Babcock Power

Technical Publication

Experience with Various Coals in Power Plants in the United States and Europe

by

H. Schuster
BBP ENERGY GmbH
Oberhausen, Germany

C. Penterson
BABCOCK POWER INC.
(formerly Babcock Borsig Power, Inc.)

Presented at
COAL-GEN 2002 Conference and Exhibition
St. Louis, Missouri
July 31 - August 2, 2002

0175

EXPERIENCE WITH VARIOUS COALS IN POWER PLANTS IN THE UNITED STATES AND EUROPE

by H. Schuster, Babcock Borsig Power, Oberhausen, Germany and C. Penterson, Babcock Borsig Power, Worcester, MA, USA

1. Introduction

Coal-based power plants in the United States and Europe use various coal grades which extend from lignites and sub-bituminous coals to a wide range of bituminous coals and anthracites.
Appropriate characterization of coal is important for the design of the steam generators, their associated firing systems and assessment of the operating results.
This paper presents examples of the design of several coal-fired units in Europe and the US describing their boiler design, firing systems and operating experience firing different types of coal.
By the selection and analysis of adequate fuel parameters, actual experience gained with the combustion of various coals in the USA and Europe can be adopted and used on either side of the Atlantic.

2. Coal Characterization

In the USA, just as in Europe, a wide range of coals is utilized which extends from lignite over a wide spectrum of sub-bituminous and bituminous coals, up to anthracites.

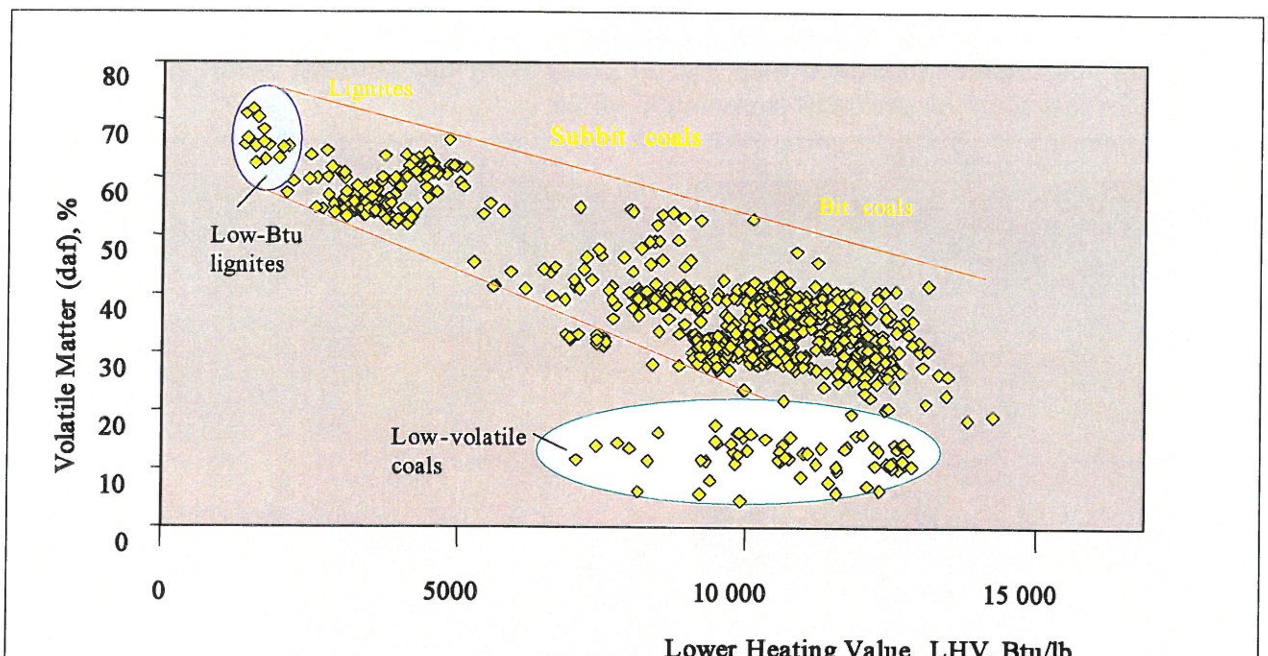

Figure 1: Wide Range of Coal Qualities

Figure 1 shows the range of coals with which we were concerned in recent times for the design of boilers and firing systems [1]. Most of the plants are located in Europe and North America, but the chart also includes a number of coals from power plants in other parts of the world (Asia, Australia, South Africa and South America). Well-proven boiler designs and firing systems are available for the entire range of coal grades.
It is necessary to evaluate a number of coal parameters in order to help insure an adequate design and optimum operation of the selected steam generator and the associated firing system.

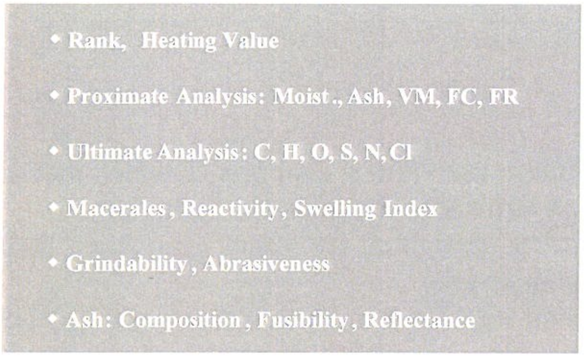

Figure 2: Coal Characterization

Figure 2 shows a listing of the important parameters for characterizing the coal grade. Besides the usual parameters for the description of the coal rank, factors such as the reactivity of coal (maceral composition, pyrolysis behavior), fusibility of ash or the reflection of ash can have a great influence in the design and operation of the boiler plants.

When characterizing the coals used in the USA and Europe, it should be recognized that coals from American and European mines belong to the group of North Atlantic coals. U.S. power plants are using almost exclusively domestic coals (imported coals account only for about 1 % of the total coal consumption). Power plants in Europe use, to a large extent, imported coals, very often from the southern hemisphere. For example, about 65 % of the hard coal used in the European Union in the year 2000 was imported and about 36 % of the imported coal was supplied by Australia and South Africa alone. Bituminous coals from the southern hemisphere, so-called Gondwana coals, due to their formation process, show a different petrographic structure of the organic substance than that of coals from the northern hemisphere. Typical examples for this coal type are coals from South Africa.

