Supercritical Boiler Technology Matures

Mark Richardson
Proposal Engineer
Power & Industrial Division
Hitachi America, Ltd.
New York, USA

Yoshihiro Kidera
Engineer
Project Development Dept.
Babcock-Hitachi K.K.
Tokyo, Japan

Yoshio Shimogori
Senior Engineer
Boiler Design Department
Babcock Hitachi K.K.
Kure, Hiroshima, Japan

1. Introduction

The Hitachi-Naka Thermal Power Station Unit No.1 of the Tokyo Electric Power Company (TEPCO), whose "Benson" type boiler was designed and built by Babcock-Hitachi K. K. (BHK is the latest supercritical coal-fired utility plant to commence commercial operation in Japan. State-of-the-art technologies such as high pressure, high temperature steam parameters of 3680 psig 1120ºF/1115ºF (604ºC/602ºC) and Hitachi's advanced burner system for low NOx combustion were integrated into the new design. Flexible sliding pressure operation, advanced steam temperature control methods, and sophisticated computer control technologies make this unit an ideal plant for load demand following applications. The sliding pressure supercritical Benson boiler technology has been fully established and has markedly surpassed drum type boilers in the areas of efficiency, flexibility in operation and availability, as proven by over10 years operating experience in Japan.

Supercritical technology was first developed in the U.S. in the 1950s. The early units however experienced problems related to reliability and operational flexibility. The technology was adopted in Japan in the 1960s, has been refined by members of the related industries and is now utilized for all new large capacity boilers. The continuing development of high strength pressure parts materials to be used for high temperature regions has enabled the technology to extend the steam temperatures to higher than 1100ºF (593ºC). Reflecting a strong desire of reduction in CO_2 emission by achieving high efficiency, recently constructed large capacity boilers in Japan have employed this technology unexceptionally. The industries in most countries in Asia, Europe and Oceania have almost adopted the supercritical technology as a standard.

This established technology can easily be applied to new U.S. coal-fired units with the same level of efficiency and reliability as those achieved in Japan. For the new 790MW net coal-fired unit under construction at the Council Bluffs Energy Center Unit 4, the application of a reference plant such as the Hitachi-Naka unit, and appropriate furnace sizing and selection of advanced materials for the special properties of U.S. coals, shall ensure the same levels of high performance as the reference unit.

Supercritical boiler technologies will contribute to provide not only stable and high quality electricity, but also a better solution for reducing CO_2 emissions and reduce impact to the environment. In this paper, the advanced technology and reliability of the latest supercritical boilers will be described.

2. Latest experience in supercritical boiler

2.1 Outline of Hitachi-Naka No.1

The Hitachi-Naka Thermal Power Plant Unit 1 (1,000MW), which commenced commercial operation from December 2003, is the latest supercritical unit to be placed in operation in Japan. The plant is located in Ibaraki prefecture in Japan, approximately 60 miles from Tokyo city. The engineering and construction of the boiler, turbine and generator (BTG) power island was managed by Hitachi Ltd. The supercritical sliding-pressure Benson boiler was engineered and manufactured by Babcock-Hitachi K.K. (BHK), a subsidiary company of Hitachi Ltd group.

At the plant rated load, the boiler can supply the turbine generator with 6,327,000 lb/h of steam at supercritical steam conditions. The main steam parameters at the turbine inlet are 3,550 psig and 1,112ºF, and the reheat steam temperature is 1,112 ºF. The plant was designed for load cycling operation, to follow the changing load demands throughout the operation day.

As Japan does not have its own coal resources, coal-fired plants in Japan have to use imported coals. Therefore, utility companies must be flexible to purchase coal from a wide range of different sources from different countries, depending on the market price levels. The Hitachi-Naka boiler was designed to be able to burn a wide variety of imported coals, including those from Australia, Indonesia, China, U.S.A. and Canada.

The main specification of the boiler is summarized in Table 1, and a cross-sectional side view of the boiler is shown in Figure 1. During the engineering process, various design features were incorporated based on past operating experience to ensure improvement in operability, maintainability and reliability together with plant performance development. These efforts were made in parallel with an activity to standardize the Benson boiler design and arrangement. As many types of coals are imported from overseas, the standardized boiler can be easily applied to meet the specific requirements for each user worldwide.

