Belchatow - Retrofitting the EU’s Largest Power Plant Site

Dr. Christian Storm*, Dr. Bernhard Pinkert*, Dipl.-Ing. Frank Adamczyk*, mgr inż. Krzysztof Matyskiewicz**

*Babcock Borsig Steinmüller GmbH (BBS)
**PGE Elektrownia Belchatow S.A.

1. General situation of energy supply in Eastern Europe

After a phase of stagnation, the industrial production begins to grow again in the Eastern European states. But in the last decades the investment in energy production was low. That is why the installed power plants remained in the state before the political change. A lot of power plants are 25 - 45 years old. On the other hand the East European states committed to fulfill the European Guidelines to reduce the emissions on air pollutants and dust. Under consideration of the remaining lifetime of pressure parts and the requirements to the environmental protection could the modernization be an alternative against the construction of new power plants.

2. Task description

The units 1-12 of power plant Belchatow were built between 1978 and 1988. The original units were identically equipped and their unit capacity amounts 370 MW. At the time of completion, the total power reached a capacity of 4,320 MW. It is since that time the largest lignite-fired power plant in Europe and one of the largest worldwide.

The power plant was fed up to the recent period by coal from the open-cast mining of Kleszczow. The annual consumption amounts appr. 34 million tons of coal. A modernization had become necessary on basis of an operation period longer than 150,000 hrs. The change of
some pressure parts is required latest after 200,000 hrs. On the other hand Poland was obliged to fulfill the European Guideline 2001/80/EG to reduce the emission of air pollutants.

Due to the large expense of modernization the owner PGE decided simultaneously to the works to implement measures to increase the efficiency. The measures were elaborated on basis of some studies.

The retrofit works were subdivided into different lots. This led to the special situation which all partners were contributed to the objectives of modernization. In addition of measures on the steam generator the main works were:

- The modernization of the steam turbine
- The exchange of HP and IP steam pipes
- The modernization of the regenerative air preheaters
- The modernization of the ESP
- The installation of a new I&C system
- The compliance of emission guidelines

3. Description of the steam generator

The units 1 to 12 of the power plant Belchatow were designed as tower type boilers with assisted-circulation evaporator-system. All boiler walls are formed by means of membrane walls with vertical tubes. The flue gas duct behind the furnace contains of 3 superheaters, 2 reheaters and a 3-stage economizer. The bundles of heating surfaces are suspended by means of supporting tubes. The supporting tubes are connected as 1st superheater stage. After leaving the boiler the flue gas is passed to the regenerative air preheaters. There are 2 air preheaters with vertical shaft installed.

The units of the power plant Belchatow are supplied with lignite coal from the mines Kleszczow and Szczerow. The combustions system consists of 8 beater-wheel mills, type N230.45 (manufaturer FPM Mikolow under licence of EVT) and 2 jet burners for each mill. The burners are aligned to a tangential circuit.

The evaporator system of the boiler is equipped with 2 circulation pumps, designed for 100% load (1 operating, 1 stand-by pump).

The safety equipment of the pressure part includes 2 HP reduction valves and 4 safety valves, installed after the re heater outlet.
4. **Description of modernization of units 3, 4 and 5**

The modernization of pressure parts and combustion system includes the following measures:

Installation of a low-NOx firing system by exchange of the coal dust burners and installation of an overfire air system (2 OFA levels)

- Exchange of the afterburner grate and installation of monitoring cameras
- Exchange of superheater bundles to increase the lifetime and steam temperatures
- Renewal of the attemporators including the control valves
- Exchange of the connecting tubes
- Installation of an additional feedwater preheater (unit 5)
- Installation of a separator in the hot air ducts to reduce the abrasion
- Modifying of the coil in the mill chamber and exchange of the classifiers
- Installation of new steam blowers for purifying the tube bundles and water gun blowers for cleaning the furnace walls
- Installation of an economizer-circulation system for the start-up process
- Exchange of the feedwater start-up control valve
- Renewal of cold and hot air ducts
- Overhaul of the FD and ID fans

Not included in the BBS scope was the modernization of the steam heated air preheaters and regenerative air preheaters.
Figure 1: Boiler drawing unit 5 after modernization (steam temperatures 570/570 °C, feedwater temperature 275 °C, highest efficiency)
5. Process design of modernization

5.1. Water – steam - cycle

The most important elements to improve the efficiency are the increase of steam temperatures and pressure. This was only possible with the simultaneous exchange of HP and IP steam pipes and HP and IP as part of the steam turbine. The LP part of the turbines was already modernized in the last 15 years.

