Design concept and operation experience of recent hard coal fired power boilers

Hellmuth Brüggemann, Reinhard Gollnick [(1)]
Konrad Ebert, Dr. Michael Kübel [(2)]
[(1)] ALSTOM Boiler Deutschland GmbH, Stuttgart/Germany
[(2)] EnBW Energie Baden-Württemberg AG, Stuttgart/Germany

Abstract

There are many good reasons, why coal-fired power plants continue to play an important role for the European energy supply. The remarkable increase of the renewable energy sources contribution to the electricity supply over the last years needs a reliable partner, who will be able to deliver the power whenever needed and renewable energy cannot contribute enough to the power demand of the public grid. Modern power steam generators therefore need to satisfy additional requirements in terms of flexibility. In order to cope with those economic, operational and environmental requirements today and in the future, an advanced plant design is essential.
The new hard coal fired power plants, fired with bituminous coal from worldwide sources, have an electrical output of more than 900 MW_{el}. With an overall plant efficiency over 46 % the specific CO_2-emissions are far below the global and even the European average.
High boiler steam parameters of 603 °C / 292 bar, 621 °C / 61 bar for the HP and RH section, low emissions, a wide coal range, and the use of advanced materials are the main significant features of this steam generators. During the design, special attention has been paid to allow low load operation of the plant and to support the grid demands to a high extend.
These high efficient and flexible steam generators have successfully passed the test runs. First operating experience during that time and before has been collected and experience in their day to day operation have been collected.
This paper gives an overview of the recent boiler design concepts with focus on the firing systems tilting burners, and demonstrates for selected load cases the successful operation experience from full load to lowest technical load during their day to day operation.

The RDK Power Plant

The Rheinhafen Dampfkraftwerk (RDK) Power Plant is located in the City of Karlsruhe at the river Rhine (Figure 1). The history of the power plant goes back in the 1950s when the first bituminous coal-fired units started their operation. Before a capacity of 1208 MW was installed in total comprising of four power blocks: Unit 4 is a modern Combined Cycle Plant, units 5 and 6 are two oil/gas fired units, currently in cold reserve and unit 7 is a 550 MW bituminous coal fired unit. The Power Plant also supplies the city of Karlsruhe with district heating.
In December 2006 EnBW decided to enlarge the site by a new 912 MW unit. The new unit, taking the name RDK8, is expected to be worldwide a milestone in terms of efficient power generation from bituminous coal, with a plant efficiency above 46 % and in terms of environmental performance with clearly lower emissions than the corresponding German and European limits.

Figure 1: Overview RDK power plant (Source: EnBW)

Dates and Milestones

Alstom was selected for supplying the boiler and the turbine island of RDK8 (Figure 2). The phase for public approval started in April 2007 and was finished in February 2008 with the approval for erection of the authority of Regierungspräsidium Karlsruhe. First works were commenced on the construction site in March 2008. Erection of the main steel structure started in March of the following year. Pressure tests were successfully passed in May and June 2012 for each of the pressure part systems. The test run was started on 16th April and was successfully finished on 16th May 2014.