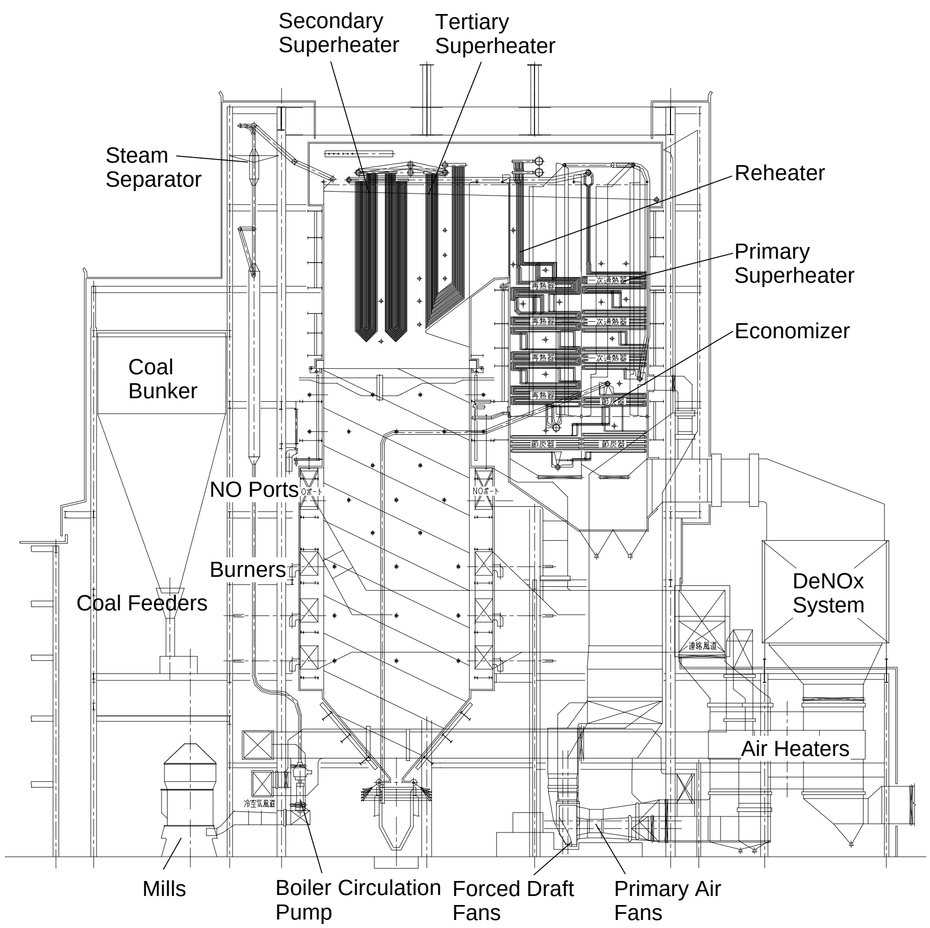


Figure 1 Side View of Hitachi-Naka No.1 Boiler

Table 1　Main Specification of the Boiler

Item			Specifications of the Hitachi-Naka No.1
Generating Capacity (Gross)			1000 MW
Boiler Type			Babcock-Hitachi Supercritical Sliding Pressure Operation Benson Boiler
MCR	Steam Pressure	Main	3550 psig
	Steam Temperature	Main	1112 deg. F
		Reheat	1112 deg. F
	Economiser Inlet: Feedwater Temperature		548.4 deg. F
Combustion System			Pulverized Coal Fired
Draught System			Balanced Draught
Steam Temperature Control System		Main	Water-Fuel Ratio Control and Staged Spray Attemperation
		Reheat	Parallel Gas Dampering and Spray Attemperation

2.2 Operating experience

Since the start-up period, the Hitachi-Naka boiler has been operating with stable and reliable performance parameters for both steady load and dynamic load operation modes. The main features of the boiler performance are summarized as follows.

2.2.1 Boiler performance

The main steam and reheat steam temperatures have reliably achieved 1112 deg. F. The boiler efficiency was confirmed to be higher than the anticipated values at each tested load.

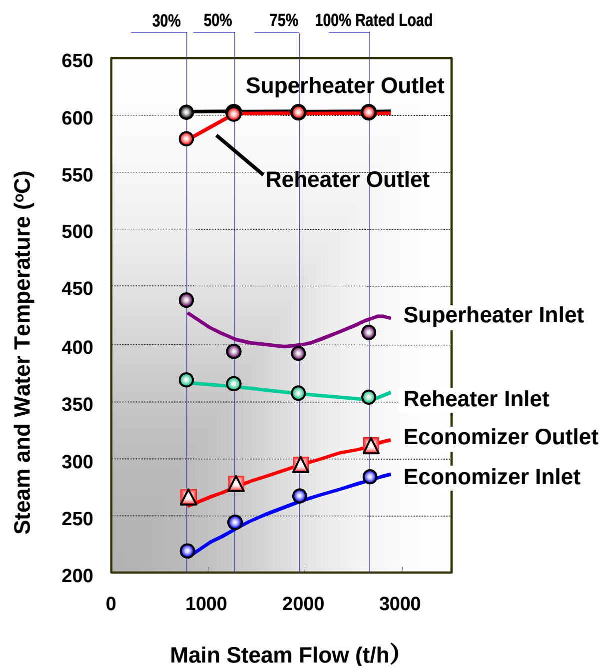
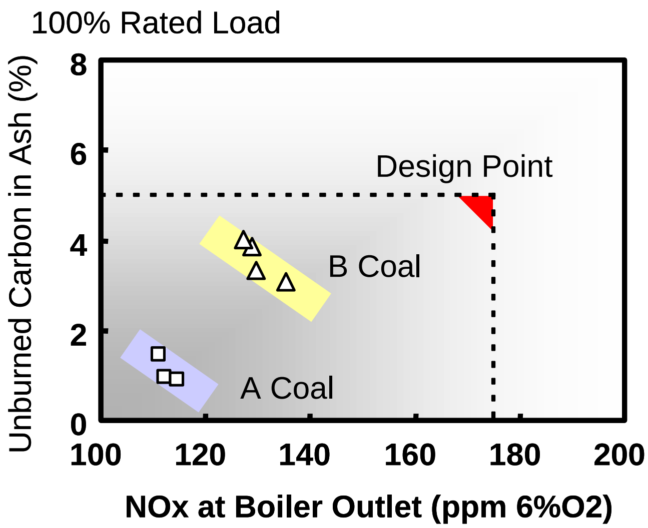


Figure 2 Static Characteristics of Steam and Water Temperature

2.2.2 Combustion performance

The Hitachi-Naka No.1 boiler is the first unit equipped with the newly developed Hitachi NR-3 burner. The NR-3 burner is the latest design in the NR series of rapid ignition low-NOx pulverized coal burners for large-scale commercial plants. The results of combustion testing are summarized in Figure 3.

Two types of coals, type A coal from Indonesia and type B from Australia, were tested during the commissioning phase. For both the coals, combustion tests were made with varying combustion settings and adjustments including air flow ratios. As shown in Figure 3, a reduction in outlet NOx emission led to less complete combustion of the fuel, resulting in a higher unburned carbon (UBC) level in the fly ash. As type B coal has a high fuel ratio (i. e. ratio of fixed carbon to volatile matter, 2.0) and high nitrogen content, it is normally difficult to achieve low levels of both NOx and UBC in the fly ash simultaneously. However, when burning type B coal, the observed NOx emission and UBC were much lower than the design point In the case of type A coal, which has lower fuel ratio and nitrogen content, significantly lower NOx and UBC emissions levels were measured.



Coal	A Coal	B Coal
Country	Indonesia	Australia
Fuel Ratio (-)	1.00	1.99
Ash(dry%)	9.3	7.4
N(dry%)	1.3	1.8

$$\textbf{Fuel Ratio} = \frac{\textbf{Fixed Carbon}}{\textbf{Volatile Matter}}$$

Figure 3 Combustion Test Results at 100% Rated Load

Figure 4 below shows a photo of the flame condition while firing type B coal at minimum load i.e. 30% rated load. Even though the fuel contains low volatiles content and hence is difficult to burn, a bright and stable flame was maintained at the tip of the burner nozzle.