Kentucky | **South Africa**

Kentucky		South Africa	
Rank HVB-A,	**Micr. Refl. 0.8 %**	**Rank HVB-B,**	**Micr. Refl. 0.73 %**
Vitrinite 73.4 %,	**Liptinite 8.8 %**	**Vitrinite 25.8 %,**	**Liptinite 4.2 %**
Inertinite 10.2 %,	**Minerales 7.6 %**	**Inertinite 60.6 %,**	**Minerales 9.4 %**
Reactive Components 87 %		**Reactive Components 46 %**	

Figure 3: Petrographic Analyses of Coals

Figure 3 shows the petrographic structure of a typical coal from South Africa and a high-volatile bituminous coal from Eastern Kentucky. Important characteristics of the South African coal, when compared with the US coal, are:

- A maceral composition with a high inertinite content of about 60 % (vs. Kentucky coal with 10 %) and a content of reactive components of 46 % compared to Kentucky coal with 87 %;
- Specific ratios of carbon to hydrogen and oxygen indicate advanced demethanizing of the coal;
- A volatiles heating value that is approximately 30 % lower than that of the northern bituminous coal.

For the combustion process these characteristics result in reduced pyrolysis properties and lower reactivity leading to less favorable ignition and burnout conditions. By utilizing modern firing systems, it is possible to process and fire these more difficult coal grades without any operational problems, as will be discussed below.

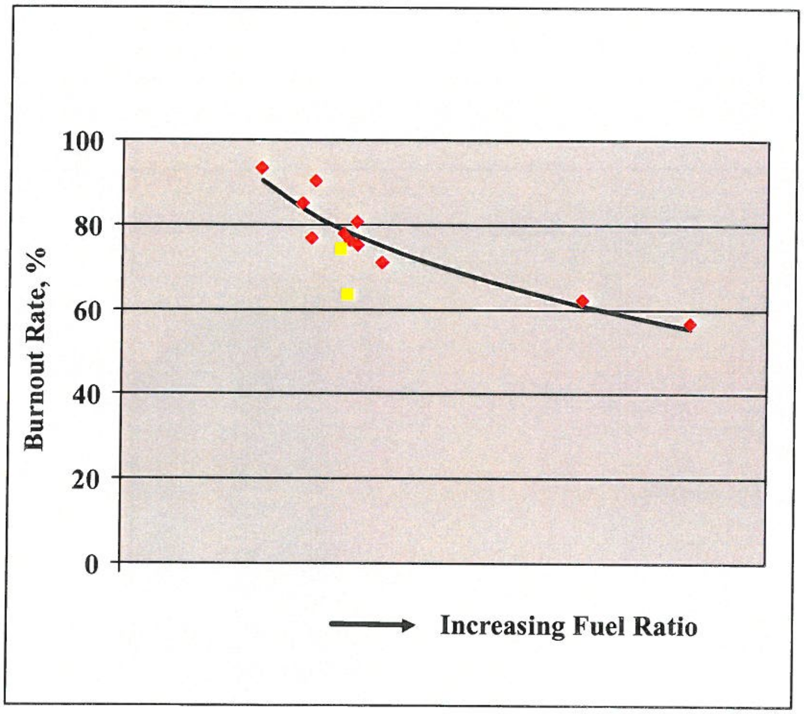

Figure 4: Drop Tube Combustion Tests

For evaluating the combustion behavior of coals, special drop tube combustion tests can be very useful. Using this device, the reactivity for various coals can be determined under standard conditions. Test results for a number of coals, used in power plants in North and Central America, *Figure 4*, show a fairly good correlation between burnout rate and fuel ratio (fixed carbon/volatile matter) for most of the US coals, but indicate also remarkable deviations for some of the non-US coals (yellow symbols). The comparison of a new type of coal with well known cases allows a fairly good prediction of coal burnout in newly designed furnaces as well as for firing system modifications.

3. Examples of installed coal-fired steam generators

This section reports on some examples of installed steam generators, their designs and their operating experiences, broken down by coal grade.

3.1 Lignite-fired boilers

Lignite occurs in the USA only in certain regions (Dakota, Texas) and therefore plays a minor role in the overal US power generation market. By contrast, in some areas of Europe, lignite is an important domestic coal type used for power generation. In Germany 27 % of electric power was generated from lignite in 2001. Several new large modern lignite-fired steam generators went on-line in recent years.

Figure 5 shows, for example, the steam generator design for two new lignite-fired units with a capacity of 933 MWe each. The technical challenge for the design of the plant resulted from the plant size, the coal quality and the requirements regarding limitation of emissions [2]. The steam generator is a supercritical Benson type boiler with steam conditions of 3879 psig / 1029°F / 1081°F. It is a tower-type boiler with a furnace cross-section of 75.5 x 75.5 ft and 535 ft in height. The coal is characterized by lower heating values (LHV) from 4200 to 4800 Btu/lb, water contents of about 52%, and ash contents of 4.9 to 8.5 %, as well as an increased slagging tendency. Essential features of the firing system are the flue gas extraction from the furnace and integral fan beater mills for combined drying and grinding of the raw coal, as well as a tangential firing system with lignite-specific jet burners. For reduction of the NOx emission level, the firing system is provided with air staging in the furnace incorporating multi-stage supply of burnout air. The two units went into operation in 1999 and 2000. The steam generators have provided, to date, good operating results and high reliability. The guaranteed availability of 95 % was achieved in 2001 with sufficient margin. The net unit efficiency, based on the net calorific value, is 43%. NOx emissions are maintained at values below 0.17 lb/MMBtu through optimum firing conditions.