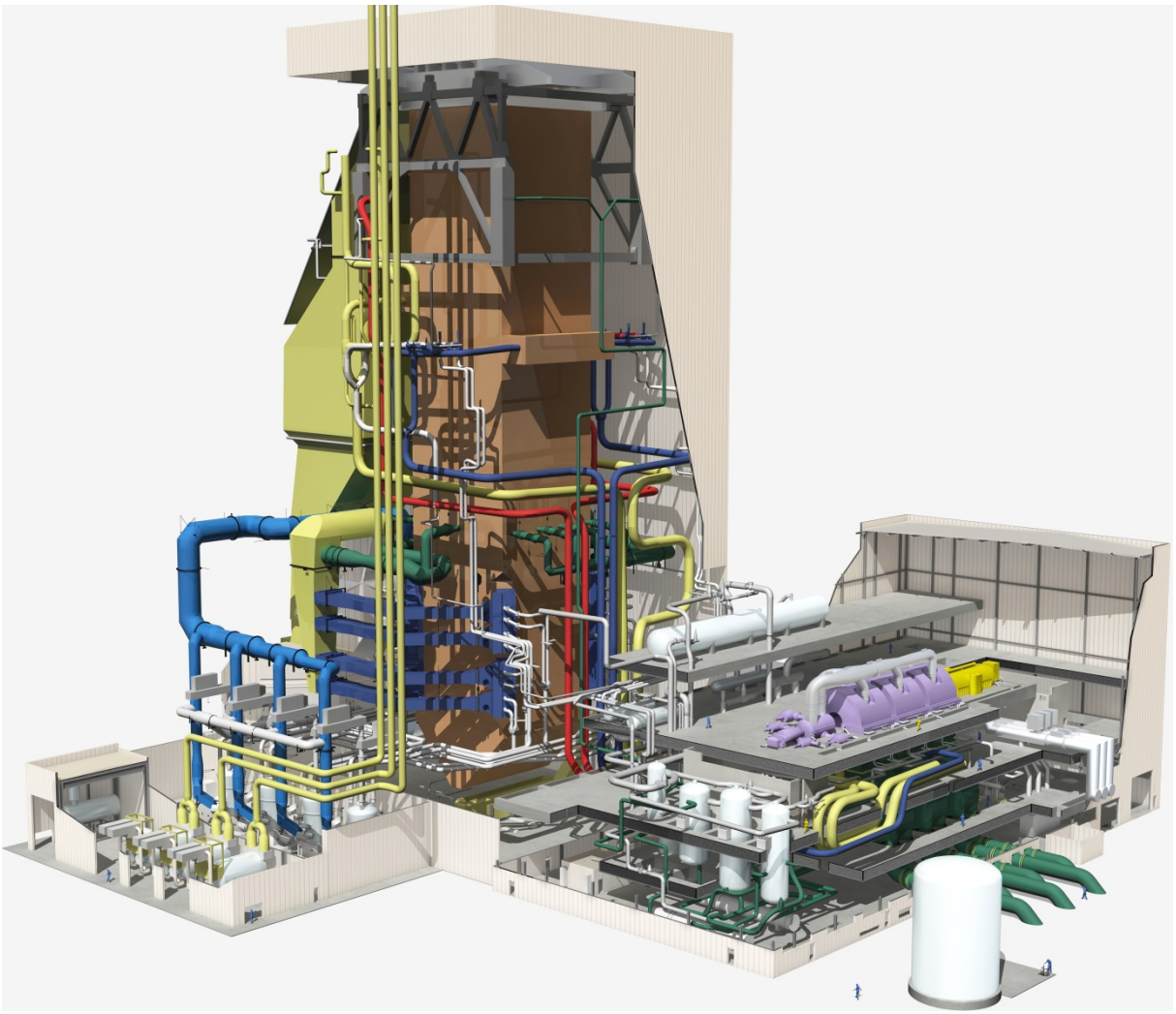
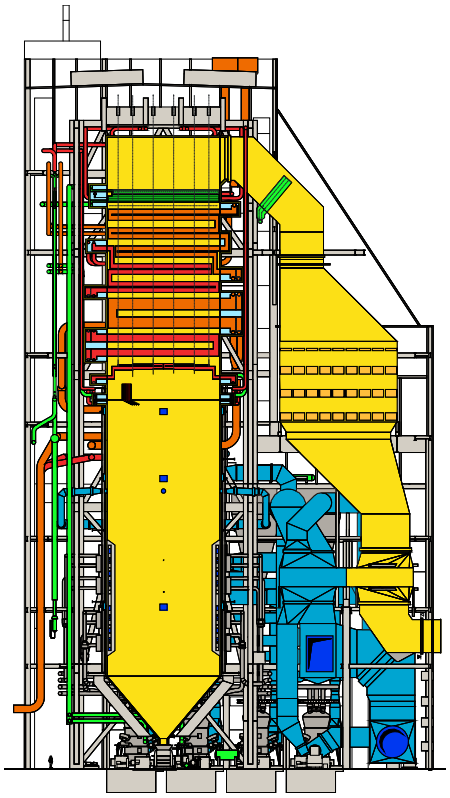


Figure 2: 3-D-Model of boiler and turbine house RDK8

Boiler design

The boiler is designed for ultra-supercritical steam parameters with 292 bar and 603 °C on the live steam side and 61 bar and 621 °C on the reheat side at BMCR, representing the highest parameters used for tower type boilers (Figure 3). This is based on the once through technology which started commercially in the 1970s and gradually developed to higher steam parameters and to supercritical steam cycles while the main components remained but size and the pressure part material was further developed. [1]