Figure 4 Flame from NR3 burner at Minimum Load
(Type B Coal)

2.3 Design Features of the Hitachi-Naka No.1 Boiler

The following are features that are incorporated into the design of the Hitachi-Naka boiler, in particular for once-through sliding pressure operation with supercritical steam parameters.

2.3.1 Sliding pressure operation

As the nuclear power has become the primary source for base load generation in Japan, coal-fired power plant equipment suppliers were challenged to design new supercritical coal-fired units with flexibility for frequent load cycling. By adopting the sliding pressure operation with lower boiler pressures at partial loads, the plant heat rate can be improved at partial loads due to 1) improvement of high pressure (HP) turbine efficiency, 2) reduced auxiliary power consumption by boiler feed pumps, and 3) higher steam temperature at the HP turbine outlet. In addition to the plant efficiency advantages, there are other benefits such as reduction in start-up time, increase in ramp rate and reduced erosion of bypass valves as described in Section 3 of this paper.

2.3.2 Spiral Waterwall

For sliding pressure boilers, maintaining uniform fluid conditions during low load / low pressure operation becomes critical to reduce the potential of tube damage caused by high metal temperatures. The lower part of the Hitachi-Naka boiler furnace is arranged in a spiral configuration such that the fluid path wraps around the boiler as it travels up the furnace. A comparison of fluid temperature distribution between the conventional vertical wall and the spiral waterwall is shown in Figure 5. As a result of the uniform waterwall fluid temperature profile that is achieved across the full range of boiler loads, the spiral waterwall system does not require any flow adjusting devices to be installed at the furnace inlet.

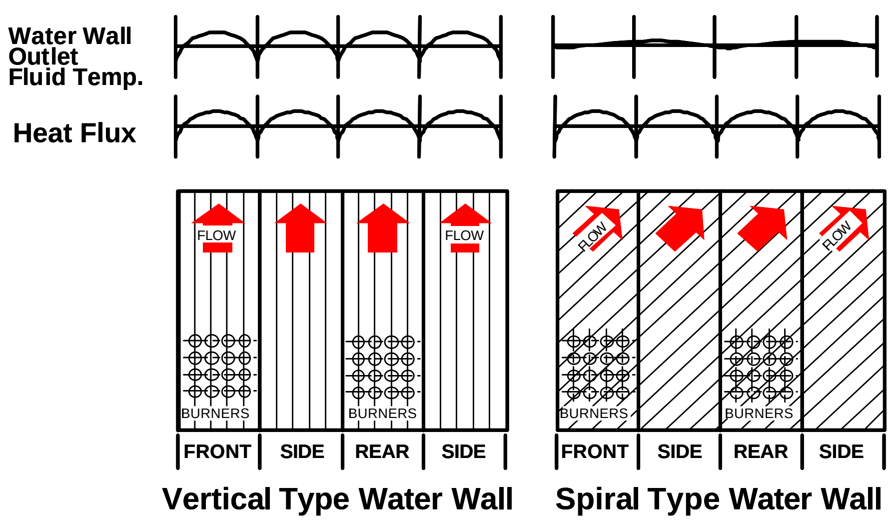


Figure 5 Fluid Temperature profile comparison for Water Wall Type

2.3.3 Steam Separator

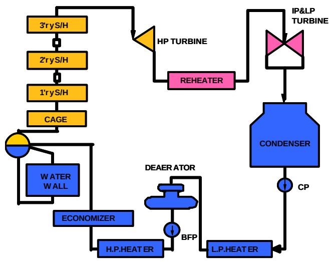
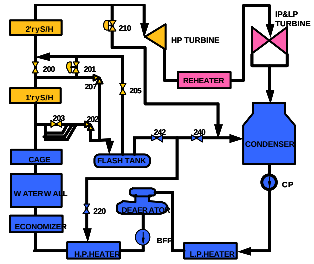
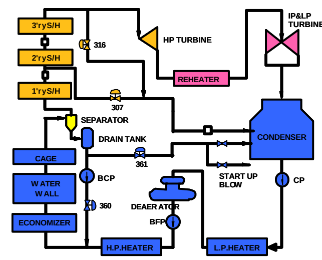
As the Hitachi-Naka boiler is a Benson type unit, a steam separator and a separator drain tank were installed to separate the steam and the water at the furnace outlet during a low-load recirculation operation. This design is different from that of a conventional NC boiler, for which a steam drum is installed to separate the water from the steam under all operating loads. The steam drum is designed to have sufficient water storage capacity, and usually contains complicated internal parts, such as steam cyclones, scrubbers, internal feed pipes, and baffles. Because of the complex internals, steam drums require a large amount of maintenance work during outage periods. However, the steam separator design of a Benson boiler is simple in configuration and has no internal, therefore significantly less maintenance work is required.

2.3.4 Boiler start-up systems

The Hitachi-Naka Boiler includes fully automatic start-up systems such as the turbine bypass system and the low load recirculation system. The turbine bypass system was designed to minimize the start-up time by controlling the main steam pressure and temperature before turbine rolling, and enabling the steam to flow through the superheater sections at a short time after light-off. The low-load recirculation system was designed to recover residual heat during start-up by circulation of the un-evaporated water from the furnace back to the economizer inlet, which also can assist in reducing start-up time. As this system is automatically operated, the start-up process is as simple as with a natural circulation (NC) boiler.

Table 2 shows a comparison of the start-up systems betweem a NC boiler, a constant pressure once-through boiler and a sliding pressure Benson type boiler (the Hitachi-Naka boiler).

Table 2 Comparison of Start-up Systems

<table>
<tr><th></th><th>NC Boiler</th><th>Typical Constant Pressure Operation Once Through Boiler</th><th>Benson Boiler</th></tr>
<tr><td>Flow diagram</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Start-up bypass system</td><td>- Not installed
- Operation of drain valves is necessary to establish turbine start-up condition</td><td rowspan="2">- Required for
· Maintaining furnace minimum flow
· Heat recovery to HP heater and deaerator through flash tank
· Ramping (shift from recirculation mode to once through mode, temperature dip is inevitable)
- Continuous recirculation mode operation is impossible</td><td>- Installed for steam temp and press control (TB bypass)</td></tr>
<tr><td>Low load recirculation system</td><td>- Not required</td><td>- Required
- Maintaining furnace minimum flow
- Automatic smooth shift operation from recirculation mode to once through mode
- Direct heat recovery to economizer inlet
- Continuous recirculation operation is possible</td></tr>
<tr><td>Start-up pressure at furnace during cold start</td><td>- Atmosphere</td><td>- Full pressure (3500psig)</td><td>- Atmosphere</td></tr>
</table>

2.3.5 Main and Reheat steam temperature controls

As the Hitachi-Naka boiler was to be designed to fire coals with a wide range of combustion and slagging properties, the steam temperature control system was designed to maintain rated temperature in varying heat absorption profiles and load levels.