2 x 933 MWel / 2 x 5,335,000 lbs/hr

- **Once-through steam generator, Benson®**
- **Lignite LHV = 4,500 Btu/lb**
- **Supercritical steam parameters:**
  1029 °F / 1081 °F / 3879 psig
- **Net efficiency of 43 %**
- **Commissioning : 1999/2000**

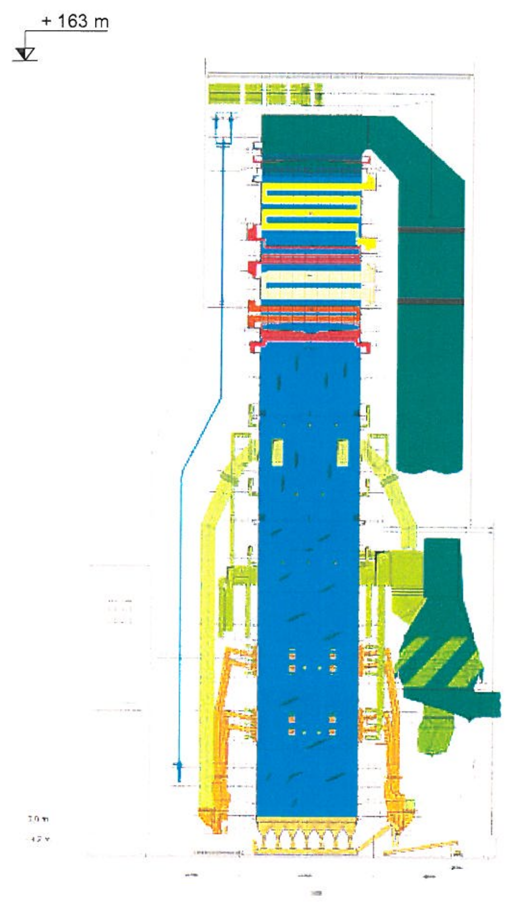

Figure 5: Boiler of Lippendorf P.S., Germany

3.2 Boilers for sub-bituminous coals

Sub-bituminous coals are of minor importance in Europe. In some plants domestic coals or imported sub-bituminous coals from Indonesia and the USA are used.
In the USA, however, the large deposits of Western sub-bituminous coal are of great relevance for power generation. Presently, the best-known type is the Powder River Basin (PRB) Coal. In the past a multitude of power plants were originally designed or subsequently retrofitted for firing PRB Coal. PRB Coal is also anticipated to be the fuel for many new power plant projects. A mining output of 400 million tons of PRB coal is projected for 2005 for utility power generation.
Besides specific problems with coal handling due to its high reactivity and propensity to ignite, special attention has to be paid to some specifics of the coal for the design of the boiler and firing system. These are the high moisture content of abt. 25 to 31 %, an attendant reduced heating value (HHV 7800 to 8600 Btu/lb), the high reflection of the ash deposits in the furnace and the low softening temperature of the ash.
The specific behavior of PRB Coal needs to be evaluated particularly well during the conversion of existing plants to this coal. As an example *Figure 6* shows the steam generator of a 225 MW unit which was originally designed for operation with bituminous coal and commissioned in 1968. The unit was a natural circulation design, producing 1,502,000 lbs/hr of main steam at nominal 2591 psig /1005°F/1005°F. The furnace was rather small compared to today´s standard, with 16 burners arranged on the front wall. Steam temperature control was accomplished with split backpass gas flow (dampers) and superheater spray.

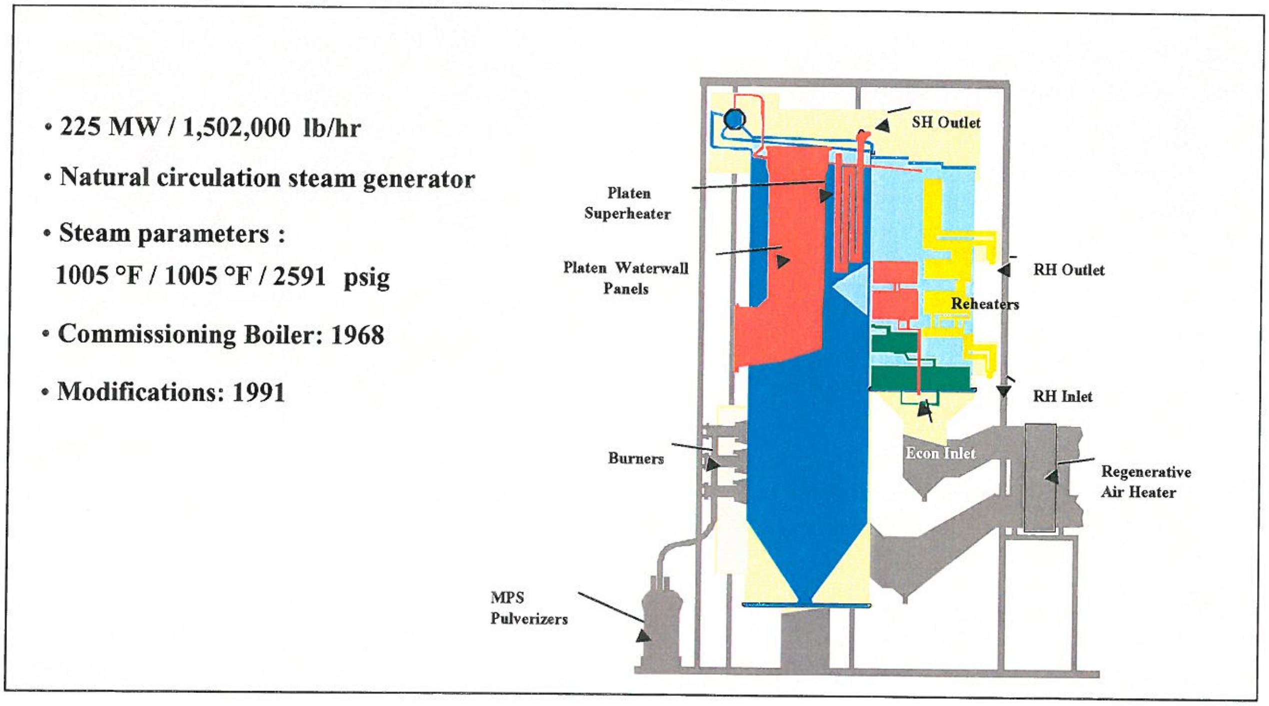

Figure 6: Boiler Retrofit Bit. ⟶ PRB Coal, Unit in Upper Mid West US

In 1991, the boiler was retrofitted for the combustion of PRB Coal [3]. Three new MPS mills were installed. Tests and calculations showed that furnace heat absorption with PRB coal was dramatically lower because of the increased reflection of the ash deposits, FEGT would increase unacceptably and a unit derating of 45 to 50 % would be required. This behaviour was compensated, to a great extent, by the installation of platen waterwall panels as additional cooling surface, as shown in the drawing. This and further adaptation measures in the area of the convective heating surfaces and additional cleaning devices enabled the unit to operate up to 88 % of boiler load with 100 % PRB coal , keeping the FEGT under a critical value of 2250°F. The combustion results were very good, with a Loss of Ignition (LOI) of less than 1%.