Live Steam
312 bar (Design Pressure)
603 °C
652 kg/s (2,347 t/h)

Reheat Steam
77 bar (Design Pressure)
621 °C
542 kg/s (1,951 t/h)

Feedwater
305 °C

Fuel
Bituminous Coal (Import)

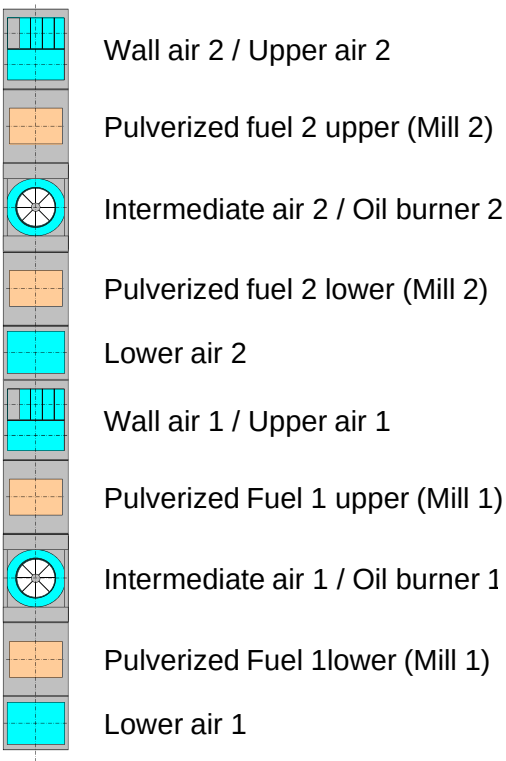
Figure 3: Side Elevation of boiler

The boiler is of tower type design and all systems are designed under consideration of the most economical and reasonable technical solutions. The capacity of the boiler is optimized in order to take full advantage of the economy of scale for single flue gas train plants using the largest Regenerative Air Preheater built with a diameter of the rotor of 21.7 m.

Firing concept

The boiler is equipped with Alstom's Low NO_X Tangential Firing System (LNTFS) realizing axial and radial air staging principles with pulverized coal (PC) tilting burners. The tangential firing system is designed as a direct firing for imported coal with 4 bowl mills. The compact burners are located in the four corners of the furnace and allow a most efficient use of the furnace for the combustion process. The burner nozzles can be tilted up- and downwards to adopt the furnace outlet temperature to compensate for different fuel and different loads, thus supporting highest possible cycle efficiency without spray water attemperation. The proven axial and radial air staging concept allows substoichiometric low NO_X combustion in the burner zone, providing a portion of air to the furnace walls by designated wall air nozzles to prevent high CO–levels causing corrosion and further improving carbon burn out of tramp coal particles. Figure 4 shows the arrangement of the burner nozzles of one compartment, combining two complete burners located in the furnace corner. In total there are eight compartments. The combustion air is supplied via separated nozzles as lower, intermediate and upper secondary air nozzle according to the following burner array:

- Combined upper secondary and wall offset air
- Upper coal and primary air
- Combined intermediate secondary air and oil burner for start up
- Lower coal and primary air
- Lower secondary air