The primary parameter for the steam temperature control is the ratio of a furnace water flow to a fuel input. This simple and effective temperature control method cannot be used with an NC boiler as its water flow in the furnace is driven by a natural circulation phenomenon. For additional controllability, superheater attemperators were installed between each superheater sectionsto maintain a rated main steam temperature steadily when firing different types of coals with variant combustion properties.

For the outlet reheater steam temperature (RST) control, a gas flow biasing system with a parallel damper was adopted to maintain a rated steam temperature over a wide load range without the help of water spray attemperators, which were installed for emergency. For the Hitachi-Naka boiler, a backpass heating surface arrangement has been optimized for improved controllability of RST. In Figure 6, RST fluctuations during a load ramp from 50% to 100% are shown for an older unit (previous design) installed with a gas recirculation system and the Hitachi-Naka boiler (no gas recirculation system). The results show that fluctuations in RST for the Hitachi-Naka boiler were kept to a minimal level similar to the older unit, and without use of the reheater spray attemperator. These provisions for steam temperature control in the Hitachi-Naka boiler help the power block to achieve a lower heat rate.

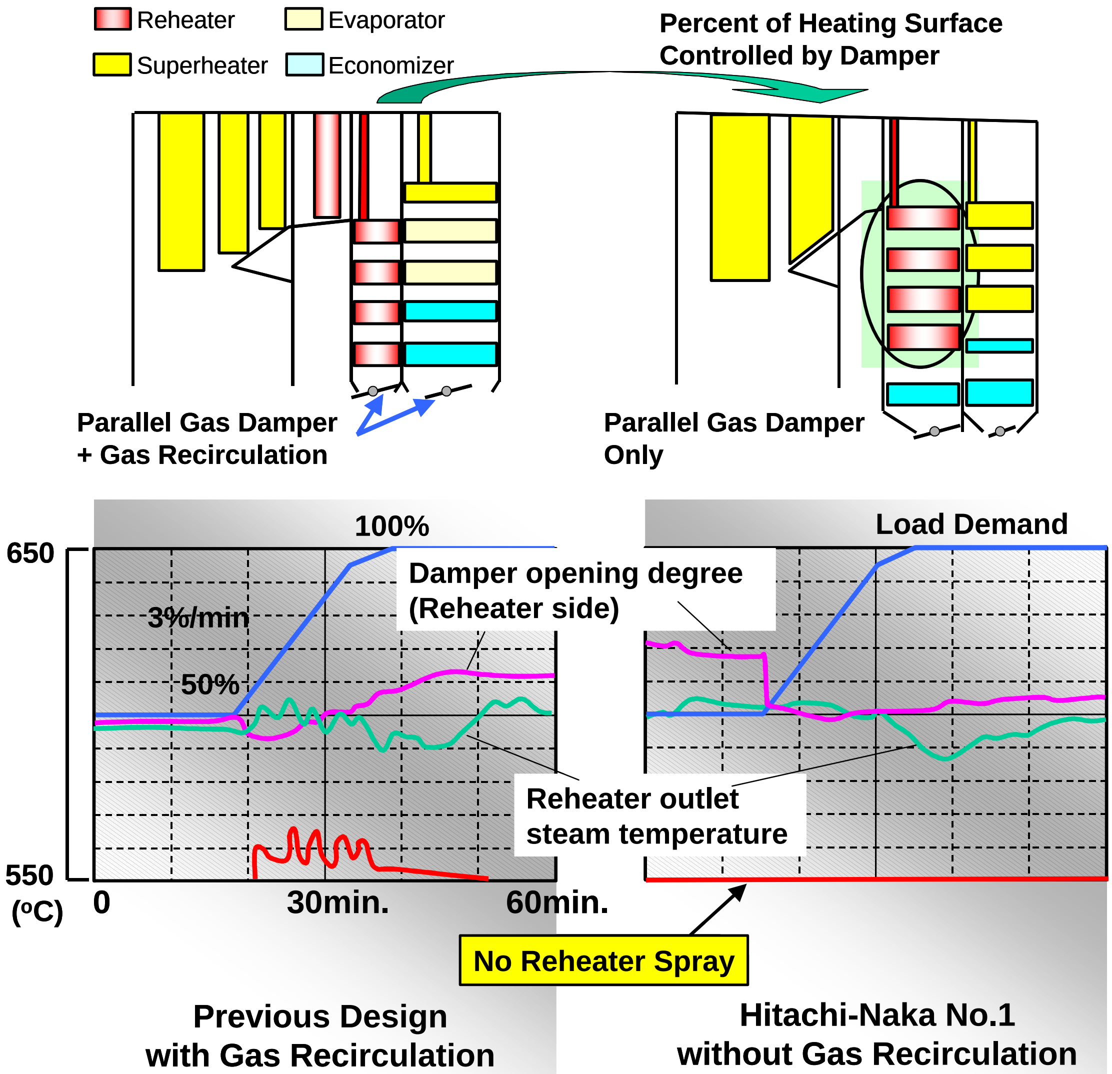


Figure 6　Reheater Outlet Steam Temperature Fluctuation during Load Change

2.3.6 Advanced control systems

The latest developments in plant distributed control systems have led to a highly automated operation from boiler light-off to shutdown. Advanced dynamic control from computerized calculation algorithms for the main control functions (e.g. steam temperature control) have been developed such that recently installed boilers can be controlled with reduced operator action.

3. Application of the technology to U.S. projects

3.1 Historical issues of supercritical units in the U.S.

Once-through supercritical boilers have been installed in the U.S. since the 1950s. Some of the earlier constructed units have experienced various problems related to operation and reliability. Typical issues are listed in Table 3.

