in this case, coal) into thermal energy by heating water and converting it into superheated steam. The thermal energy is then converted into mechanical energy in the steam turbines where the steam at high temperature and pressure drives the turbine blades. This mechanical energy, in the end, is converted into electric energy through the generator.

Part I - Fuel Processing

The coal needs to be processed before it can be used to produce energy. As a solid fuel that comes in bulk, it needs to be crushed (it can be done with a rotating bowl with rolls) into fine particles suited for the combustion process that will take place in the boiler. This is done in the pulverizers (also known as coal mills) that receive the bulk coal from the coal feeders in the center pipe [**1**] and primary air, just below the bowl [**2**] (previously heated to remove the moisture that is not suitable for combustion processes). To ensure that the coal particles leave the pulverizer with the adequate fineness in the top region of the mill [**3**] there is a rotational part, named the dynamic classifier, that acts as a screen for the coal particles.
In the picture below the internal components of a High-Pressure (HP) vertical spindle roller mill can be observed.

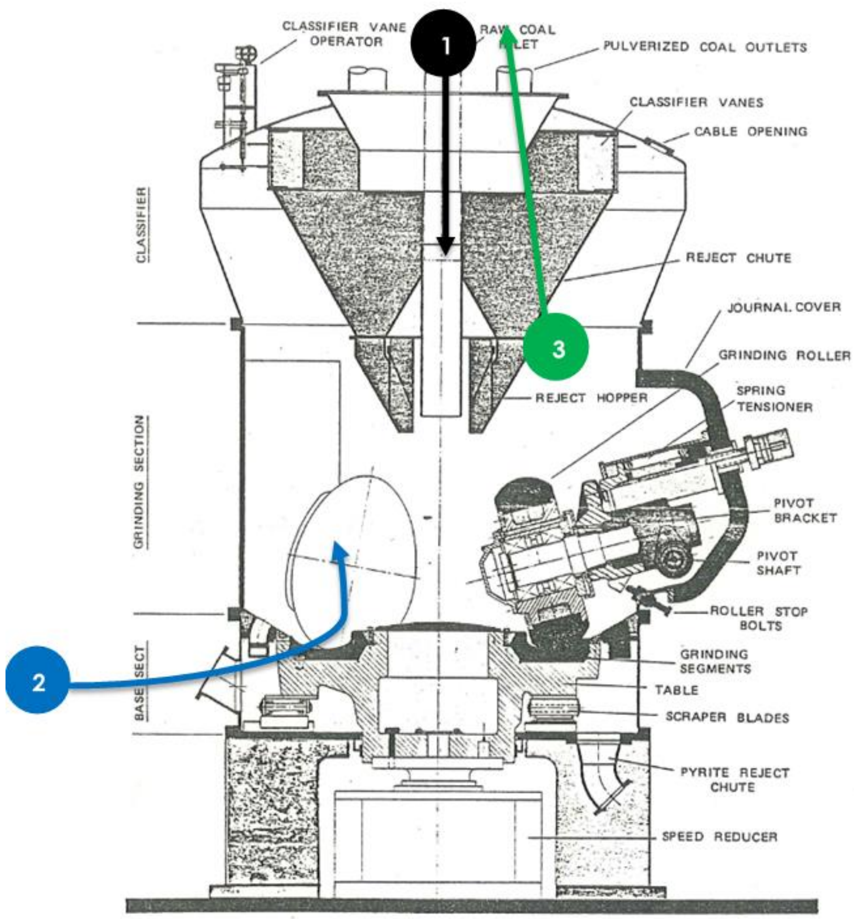


Figure 1: [1] Coal inlet; [2] Primary air inlet; [3] Coal + Primary air outlet.