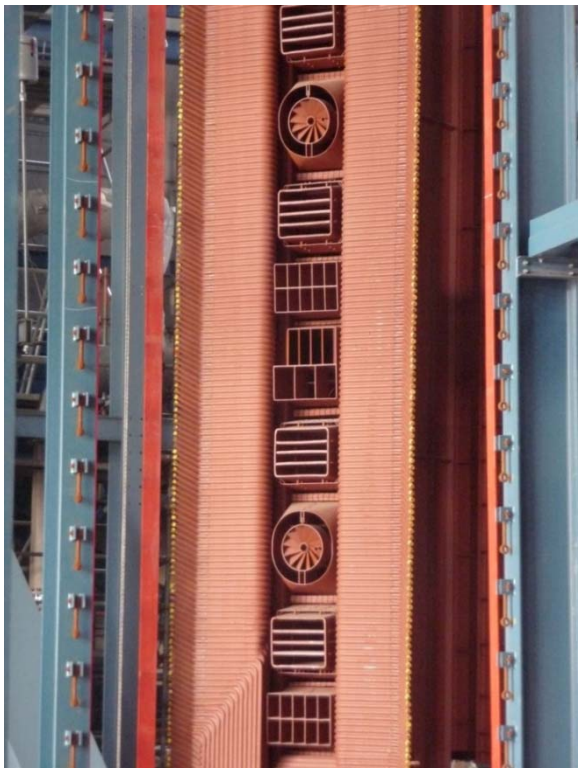


Figure 4: Arrangement of burner nozzles

Four bowl mill of size SM29/18 with dynamic classifiers provide sufficient capacity for drying and grinding for a variety of bituminous coals. The mills are arranged on one side of the boiler.
Full load is achieved with all four mills in operation; there is no reserve mill foreseen. In order to achieve a good burnout of the coal within the specified range, while keeping a low primary NO_X emission a fineness of approx. 10 % rest on the 0,09 mm sieve will be achieved. This value will be controlled by the speed of the dynamic classifier. Each mill has 4 dust outlets serving one level of the burner system in the four corners of the boiler. The division of the coal dust pipe per burner takes place directly before the burner in order to maintain a good coal dust distribution. The pulverized fuel is transported via the PC system, designed with a similar pressure drop in each connection to the burners to have an improved PC distribution. The mill PC duct and burner system as well as the mill and firing operating ranges are shown in Figure 5.

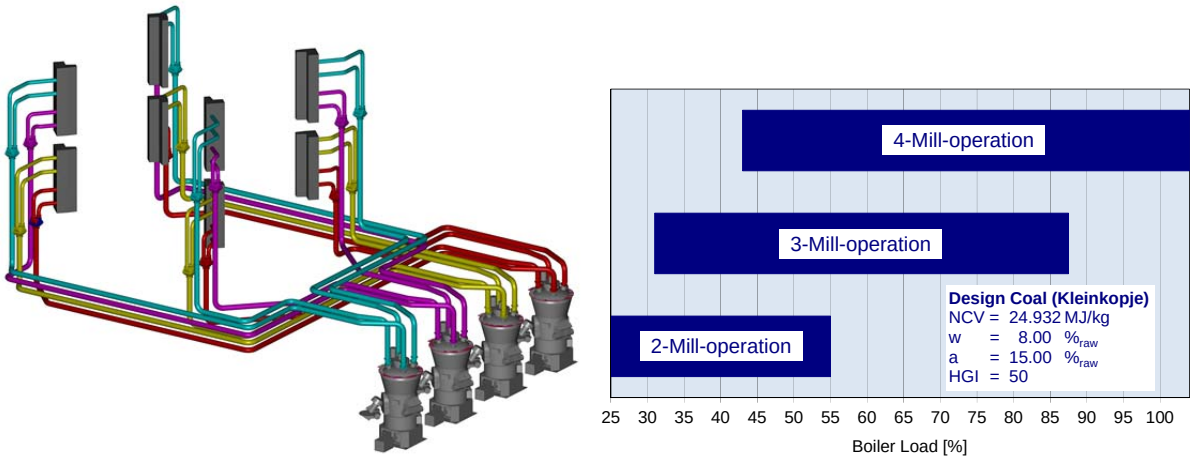


Figure 5: Arrangement of mills, pc ducts and burners, operating ranges for mills and firing system

The firing system is designed for a broad, fuel range from international traded coals under consideration of a flexible operation. Figure 6 illustrates the variety of specified fuel with a heating value from 23.0 up to 29.3 MJ/kg. To further improve the fuel flexibility single coals outside of this coal range can also be burnt, or mixed with coals within the range shown below. Therefore 2 bunkers for each mill are foreseen so that the coal can be blended by the feeding system from the bunkers to the mill.