The original supercritical units installed were designed for constant pressure operation, i.e. the boiler operates at full load pressure from start-up and across the entire load range. For start-up, constant pressure operation boilers require a start-up bypass system, which is complex in configuration and operation compared with the new sliding pressure Benson boilers. As a result, the start-up time for constant pressure boilers is longer and the plant minimum load must be kept higher than for the sliding pressure units. In addition, the load ramp rate of constant pressure operation is restricted because of the limit in temperature change rate in HP (High Pressure) turbine during a load change.

The start-up valves on constant pressure boilers have to withstand larger pressure differentials during bypass operation, which leads to higher erosion damage and hence the requirement for more frequent valve maintenance.

Severe slagging on the waterwalls as well as the coils has been one of the major issues in older coal-fired boilers constructed during the 1960s and 1970s. This was primarily because the furnaces of those plants were relatively small in volume. Since then, the furnace size has been continuously reviewed for better performance, and larger sizes have been used for recently constructed units. Appropriate furnace dimensions including plan area, height and volume must be provided to reduce slagging potential, regardless of whether the boiler is to be designed as sub-critical, supercritical, NC or once-through type.

Table 3 Causes and countermeasures of experienced problems

Issues experienced in older supercritical units	Causes	Countermeasures (As applied in new supercritical units)
Erosion of start-up valves	High differential pressure due to constant pressure operation and complicated start-up system	Sliding pressure operation, simplified start-up system, and low load recirculation system.
Long start-up times	Complicated start-up system and operation (ramping operation required, difficulty establishing metal matching condition, etc.)	Sliding pressure operation, simplified start-up system, and low load recirculation system.
Low ramp rates	Turbine thermal stresses caused temperature change in HP turbine during load changing (due to constant pressure operation)	Sliding pressure operation.
High minimum stable operating load	Bypass operation & pressure ramp-up operation required	Application of low load recirculation system
Slagging	Undersized furnace and inadequate coverage by soot blower system	Design of adequate plane area heat release rate and furnace height, without division walls. Provision of adequate system of soot blowing devices and/or water blowers.
Circumferential cracking of water wall tubes	Metal temperature rise due to inner scale deposit and fire side wastage	Oxygenated water treatment (OWT). Protective surface in combustion zone of furnace for high sulfur coal, e.g. thermal spray or weld overlay.
Frequent acid cleaning	Inappropriate water chemistry	Application of OWT
Lower efficiency than expected	High air leakage due to pressurized furnace. RH spray injection required due to complications of RH steam temperature control in the double reheat cycle configuration.	Tight seal construction. Single reheat system with high steam temperature and temperature control by parallel damper gas biasing.
Low availability	All the above	All the above

3.2 Improved Design Features for PRB coal-fired Supercritical boilers

3.2.1 Council Bluffs Energy Center Unit 4

The new coal-fired boiler under construction at Council Bluffs Energy Centre Unit 4 (CBEC 4) shall be the first new generation coal-fired supercritical Benson boiler to be built in the U.S.A. The boiler shall include the latest in design features for advanced supercritical steam conditions. The design and major engineering of the new plant is already complete, and the unit is currently under construction. CBEC 4 is on schedule to commence commercial operation in June 2007. Table 4 shows the main specification of the boiler for CBEC 4.

Table 4　Main Specifications of CBEC 4

<table>
<tr><th colspan="3">Item</th><th>Specifications of the
CBEC 4</th></tr>
<tr><td colspan="3">Generating Capacity (Net)</td><td>790 MW</td></tr>
<tr><td colspan="3">Boiler Type</td><td>Babcock-Hitachi Supercritical Sliding
Pressure Operation Benson Boiler</td></tr>
<tr><td rowspan="4">MCR</td><td>Steam Pressure</td><td>Main</td><td>3690 psig</td></tr>
<tr><td rowspan="2">Steam
Temperature</td><td>Main</td><td>1050 deg. F</td></tr>
<tr><td>Reheat</td><td>1100 deg. F</td></tr>
<tr><td colspan="2">Economiser Inlet:
Feedwater Temperature</td><td>555.1 deg. F</td></tr>
<tr><td colspan="3">Combustion System</td><td>Pulverized Coal Fired</td></tr>
<tr><td colspan="3">Draught System</td><td>Balanced Draught</td></tr>
<tr><td colspan="2" rowspan="2">Steam Temperature
Control System</td><td>Main</td><td>Water-Fuel Ratio Control and
Staged Spray Attemperation</td></tr>
<tr><td>Reheat</td><td>Parallel Gas Dampering and
Spray Attemperation</td></tr>
</table>

The key features of the boiler design and arrangement for CBEC 4 were based on the Hitachi-Naka No.1 boiler as a reference. Although the steam generating capacities are different, a standardized design approach was used such as the successful performance at Hitachi-Naka could be applied to CBEC 4 and engineering work for the new unit could be reduced. As described in the following sections, the boiler was designed with the necessary countermeasures to prevent the problems that were experienced in the original supercritical units installed in the U.S.