More recently additional experience has been gained in retrofitting existing PRB fired boilers up to 600 MWe in capacity for NOx reduction. Experience indicates that NOx levels can be reduced to values below 0.2, approaching 0.15 lb/MMBtu [4].

Figure 7 shows the design of a steam generator for a newly planned 725 MW unit in the USA, firing PRB Coal. It is a supercritical, Benson-type once-through boiler. The grinding system and the furnace are dimensioned with due regard for the properties of PRB Coal. The firing system has been designed with five MPS mills and an opposed arrangement of 30 low-NOx burners. Commissioning of the plant is planned currently for 2006.

- **725 MWel gross / 4739 k lb/hr**
- **Once-through steam generator , with sliding pressure operation**
- **Fuel: PRB**
  HHV: 8173 BTU/lb
- **Supercritical steam parameters**
  SH: 1055 °F / 3806 psi
  RH: 1051 °F / 838 psi
- **Opposed firing system**
  30 LowNOx - Burners
  5 MPS mills
- **Commissioning : 2006**

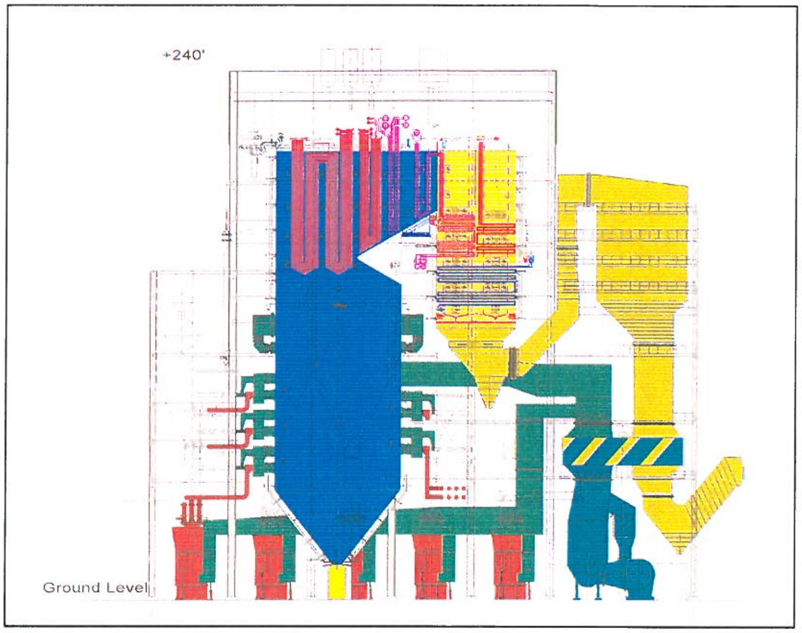

Figure 7: Supercritical Benson® Boiler for PRB Coal

3.3 Boilers for bituminous coals

The bituminous coal category presents a very wide range of coal properties. In the past, power plants in the USA were often designed for a few coals from the local region, that means for a limited coal range. Plants in Europe today are primarily required to use imported coal from the entire world with an accordingly wide quality range ("World Coal").

Discussed below are three examples of existing plants firing various bituminous coals. *Figure 8* shows one of the few new coal-fired steam generators built in the USA in the past 10 years. It is a typical type of small steam generator with a steaming capacity of 1,250,000 lbs/hr with subcritical steam parameters. The boiler is a natural circulation design with split backpass gas flow control by dampers. The firing system has been designed as a front-fired system with 16 low-NOx burners at four levels and four mills. The fuel used is a Eastern Kentucky High-volatile Bituminous Coal with a range of the design coal of HHV from 12,500 to 13,200 Btu/lb, volatiles from 32 to 38 % and an initial deformation temperature of the ash (oxidizing) of above 2,300°F. Available coal analyses from the operating plant indicate an even more narrow range of coal data. The plant has been running successfully since 1994.

- **1 x 165 Mwel / 1,250,000 lb/hr**
- **Steam parameters**
- **2520 psi, 1005 °F / 1005 °F**
- **Bituminous Coal**
- **Drum Boiler**
  - **–Twin Gas Pass**
  - **–Atrita Pulverizers**
  - **–Low NOx CCV Burners**
- **Commissioning: 1994**

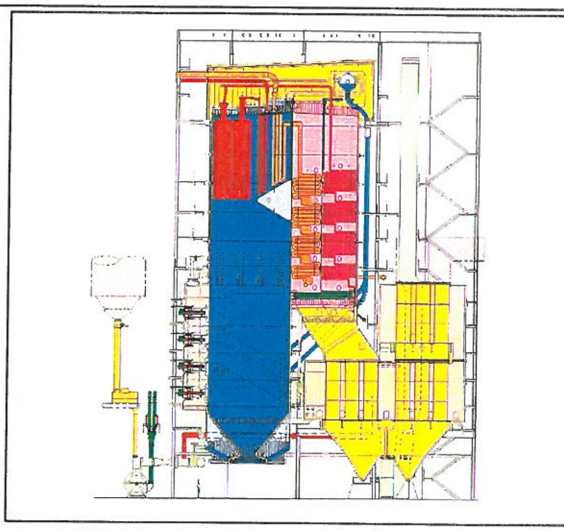

Figure 8: Coal-fired Boiler in South-East US

- **2 x 350 MW / 2 x 2,381,000 lbs/hr**
- **Once-through steam generator, Benson ®**
- **Bit. Coal**
- **Supercritical steam parameters:**