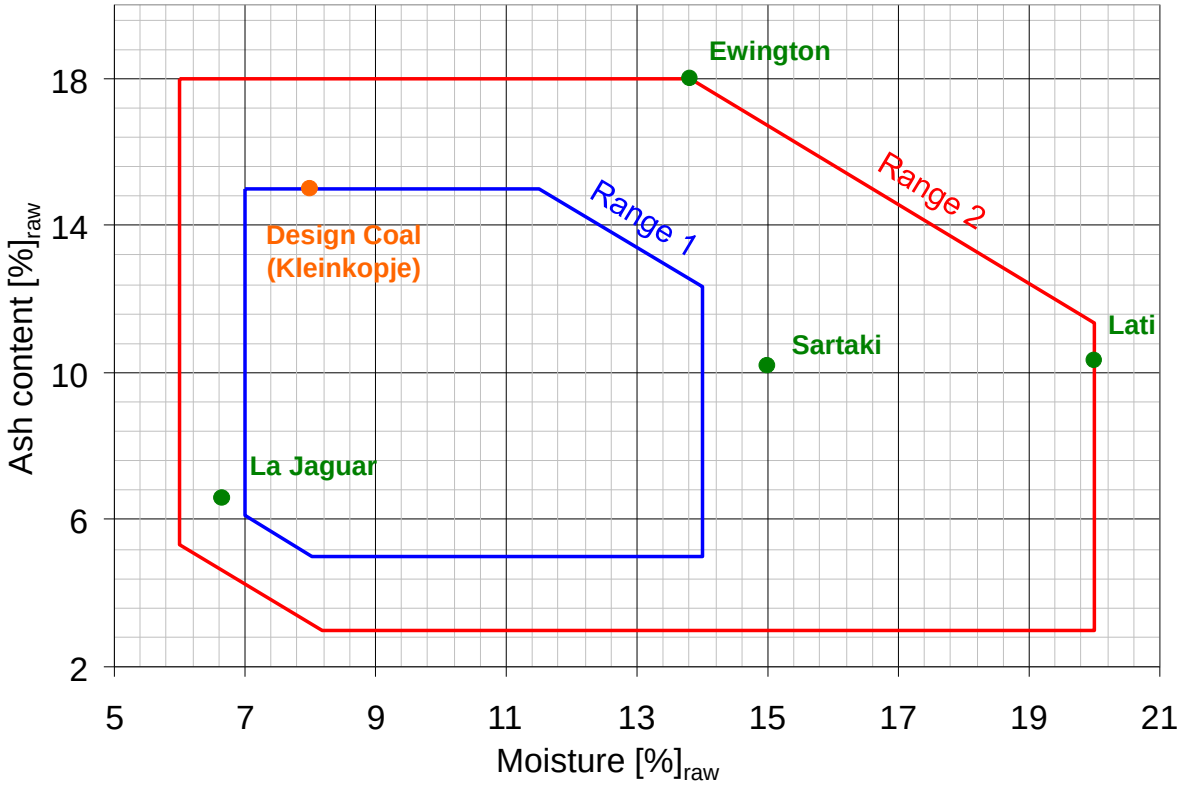


Figure 6: Coal range diagram

Operating Experience

Low excess air:
The excess air ratio for the combustion was designed for only 15 % during full load of the boiler, thus increasing the boiler efficiency by reducing flue gas losses as well as reduction of auxiliary power for the ID and FD fans. Additional cost savings could be realized, since air and flue gas ducts could be reduced in size. The lower excess air does not negatively impact the carbon burn-out as it was a result of good PC fuel preparation and improved combustion air distribution and it supports operation with low NO_X-concentration upstream the SCR.

Low load operation:
High flexibility of the boiler was already considered during the design phase as is essential to compensate fluctuating generation of solar and wind power and satisfy the grid's demand. Therefore the minimum design load was defined to be at only 20 %. This load point, usually operated with two mills in operation was tested with two and one mill in safe and stable operation and realized in the control philosophy of the boiler. These works followed the example of the predecessor power plant of EnBW, Unit 7 of Heilbronn in Germany, where the one mill operation already has been implemented [2]. The compact tilting-burners support a stabile operation at lowest loads and least possible steam temperature reductions. The low

load operation capabilities are shown in Figure 7, demonstrating the transition from two to one mill operation at low load.