<table>
<thead>
<tr>
<th></th>
<th>Original Design</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
<th>Unit 7-12</th>
</tr>
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<tbody>
<tr>
<td>Year of Contract</td>
<td>2005</td>
<td>2007</td>
<td>2009</td>
<td>2011</td>
<td></td>
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<tr>
<td>HP Mass Flow</td>
<td>t/h</td>
<td>1090</td>
<td>1,100</td>
<td>1,100</td>
<td>1,125</td>
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<tr>
<td>HP Steam Temperature °C</td>
<td>540</td>
<td>550</td>
<td>550</td>
<td>570</td>
<td>560</td>
</tr>
<tr>
<td>Reheated Steam Temperature °C</td>
<td>540</td>
<td>570</td>
<td>570</td>
<td>570</td>
<td>570</td>
</tr>
<tr>
<td>Boiler Feedwater Temperature °C</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>275</td>
<td>255</td>
</tr>
<tr>
<td>HP Steam Pressure MPa</td>
<td>17.7</td>
<td>18.0</td>
<td>18.0</td>
<td>18.5</td>
<td>18.7</td>
</tr>
<tr>
<td>Gross Efficiency %</td>
<td>38.1</td>
<td>39.3</td>
<td>39.3</td>
<td>40.1</td>
<td>39.4</td>
</tr>
<tr>
<td>Lower Calorific Value MJ/kg</td>
<td>7.75</td>
<td>7.75</td>
<td>7.75</td>
<td>7.75</td>
<td>7.75</td>
</tr>
<tr>
<td>Fuel Mass Flow t/h</td>
<td>442</td>
<td>449</td>
<td>449</td>
<td>431</td>
<td>450</td>
</tr>
<tr>
<td>Generated Heat MW</td>
<td>852</td>
<td>870</td>
<td>870</td>
<td>860</td>
<td>874</td>
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<tr>
<td>Combustion Power MW</td>
<td>946</td>
<td>960</td>
<td>960</td>
<td>948</td>
<td>965</td>
</tr>
<tr>
<td>Generator Output MW</td>
<td>360</td>
<td>380</td>
<td>380</td>
<td>380</td>
<td>380</td>
</tr>
</tbody>
</table>

Table 1: Process data of original design modernized units

According to the data from table 1 the gross efficiency can be increased up to 2 %. After its modernization unit 5 achieves an increased combustion power of 2 MW and a higher generator output of 20 MW. The units recently operate by use of coal from the Belchatów mine. The fouling characteristics of this coal are mostly moderate. The modernization was carried out under consideration of the future use of coal from the Szczerzow mine. This coal contains of a more unfavorable mineral composition, which leads to more fouling at the heating surfaces.
These facts have already been considered in the boiler design.

<table>
<thead>
<tr>
<th></th>
<th>Design Coal</th>
<th>Fuel Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>Ma%</td>
<td>23.20</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Ma%</td>
<td>1.92</td>
</tr>
<tr>
<td>Sulfur</td>
<td>Ma%</td>
<td>1.07</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Ma%</td>
<td>0.32</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Ma%</td>
<td>10.69</td>
</tr>
<tr>
<td>Moisture</td>
<td>Ma%</td>
<td>51.40</td>
</tr>
<tr>
<td>Ash</td>
<td>Ma%</td>
<td>11.40</td>
</tr>
<tr>
<td>Volatiles {daf}</td>
<td>Ma%</td>
<td>54.00</td>
</tr>
<tr>
<td>LHV</td>
<td>MJ/kg</td>
<td>7.75</td>
</tr>
</tbody>
</table>

Table 2: Fuel characteristics of modernization

5.2. Pressure part and superheater circuit

The increase of superheated steam pressure was not problematic because the design pressure on the superheater outlet was 21.0 MPa according to the original design. But the increase of steam temperatures required the enlargement of heating surfaces. For the re heater the originally planned space for the enlargement of reheater 1 could be used.

As a result of the enlargement of the reheater surfaces the superheater P1B, arranged behind the reheaters, now receives a lower level of heat. To compensate this and increase the superheater outlet temperature by 30 K, it was necessary to extend the superheater surface substantially. This problem was solved by separation of the evaporator und the use of the upper part as superheater surface. For unit 5 the separation point was located at level 45 m.

The higher feedwater temperature required the installation of an additional extraction on the HP turbine part and a 3rd feedwater preheater. The cold re heater mass flow was reduced by 50 t/h. The reduction of the combustion power required the installation of a 4th stage of super heater P1B and the move of economizer bundles 3 m above. The economizer surface was adapted to the required flue gas temperature of RAPH inlet.
5.3. Design of firing system

Under consideration of the given boundary conditions and the costs a new design of the firing system was developed. Especially the measures of the furnace chamber and the level of the lowest superheater could not be changed under consideration of the cost. According to the volumetric heat release rate of 0.10 MW/m² the furnace outlet temperature amounts to 1,070 to 1,090 °C. Under consideration of the existing hot flue gas recirculation it was not possible to arrange the overfire air injection between hot flue gas recirculation and 1st superheater.

The new firing system is based on Low-NOx jet burners with 3 coal dust injections according to the newest BBS-design. In order to realize a high jet momentum a high velocity level at the coal dust and air injections was selected.