  SH : 1004 °F / 3625 psig

  RH: 1004 °F / 573 psig
- **Commissioning: 1983**

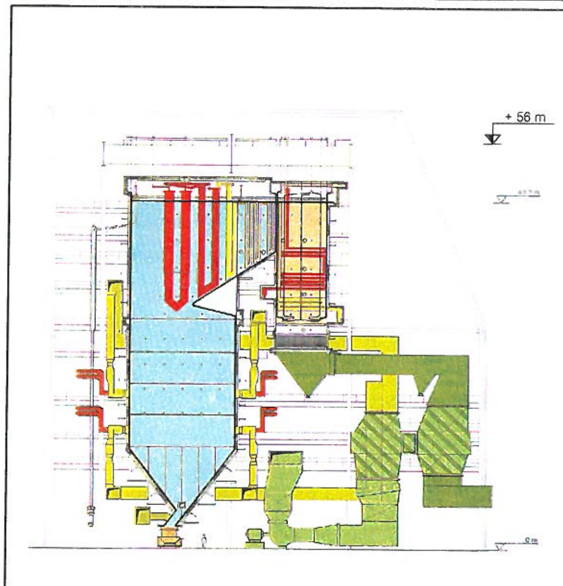

Figure 9: Boiler of Studstrup P.S., Denmark

The second example, shown in *Figure 9*, is the coal-fired steam generator of a plant in Denmark with a capacity of 2x350 MWe. The steam generators have been designed as once-through boilers, Benson type, with supercritical steam parameters and as a two-pass design with platen superheaters. Sixteen burners in an opposed arrangement and four MPS mills are the major components of the firing system for each unit. Since its commissioning in 1983 various bituminous coals, mainly from Australia, Columbia, Poland, South Africa and the USA have been used. Coals ranging from 23 to 36 % volatiles and lower heating values from 10,500 to 12,400 Btu/lb were used. All of these coal qualities have been fired alone or as blends without any operating restrictions. Although the furnace is relatively compact, there are neither burnout problems nor any severe slagging.

553 MWel gross / 3,307,000 lbs/hr

- **Once-through steam generator, Benson ®**
- **Steam parameters:**

  545 °C / 262 bar (1013 °F / 3800 psi)

  562 °C / 53 bar (1044 °F / 769 psi)
- **Bituminous Coal**
- **Opposed firing system / 16 Burners / 4 MPS**
- **Plant efficiency of 43 % net (based on LHV)**
- **Boiler availability of 99.3 % (av. 1993 - 2000)**
- **Commissioning: 1992**

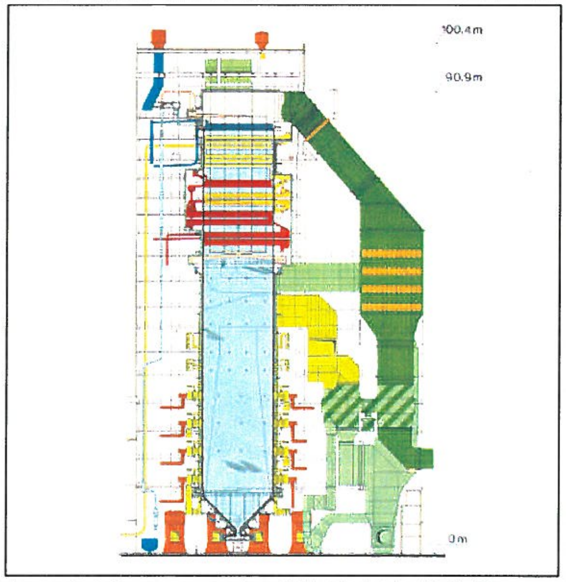

Figure 10: Boiler of Staudinger P.S., Unit 5, Germany

The third example is a modern steam generator design for a supercritical 553 MWe unit in Germany. The steam generator, *Figure 10*, is a tower-type Benson boiler with single reheat. The steam parameters are 3800 psig/ 1013°F / 1044°F, the net efficiency of the unit is 43 % (based on LHV). The air/flue gas path is of single-line design. The firing system has been designed with an opposed burner arrangement at four levels, with four mills, 16 burners and an overfire air system. The mills installed are MPS mills with a hydro-pneumatic grinding force system and rotary classifier, *Figure 11*. The pulverized-coal burners are DS-type low-NOx burners, *Figure12*, which produce an intensive pyrolysis, very stable ignition and reduced NOx formation. In the vertical flue gas duct a high-dust SCR system has been installed between the steam generator and the air heater for further NOx reduction.