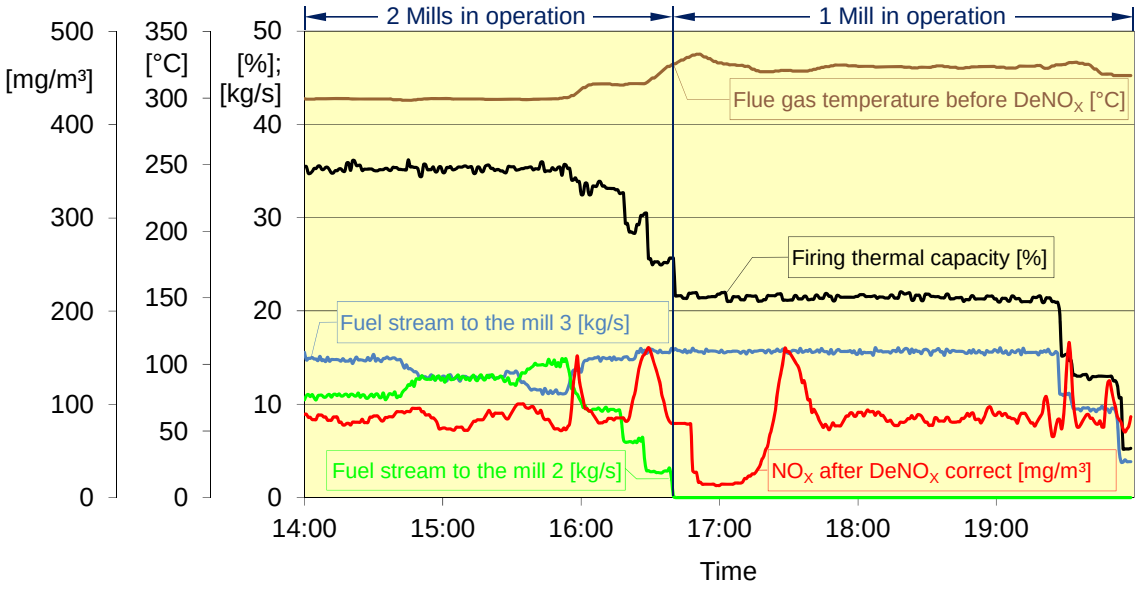


Figure 7: Transition from two to one mill operation at low load

Emissions and combustion efficiency:
In operation, the firing systems and tilting burners proved unproblematic. Expected NOx-concentrations upfront SCR were achieved and enable the catalyst to be operated according to the design of only 100 mg NOx/m³. The operation of the burner tilt was efficient and did not show any problems. In terms of carbon conversion the firing system was exceeding the expectations and maintains a very good combustion efficiency. Combustion results of utilized coals showed concentrations below 1 % TOC (total organic carbon) in the fly ash and below 3 % TOC in the wet ash. Optimization for further coals of the fuel range is continuing.

Operation experience with tilting burners:
During the commissioning phase the capabilities of the tilting burners were widely tested and respective presettings were implemented in the boilers control logic. Thus the position of the nozzle tilt was estimated by the control, the new setpoint for the tilt angle was defined and the tilt drive activated to smoothly reach the new position. By this the use of reheat spray was minimized for a better cycle efficiency. An example of a load change, causing a tilt adaptation at lowest reheat spray flows is shown in Figure 8.