The first overfire air injection was arranged below the discharge point of the hot flue gas recirculation. The number of nozzles was increased from 12 at unit 3 to 18 at unit 5. The optimized arrangement was determined by means of CFD simulations.

The 2nd stage of overfire air injection was arranged in the area of superheater 3 under application of lances. The reason for this arrangement is the necessary delay time of flue gases between the burners and the last air injection.

![Image](image_url)

Figure 2: Lances of overfire air level 2, arranged in the area of superheater 3
The number of lances was conditioned by the number of rows of supporting tubes, the number of nozzles of each lance follows the number of superheater plates.

**Figure 3: Arrangement of coal dust burners, overfire air injections and burner details**

### 5.4. Coal mill and classifier

The 8 beater-wheel mills are equipped with a geared clutch to influence the speed. The speed can be regulated in the range between 420 and 500 rpm. This allows a maximum volumetric flow of 320,000 m³/h according to a nominal fuel input of 80 t/h. The need of fuel at 100% boiler load amounts to 450 t/h and the can be reached by 6 operating mills only.

The analysis of the mill and classifier showed that the Low-NOx-Combustion required some modifications. The first modification was a new design of the mill chamber coil because the old one was too large which sometimes resulted in an unstable discharge of coal dust.

The new designed classifiers were supposed to accomplish a better coal dust distribution to the burner and a more stable transport. For a better control of the flue gas temperature behind the classifier a flue gas recirculation duct was installed. The flue gas recirculation is equipped with an electrical control flap.
6. Process data of the water and steam part

A requirement of the modernization contract were some guarantee values for steam temperatures and emissions (CO and NOx) requested by the customer. To fulfill these requirements the HP steam temperature, in the range between 50 to 100% boiler load, had to maintain constant as well as the range of the reheater steam temperature between 70 to 100%.

The thermodynamic boiler design was based on measurements before the modernization. The results have been transformed to the modified firing system. Figure 4 shows a comparison between predicted and measured values of the transferred heat to the different heating surfaces. The very low transferred power to heating surfaces P0 and P1A results from the important content of moisture in the saturated steam and has been considered in the process calculation of unit 5. The required steam temperatures were reached.

![Figure 4: Comparison between calculated and measured heat consumption (unit 3)](image)

At the beginning of the optimization it was difficult to reach the required steam temperature at partial load. The temperature on superheater outlet was only in the range between 530 and 540 °C due to the NOx-optimized firing system. If the combustion operates with a high air excess the steam temperature was low. After reducing the air excess in the burner level and optimizing the relation between OFA1 and OFA2 it was possible to reach the required steam temperatures at partial load. The reduction of the air excess in the burner level led simultaneously to lower CO and NOx emissions.
7. **Optimization of the firing system**

The optimization of the firing system was carried out by the commissioning personnel. The process engineering department evaluated the process data with the help of numerical calculations. For the combustion process some CFD studies had been carried out. During commissioning the engineers detected the negative influence of primary air.
The results show that a high level of primary air volumetric flow has a negative influence on the emissions. This results from a later ignition due to the lower momentum of burner jets. For this reason the primary air flow was reduced which required the increase of the flue gas temperature in front of the mills. The control concept of the mills was modified.

The next main focus was the general optimization of air flows to the afterburner grate, the mills (primary air), the burners (secondary air) and the overfire and wall air systems under consideration of the air staging in the combustion chamber.

![Figure 7: Optimization of the control curves for the overfire air (unit 5)](image)

Figure 7 shows the adaption of the OFA curves during the commissioning works. The values at nominal load were only marginally changed. At partial load a significant modification of the curves was necessary. At lower loads up to 70 % the OFA1 dominates in the overfire air system. At higher load the OFA2 injection is mainly responsible for controlling emissions. The conclusions of these experiences are:

- Under consideration of the existing measures of the combustion chamber the installation of 2 OFA levels was indispensable
- The OFA2 level must be arranged in the maximum possible distance to the upper burner

A typical run of the emissions and the unit power over 24 hrs is shown in figure 8.
8. Summary and outlook

The retrofit of the units 3, 4 and 5 included the extension of the lifetime and the reduction of the CO and NOx emissions. The NOx emission was reduced from 350 mg/Nm³ below 200 mg/Nm³, the CO emission respectively. Unit 7 is in commissioning phase, Units 8 – 12 will follow between 2013 and 2016.

Furthermore the unit power was increased from 370 to 380 MW. The modernization also increased the boiler efficiency by modernizing the turbine HP and IP parts and increasing the HP and IP temperatures. At unit 5 the feedwater temperature was increased from 255 to 275 °C, additionally. The gross efficiency of the unit was increased by 2 %. These modifications correspond to a reduced coal consumption of 70 million tons in 30 years (10 units) which allows the extension of the coal mines and the power plant’s operation time up to 1½ year.

The retrofitting of Poland’s largest coal fired power plant can be a model for other power plants in Eastern Europe.