Part II – Inside the Boiler

The boiler receives a mixture of pulverized coal and primary air (as the carrier of these particles) that enters the center section of the burners. In this case, each boiler has 5 rows [**1, 2, 3, 4 and 5**] of 4 horizontal burners each installed on the front wall of the furnace [**6**]. Each row of burners receives the coal from one mill. As more air is required for the combustion of coal, the secondary air enters the burners from a windbox that is common for the entire row of burners (with a control damper on each side to regulate the airflow). To reduce the NOx emissions, the final air required to complete the coal combustion enters a region just above the burners called boosted overfire air [**7**].

In terms of heat transfer, the boiler has several internal components as depicted in the picture below (an educational video can be found on this link).

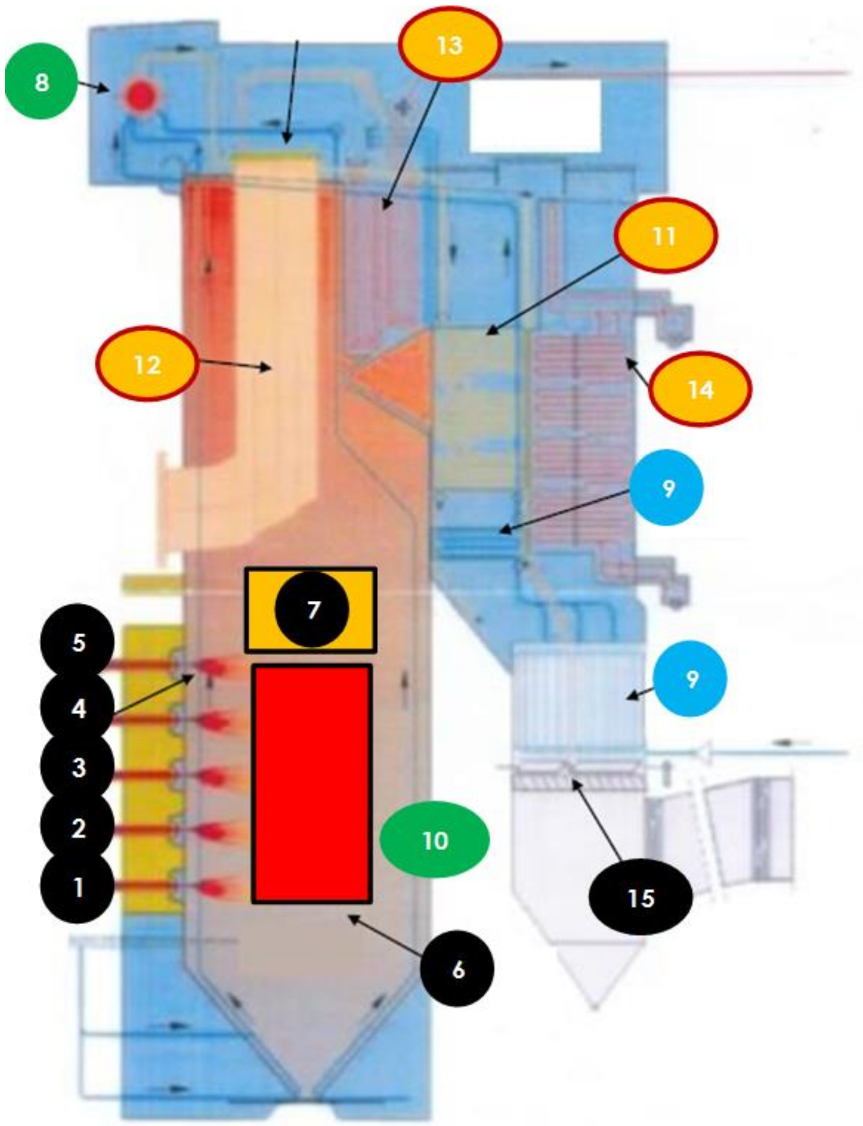
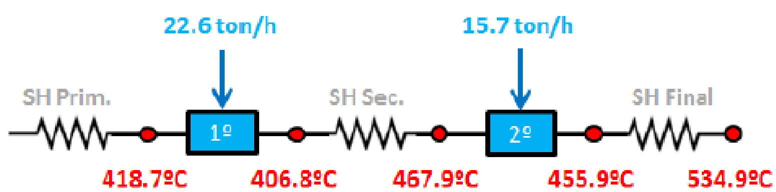