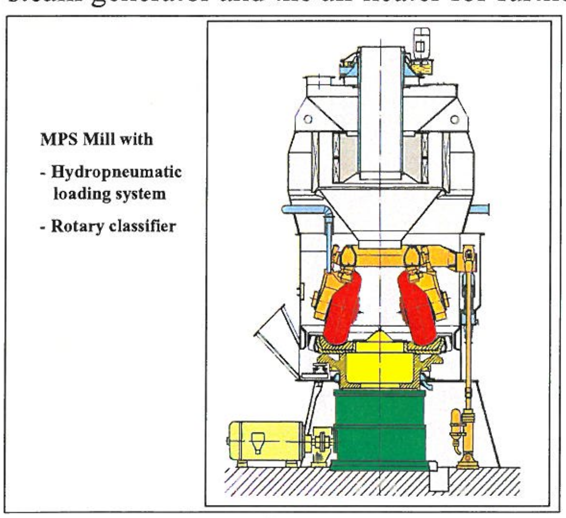

Figure 11: MPS Mill

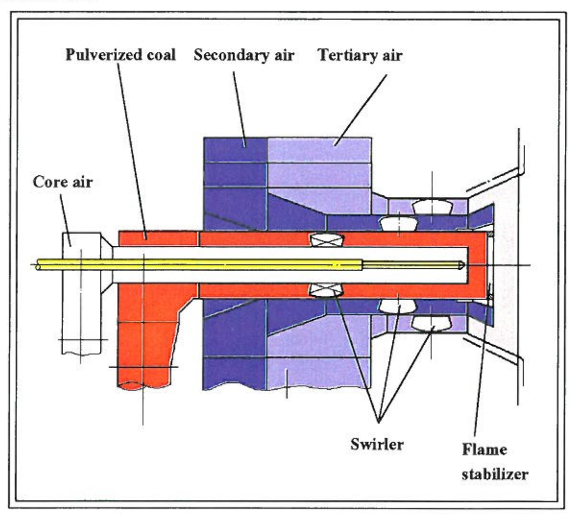

Figure 12: DS Burner

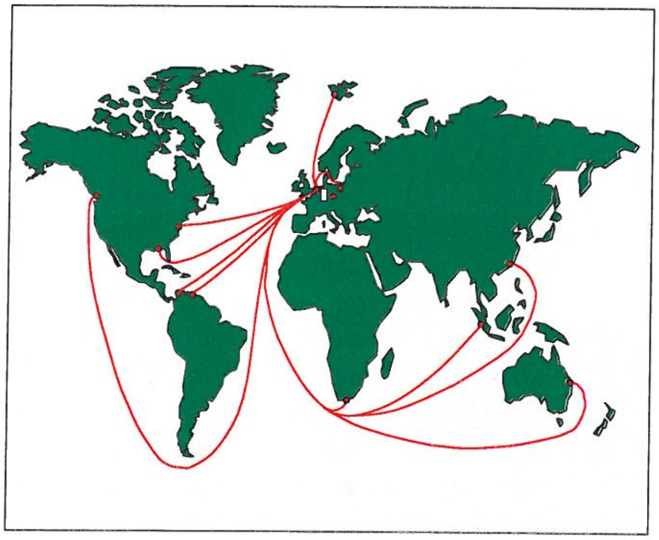

Figure 13: World-wide Coals for Staudinger P.S.

Already at the planning stage the plant was expected to fire a wide coal range. The flexible grinding system and the burners with high ignition stability provide the necessary firing-side prerequisites.

The unit has been in operation since 1992. Since the start-up, more than 30 different coal types and blends have been used. *Figure 13* shows that the coals used came from almost all coal-exporting countries around the world; *Figure 14* gives the bandwidth for some major coal parameters (contractual range vs. actual experience).

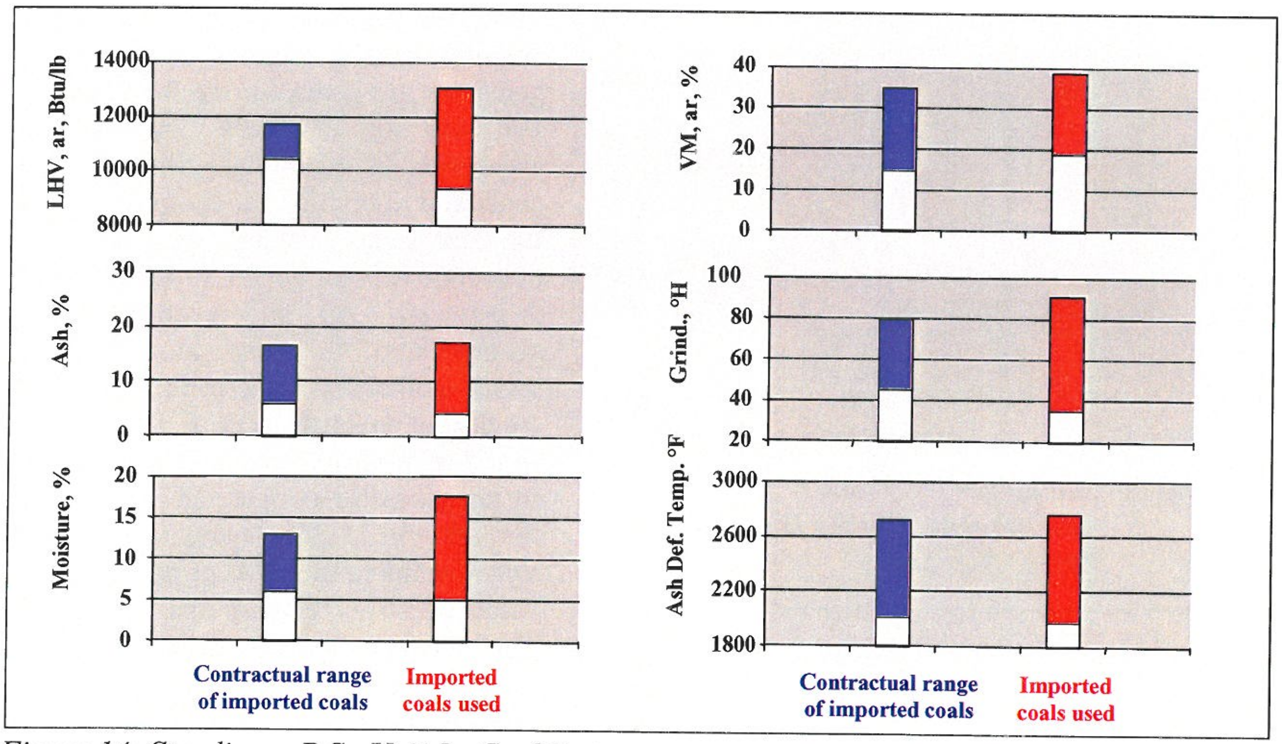

Figure 14: Staudinger P.S., Unit 5 - Coal Data

Operating experience [5] has shown that the entire fuel range can be used with unchanged burner settings. In the case of major changes of the coal quality, it is only advisable to adjust the mill settings.

As an example of the operating results, *Figure 15* shows the NOx value at the boiler outlet for several coal qualities as a function of the volatiles content. Favorable NOx values were also achieved with difficult coals. The emission limit of approximately 0.17 lb/MMBtu is maintained by the installed SCR system in any case. Burnout was very good with an unburned combustible content in fly ash lower than 3% for the entire range of coals.