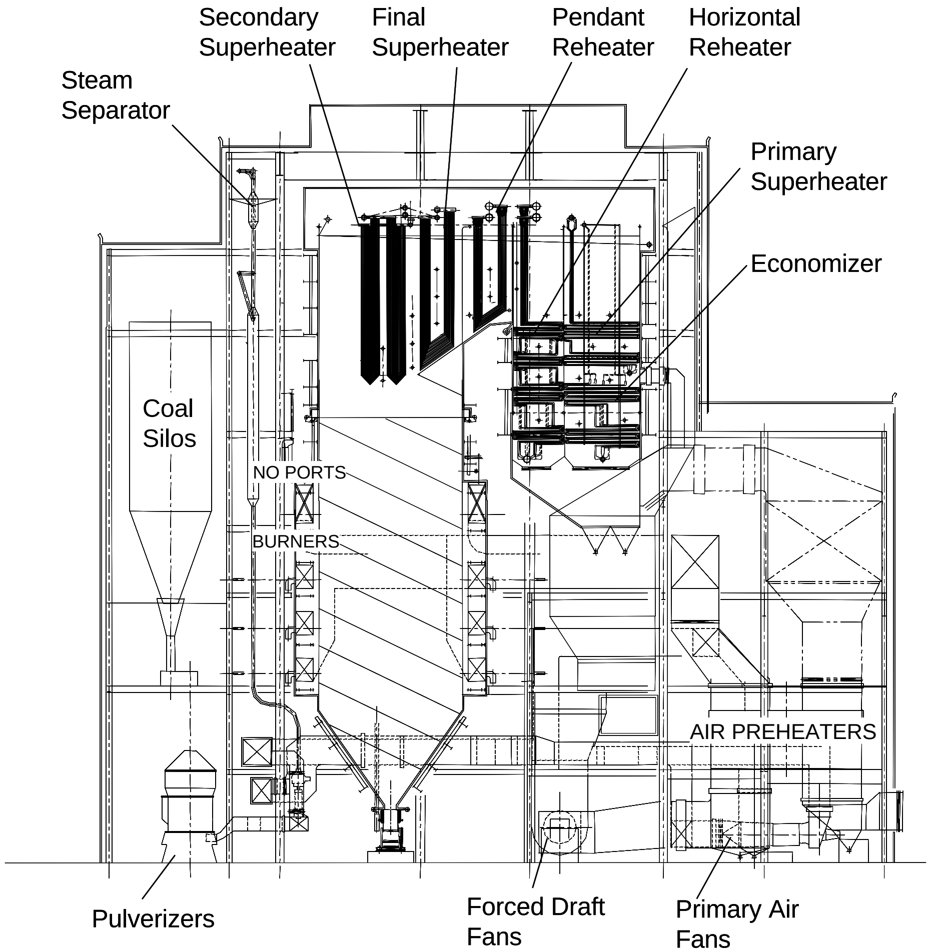


Figure 7 Side View of the Boiler for Council Bluffs Energy Centre Unit

3.2.2 Sliding pressure operation

Sliding pressure operation with a low-load recirculation system enables the Benson type boiler to start-up with similar operation characteristics and a start-up pressure profile as for an NC drum type boiler. While the start-up valves in a constant pressure supercritical boiler have to resist a large pressure difference during the bypass operation, the start-up valves in a sliding pressure boiler are only used during the swelling period, which occurs immediately after boiler light-off. The differential pressure during such swelling is less than 100psi, and therefore the duty of the start-up valves is much less in a sliding pressure boiler than the constant pressure boiler.

For the Benson boiler, the transition from recirculation mode to once-through mode, or vice-versa, is performed automatically with the operation of the low-load recirculation system and turbine bypass system.

3.2.3 Design for high steam temperatures

(1) Advanced high strength materials

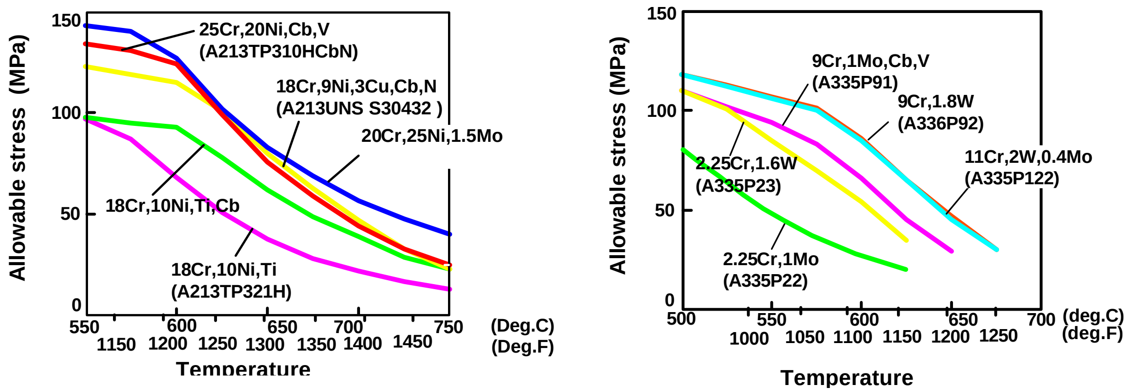


Figure 8 Comparison of Allowable Stresses between Conventional and Advanced Stainless Steel Tubes, Advanced CrMo Steel Pipes

In order to achieve steam temperatures higher than 1100 deg. F while maintaining reliability, improved high strength ferritic and austenitic materials for high temperature use have been developed. These materials have been utilized in recent coal-fired boilers in Japan that have been in operation for several years, and extensive laboratory testing has been ongoing to confirm the long term properties. The welding methods and materials have been established and proven for each of the developed materials. By application of these advanced materials, the thickness of pressure parts in the highest metal temperature regions can be reduced.

For boiler tubes for high temperature steam application, materials such as A213TP310HCbN (HR3C in Japan) and A213UNS S30432 (Super 304 in Japan) have been developed and are commercially available. These materials have up to 1.5 times higher strength at high temperatures than the traditional austenitic tube steels such as Type 310H or Type 304H materials.

The use of these materials combined with unique pressure part design features results in an overall reduction in thermal stresses compared with older boiler designs.

(2) Steam oxidation

The formation of steam oxide scale in stainless steel tubing is an important issue to be taken into account in the design for high steam temperatures. The steam oxide scale formation rate increases with operating temperature, and as a result the potential for exfoliation of oxide scales can become very high.

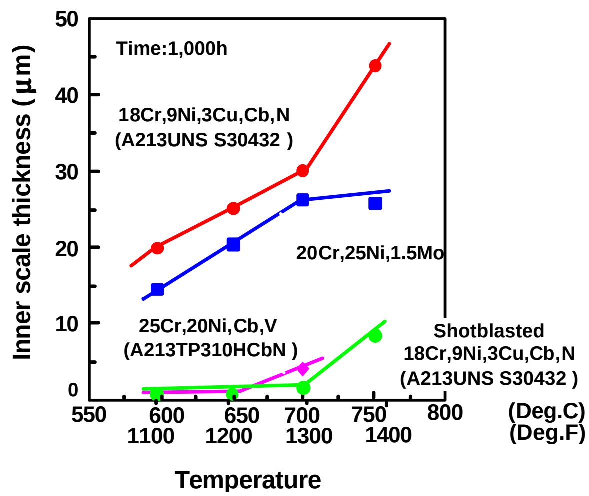


Figure 9 Effect of Temperature on Steam Oxide Scale of Stainless Steel Tubes

As a countermeasure against the once extensive scaling problems, austenitic stainless steel tubes have been internally shot blasted as part of the manufacturing process since the early 1980s. This countermeasure can be performed up to certain steam temperatures, as shown in Figure 9. By appropriate internal shot blasting, the formation of steam oxide scale on the inside surface of shot-blasted tubes is negligible in the operating range of supercritical boilers. This technique can be applied for tubes for service well above 1100ºF (593ºC).