Figure 2: [1] 1st row of burners; [2] 2nd row of burners; [3] 3rd row of burners; [4] 4th row of burners; [5] 5th row of burners; [6] Furnace; [7] Boosted Overfire Air; [8] Drum; [9] Economizer; [10] Evaporator; [11] Primary Steam Superheater; [12] Secondary (radiant) Steam Superheater; [13] Final Steam Superheater; [14] Reheater; [15] Flue Gas Damper.

- **[8] Drum:** This is a component that acts as an energy buffer and is responsible for allowing the separation of the water from the saturated steam.
- **[9] Economizer:** This is the component that is responsible for pre-heating the water that enters the boiler known as feedwater before it is converted into steam (the outlet of the economizer is connected to the drum).
- **[10] Evaporator:** This is the component where the water is transformed into steam. It is made by a set of tubes that encase the entire furnace from the bottom to the very top (the outlet of the evaporator is connected to the drum).
- **[11, 12 and 13] Steam Superheaters:** There are 3 main steam superheaters (primary[**11**], secondary or radiant[**12**] and final[**13**]) where the saturated steam is gradually superheated. After the final superheater, the steam is ready to enter the turbine, but its temperature needs to be controlled. So, for this purpose, in between each steam superheater, outside the boiler on the piping, there is a desuperheater which is an element where small spray of water is injected, so the temperature before entering the next superheater can stay stable (in reality the total heat transfer required in the steam superheaters is typically less than the actual, so there is always room to control the temperature of the steam in end of the final superheater by injecting some water on these desuperheaters).

  In the schematic below it is represented a real case of the steam temperatures (in red) across the different steam superheaters and the corresponding water flows in the desuperheaters (on blue) to control the steam temperature at the outlet.



- **[14] Reheater:** The steam that leaves the high-pressure steam turbine (the very first one) then returns to the boiler to be reheated. This process takes place on the reheater. This component is installed on the rear pass of the boiler where the flue gases as the combustion products that need to be extracted from the boiler are divided into 2 streams, one is the reheater and the other one is the primary superheater (side by side). The dampers [**15**] are responsible for controlling the separation of the flue gases in this rear pass and they are installed on both sides (their position is not independent, if they open on one side, then they close on the other side to allow the flue gases to escape the boiler at any given moment from the reheater[**14**] and primary superheater[**11**]). They are in fact the main control element for the reheated steam temperature, but in case of emergency, there is also a desuperheater that will come into play.

On a final remark, the combustion air (primary and secondary) is forced to enter the boiler though fans and to keep the pressure inside the furnace balanced (always slightly sub-atmospheric for safety reasons) the flue gases are also extracted by fans (induced draft) typically with a variable blade pitch angle for flow control purposes.

Boiler – Slagging Phenomenon

Depending on the coal composition and combustion process itself (furnace temperatures, O_2 availability, ….) there might be conditions that could lead to slag build-up, typically in between the furnace and the rear pass (mostly on the final steam superheater tubes [**13**]).

The coal has different elements that are incombustible, especially in the ash, like some metals and minerals with higher fusion temperatures. Those elements when exposed to certain temperatures can evolve to a molten state that in contact with the tube surfaces (that are cooler) start to crystallize into a very hard residue that can obstruct the flue gases passages in between the tubes. If this obstruction keeps evolving an outage might be required to remove the slag build-up and restore the heat surfaces to their normal condition which has implications in terms of energy production.

We have identified in the datasets made available 2 episodes (with different severity levels) of slag build-up that happened in the past. The challenge is to use the entire dataset and classify how many and when additional slag build-up episodes have happened, so we can have a predictive tool to access when we could be close to this type of phenomenon.