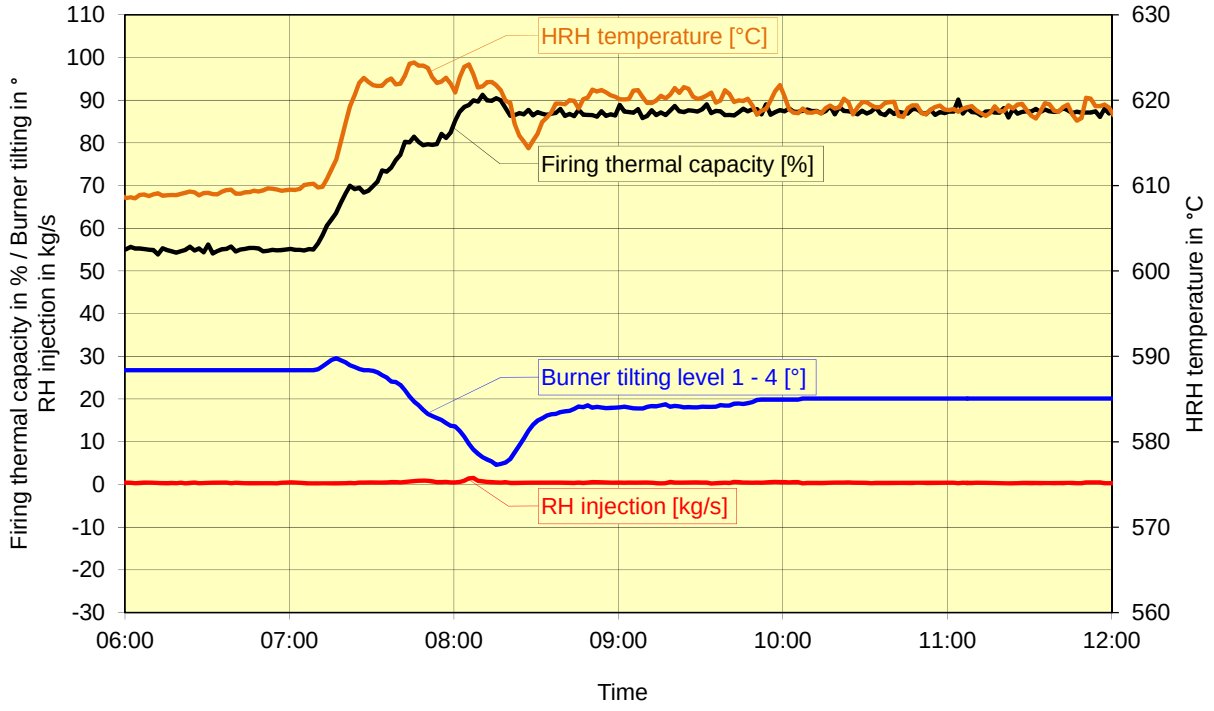


Figure 8: Load change, causing tilt angle adaptation at lowest reheat spray flow.

Using the tilting burner technology beside the already known optimization of reheat outlet temperatures further possible influence on the process can be identified, which depending on priority and desired target parameter can be integrated into the logic of the boiler. The main parameters, which can influence the process can be seen in Table 1:

Process Parameter	Tilting Direction of Burner
Support Hot Reheat Temperature	**upwards**
Minimizing Spray Attemperation	**downwards**
Reduction of NOx-Level upstream $DeNO_X$	**downwards**
Temperature Differences between Evaporator Tubes	**upwards**
Dynamic Behaviour / Load Changes	**upwards**
Slagging Tendency in Hopper	**upwards**
Slagging Tendency in Plattens	**downwards**
Erosion of Nozzles	**Avoid longlasting extreme position**

Table 1: Influenced parameters by use of tilting burners

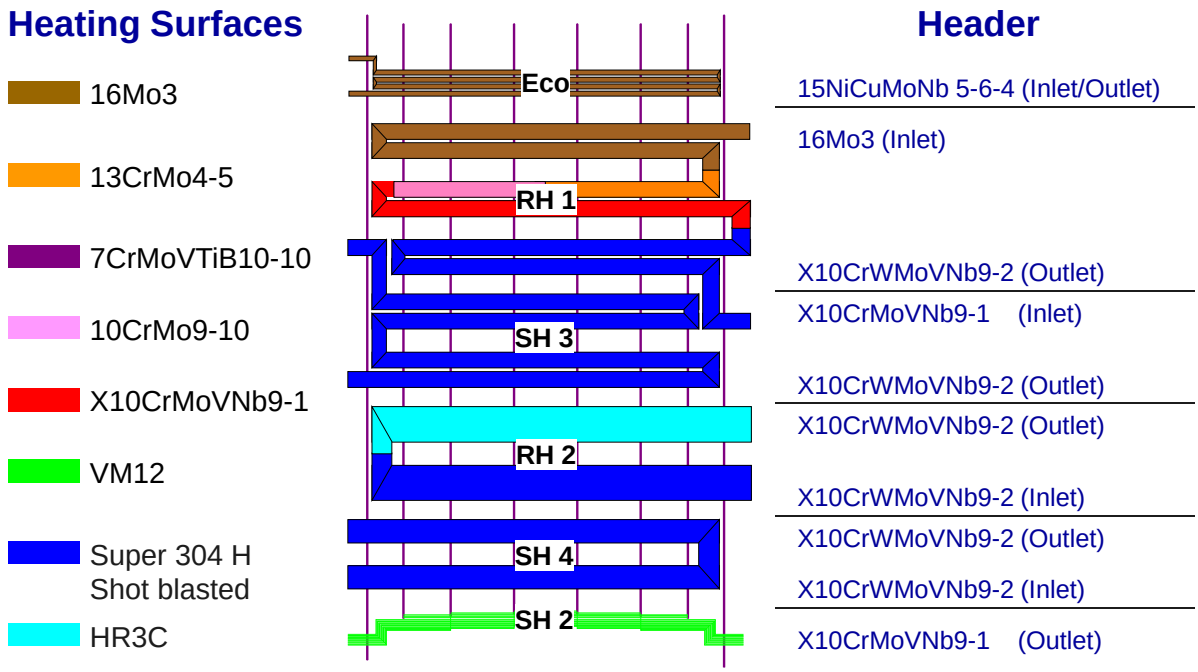
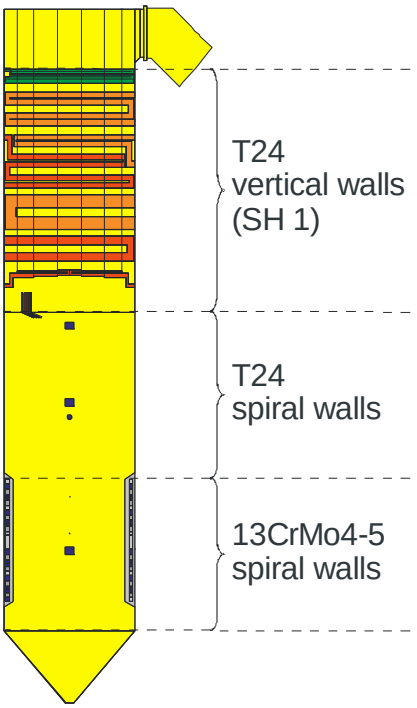