(3) Sulfidation

Sulfidation is a process where hydrogen sulfide (H_2S) created in the combustion process reacts with waterwall tubes and leads to severe wastage. The key parameters that determine the level of sulfidation are sulfur content in fuel, burner stoichiometry (the atmosphere around the burners), tube material compositions and metal temperature.

While a lower stoichiometric ratio in the combustion zone is favorable to lower the amount of NOx produced, adversely it can result in higher levels of H_2S production, and hence will promote sulfidation. Figure 10 shows the relationship between the burner stoichiometry and the concentration of H_2S produced near the burner while firing high sulfur coal. Although the level of generated H2S depends on the sulfur content, the results show that a higher stoichiometric ratio can suppress the generation of H_2S during combustion. The setting of appropriate burner stoichiometry is a significant factor in reducing the potential for sulfidation.

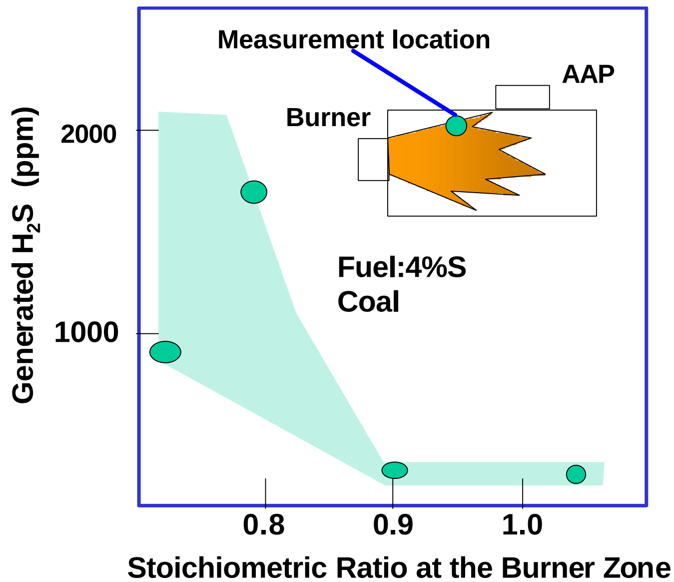


Figure 10 Influence of Stoichiometric Ratio on H_2S Generation

(4) Liquid phase corrosion

Liquid phase corrosion of stainless steel tubes at high temperature zones is a phenomenon that depends on the sulfur dioxide content in the combustion gas, the tube metal temperature, and the material composition. Figure 11 shows the effect of the SO_2 content in a simulated gas on the corrosion rate of the newly developed austenitic stainless tube materials. The corrosion test was made using an experimental apparatus and a standard corrosion mixture (SCM) at 1202ºF (650ºC). The results show that liquid phase corrosion (or simply high temperature corrosion) is strongly dependent on the SO_2 conten,t and the critical concentration for corrosion at the test temperature was around 0.1% for any of the tested materials.

The SO_2 content in the flue gas is controlled by the sulfur content of the coal burned, and 0.1% of SO_2 corresponds to approximately 1% of sulfur in the coal. Therefore, for fuels with a sulfur content of less than 1%, such as the PRB coal to be fired in the CBEC 4 boiler, liquid phase corrosion of austenitic stainless steel tubes is considered insignificant.

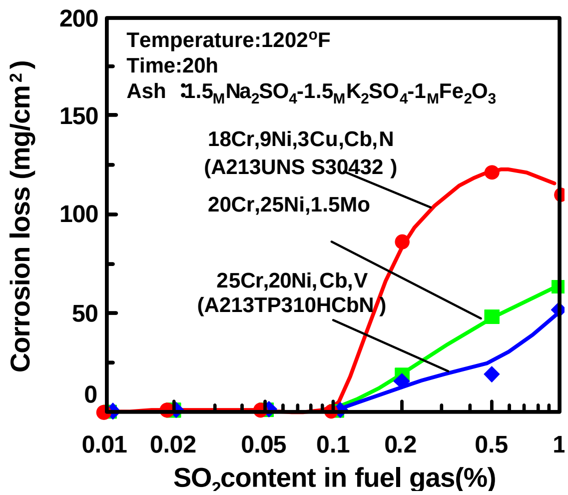


Figure11 Effect of SO_2 Content on Coal Ash Corrosion Loss of Stainless Steel Tubes

3.2.4 Inner scale deposit

For earlier supercritical boilers, the use of all volatile treatment (AVT) water chemistry had resulted in a significant increase in pressure drop through the furnace walls due to internal scaling, and hence increases in metal temperature and the necessity for frequent acid cleaning. The oxygenated water treatment (OWT, or "CWT") program was developed in Germany, and has been applied to supercritical boilers in operation for over 20 years. The use of OWT after start-up can ensure the suppression of inner scale build-up on the furnace wall tubes.

Figure 12 shows the pressure drop history of a coal-fired supercritical plant in Japan that changed the water chemistry from AVT to OWT in 1996. After 7 years operation since the change, there has been no significant increase in pressure drop. This plant has not required acid cleaning since the change, and no future cleaning is planned.

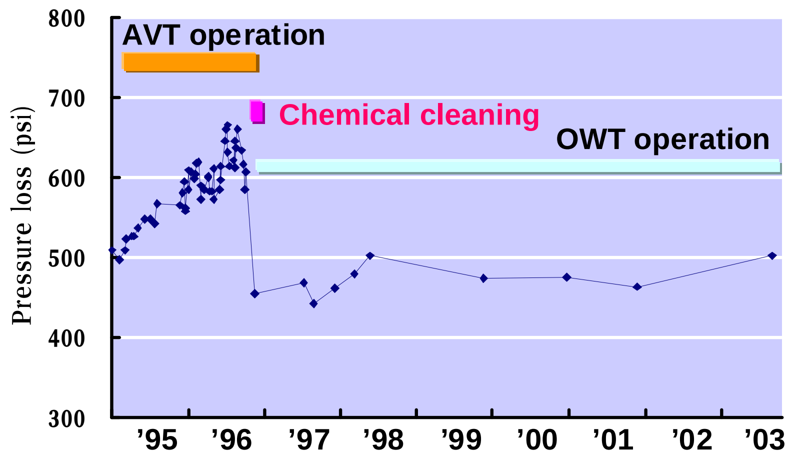


Figure 12 7-year OWT experience in 1,000MW supercritical coal firing boiler in Japan

3.2.5 Slagging and fouling

Severe slagging and/or fouling troubles that had occurred in early installed coal fired utility boilers are one of the main reasons that led to their low availability.