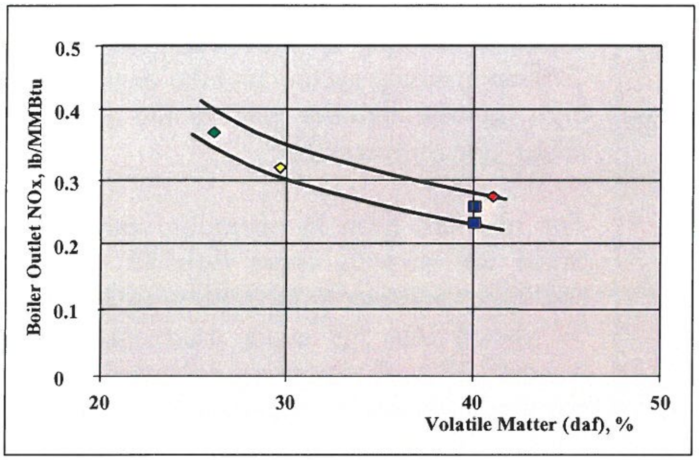

Figure 15: Staudinger P.S., Unit 5
NOx Values with Different Coals,

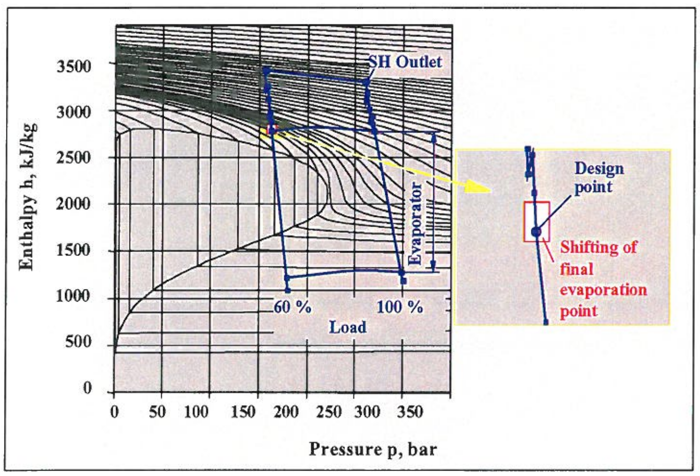

Figure 16: Staudinger P.S., Unit 5
Heat Absorption of the Heating Surface Sections

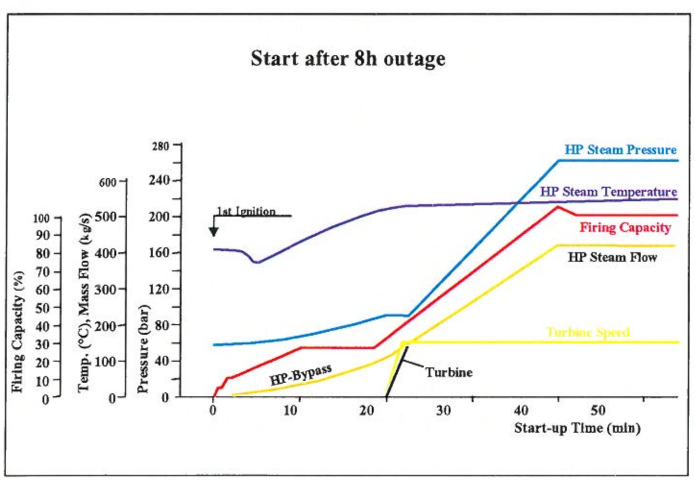

Figure 17: Staudinger P.S., Unit 5
Start-up Diagram

The Benson boiler presents an important system-inherent beneficial behavior for the combustion of a wide range of coals. Coals of different origins and qualities show a varying combustion and fouling/slagging behavior. The Benson boiler compensates for differences in heat absorption of the furnace by the variable final evaporation point. By allocation of the feedwater flow to the firing rate the boiler attains the steam temperature largely independent of the heat absorption of the heating surfaces. *Figure 16* shows the behavior of the described steam generator. In the enthalpy/pressure diagram for water vapor, the heat absorption of the various heating surface sections of the steam generator are given for the load cases of 100 and 60 %. The varying heat absorption of the furnace with different coals and operating conditions results in the marked shifting of the final evaporation point which in case of 60 % is between -2.0 and + 4.8 % of heat absorption of the evaporator. The live steam temperature is kept in all cases at the design point of 1013 °F.

In the load range from 100 to 35 %, the steam generator is operated in the once-through forced-flow mode and the live steam temperature is kept at a constant value of 1013 °F over this load range. The reheater steam temperature in the range from 100 to 60 % load is constant at 1044 °F. The coal firing system can be stably operated in the load range of 100 to 25 % with all coals in the design range without supporting oil flame.

The plant is designed for and has operated with frequent starting and rapid load transition. *Figure 17* shows a typical boiler start-up diagram for a hot start after eight hours outage. About 20 minutes after first ignition, the generator is connected to the grid, and within less than 60 minutes the plant has reached full load. This plant and its twin unit have performed up to two hundred hot starts per year since they went commercial, with high availability.

Two similar steam generators are presently being constructed for a power plant in Turkey with a capacity of 2x650 MW, commissioning is planned for 2003.

3.4 Boilers for low volatile coals

Low volatile coals and anthracites are used only in a few areas within the USA (e.g. Pennsylvania) and Europe (e.g. Spain, Germany, Ukraine) and do not play a significant role in the total electricity generation market. Experience gained at those units is being used successfully, however, for the design of new power plants burning anthracite and low volatile coals in other countries, for example in China [6].

4. Exchange of operating experience

Coal-related operating experience can be assessed, compared and then applied to other plants by means of appropriate parameters. This includes both US and European experience. Two examples will be described below.

The first example refers to the influence of the coal quality on NOx formation in the furnace. From the mechanism of NOx formation it is to be derived that mainly two fuel parameters, volatile matter and nitrogen content, are of prime importance for NOx formation. To account for this, a NOx-index can be created using the fuel ratio and nitrogen content.