Figure 9: Material Concept – Heating Surfaces

Material concept for heating surfaces:
Due to the high steam conditions, advanced materials are used which must be resistant to oxidation and corrosion in accordance with their application parameters. The materials concerned in detail are presented in Figure 9. Showing also the heating surface structure to the colours reflects the material selection. On the right-hand side of the picture the header materials are listed.
The economizer is completely made of 16Mo3. Reheater 1 consists of the materials 16Mo3, 13CrMo4-5, 10CrM09-10, X10CrMoVNb9-1 and S304H. For the Superheater 2 supporting tube screen the material VM12 is utilized, which is a newly developed 12 % Cr-material with a creep rupture strength similar to T91. The last 2 Superheaters and Reheater 2 are made of austenitic alloys. For reasons of corrosion protection, the austenite material has a mean chromium content of at least 18 %; in the hot sections of the Reheater 2 of at least 25 %. Furthermore, wherever the 18 % Cr-material is used the shot peened variant with a higher steam oxidation resistance was selected.



Due to the high steam temperatures and the high axial loads, the material 7CrMoVTiB 10-10 (T24) is employed as a wall material at the end of the evaporator spiral and in the vertical tubing part of the membrane wall (Figure 10). The supporting tubes are also made of this material for the same reason.
Separator and vessel are made of P92. For the superheaters and the reheaters, from the reheater 1 outlet onwards, also the martensitic 9 % chromium steel P92 is used as header materials.

Figure 10: Material selection of waterwalls

Summary and Outlook

With the operation of EnBW's RDK8 in Karlsruhe one of the most advanced bituminous coal fired power plant was put into commercial operation. By careful boiler process and component design, the use of advanced materials and balanced components plus progressive firing technology the power plant is prepared for a flexible operation fulfilling today's and next future's grid demands. The changing operational regime for bituminous coal fired units in Germany due to the increased supply of renewables and the need for more flexible operation of the conventional power plants [2] led EnBW and Alstom to work out further improvements to further increase flexibility of RDK8. Those measures were decided during design and later in the execution phase and consisted mainly in:

- The use of a variety of international traded coal
- the reduction of the minimum once through load and
- the introduction of the one mill operation as a normal operation mode for the minimum load, which enables a minimum load of approx. 20 % of the nominal load

Figure 11: View of boiler house

Furthermore a concept on reducing the time for load changes is under investigation and is expected to be implemented also. The plant did not show any problems with the advanced material concept and after having successfully passed the trial run now undergoes a further optimization phase. It is to be expected, that further potential of optimization can be made available for the customer and more experience can be gained with this advanced power plant with most modern power plant technology (Figure 11).

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