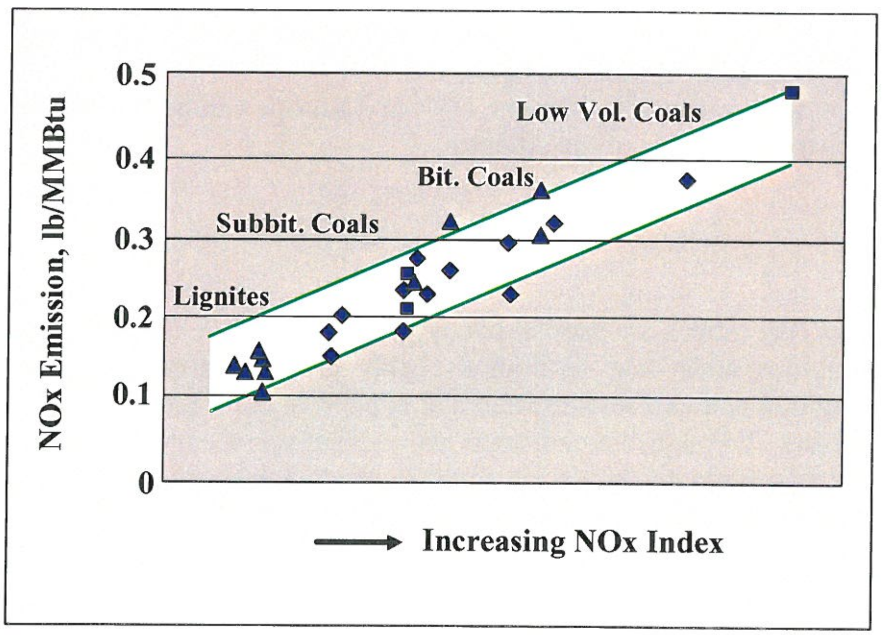

Figure 18: NOx Emission with Various Coals

Figure 18 shows NOx values for a number of large steam generators, which are equipped with modern low-NOx firing systems, as a function of the NOx index for the coal fired. The NOx index, as characteristic fuel parameter, is well suited for an approximate evaluation of the NOx values over a wide range of coal grades from lignites up to low-volatile coals. In addition it allows for a comparison of operating experience acquired in the USA and Europe with different coals.

The subject matter of the second example is the influence of the coal grade on heat transfer in the furnace. It is well-known that the ash deposits in the furnace of certain coal types, e.g. PRB Coal, is highly reflective. This leads to a considerable reduction of the radiation heat transfer and to an increase of the furnace exit gas temperature.

For this purpose a lab test was developed with the help of which the reflection properties of ash can be determined. By correlation with experience acquired in operating plants, this information can be used for the design of new boilers.

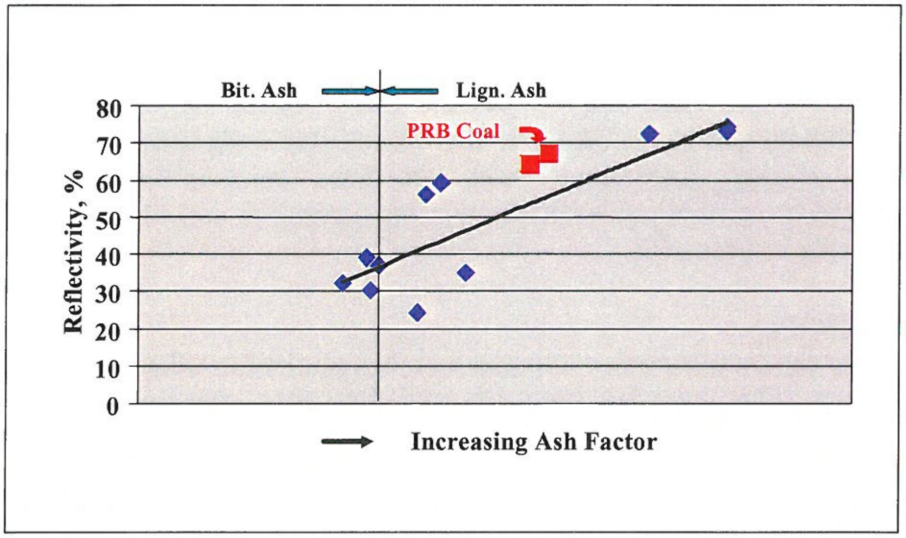

Figure 19: Reflection of Coal Ash

Figure 19 shows the lab-scale ash reflectivity determined for a number of tested coals as compared with the ash factor. Ash factor is determined from a specific relationship between constituents such as Calcium, Magnesium and Iron. The diagram indicates the influence of the ash type, where high-lignitic ash shows an increased propensity to reflection.

Besides the PRB Coal, some European lignites also show relatively high reflection rates. In particular, operating experience has shown that coal ash with reflectivities above 60 % will require special considerations in regard to the furnace design.
On this basis, experiences acquired with various coals in the USA and Europe can be utilized for the design of new coal-fired plants on either side of the Atlantic.

5. Summary

In the USA and in Europe, various coal grades are used in power plants firing coal. These extend from lignites through sub-bituminous coals and bituminous coals to anthracites. Extensive operating experience has been acquired and can be compared and applied to other plants with the help of characteristic fuel parameters. Through the exchange and evaluation of experience with various coals in American and European plants, the design of new, efficient and environmentally friendly coal-based power plants, both in the USA and in Europe, can be achieved.

References

[1] Schuster, H.: Benson Boilers for Difficult Coal and Wide Coal Ranges- Power-Gen Europe'98, June 9-11, 1998, Milan, Italy.

[2] Schuster, H., Klein, M.,Lasthaus, D., Schettler, H. and Tigges, K.D.: Investigations for the Design of the Firing System of the 930 MW Steam Generators for the Lippendorf Power Plant. VGB PowerTech, Vol. 78, No. 7, July 1998.

[3] Hunt, P.: Fuel Switching and Boiler Modifications for Maximum Steam Generation Output. 1991 International Joint Power Conference, San Diego, CA.

[4] Patel, R., von Hein, R., Penterson, C. and Dube, R.: Reducing NOx Emissions to 0.15 lb/MMBtu with Babcock Borsig Power Inc.'s Latest CCV Coal Burner Technology. 2001 International Joint Power Generation Conference, June 4-7, 2001, New Orleans, Louisiana.

[5] Simon, E., Lasthaus, D. and Schuster, H.: Reduction of NOx Emissions in the Combustion of Problematic Bituminous Coals. VGB Kraftwerkstechnik, Vol. 75, No.8, Aug. 1995.

[6] Schreier, W. and Schuster, H.: Firing Systems for Difficult Coals. XXXII. Kraftwerks-technisches Kolloquium, Oct. 24-25, 2000, Dresden.

[7] Failing, K.H. and Leblanc, B.: Supercritical Boiler Technology for Clean Coal Power Stations in the USA. Power-Gen International, Dec. 11-13, 2001, Las Vegas, NV, USA.