Furnace dimensions are determined based on the properties of coals to be burned. Most PRB coals and Eastern bituminous coals are classified as severe slagging fuels from their inherent properties. In addition to the degree of slagging, PRB coals are known to produce ash with specific characteristics, which is optically reflective and can significantly hinder the heat absorption. Therefore an adequate furnace plan area and height must be provided to minimize the slagging of furnace walls and platen superheater sections. The furnace for CBEC 4 was designed such that the exit gas temperature entering the convection pass tube coils would be sufficiently lower than the ash fusion temperatures of the fuel. For furnace cleaning, wall blowers will be provided in a suitable arrangement. In some cases as deemed necessary, high-pressure water-cleaning devices can be installed.

As for fouling, the traverse pitches of the tubes were fixed based on the ash properties. An appropriate number and arrangement of steam soot blowers shall be provided for surface cleaning.

Table 5 shows a comparison of furnace design indexes between a typical coal-fired boiler in the U.S. built in the 1960s, a typical bituminous coal firing boiler recently commissioned in Japan, and the latest PRB coal firing boiler for the new U.S. project. As shown in the table, the latest standard furnace sizes are significantly larger than for the older U.S. installations, and therefore slagging potential shall be minimized.

Table 5 Comparison between older U.S. design and Hitachi standard designs

	Typical Furnace Size in U.S. Existing Power Plant	Hitachi Standard Size	
Country	USA	Japan	USA
Fuel	Bituminous / PRB	Bituminous	PRB
Comparison of Furnace Volume	Base (100%)	180%	220%

3.3 Special considerations for high sulfur bituminous coals

The design features of the PRB coal firing unit as described above are general design features for sliding-pressure, high temperature supercritical Benson boilers which burn coals relatively low in sulfur such as PRB coals. However, special design considerations for boilers that will fire high sulfur bituminous coals are necessary.

3.3.1 Sulfidation

For high sulfur coal firing where higher potentials for sulfidation are expected, protective coatings of metal or ceramic-metal composite containing high chromium should be applied to the walls in the combustion zone of furnace by thermal spraying or weld overlay processes.

3.3.2 Liquid phase corrosion

There is always potential for liquid phase corrosion to occur on tube surfaces where ash deposits, primarily in the highest temperature superheater and reheater tube banks. In addition to Figure 11 in the previous section, another laboratory test results of liquid phase corrosion are shown in Figure 13.

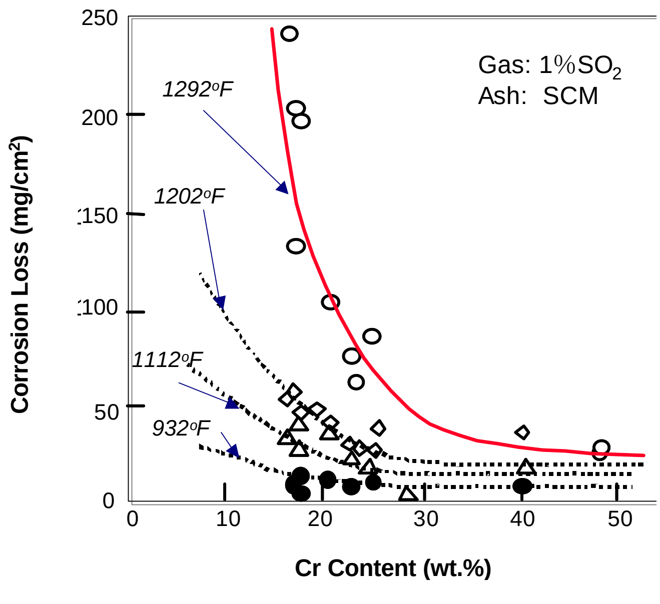


Figure 13 Relationship Between Cr and Corrosion Loss

To evaluate the corrosion rate in more severe conditions, this testing was done with an atmosphere containing 1% SO_2. The curves in the figure show the influence of chromium content in the tested tube materials on the corrosion rate at each test temperature. The results revealed that tube materials with chromium content of 25% and higher are effective for management of corrosion rates for high sulfur fuels and high steam temperatures. An advanced high strength austenitic stainless steel with nominal chromium content of 25%, of composition 25Cr20NiCbV (A213TP310HCbN), has been employed since 1990 in various types of plants including utility boilers. By using this material in new coal-fired boilers to be designed for high sulfur coals, the tube life of high temperature superheaters and reheaters can be well managed even for boilers with steam temperatures of over 1100ºF (593ºC).

3.3.3 Countermeasures for circumferential cracking

There have been cases of waterwall tube failures caused by circumferential cracking in older coal-fired boilers. It is believed that this cracking is caused by the combination of a number of phenomena, including the metal temperature rise due to inner scale deposits, the thermal fatigue shocks caused by sudden waterwall de-slagging, and the tube wastage or deep penetration caused by sulfidation.

Metal temperature rise due to inner scale deposits can be prevented by the application of an OWT water chemistry regime. In high sulfur coal firing boilers, the tube wastage from sulfidation can be controlled by applying protective coatings in appropriate areas of the furnace, as well as by the selection of optimum burner stoichiometry. The sudden metal temperature change due to periodic de-slagging can be minimized by optimized operation of wall blowers or high-pressure water cleaning systems.

4. Conclusion

Supercritical boiler technology has matured, through advancements in design and materials. Although earlier installed units in the U.S. had experienced various operation and maintenance problems, coal-fired supercritical units supplied around the world over the past severals years have been operating with high efficiency performance and high availability.

The Hitachi-Naka No.1 Boiler is the latest coal fired supercritical Benson boiler in Japan, based on a vast experience of design and construction over the previous two decades. The next generation of supercritical Benson boilers in the U.S. can achieve an equally sound performance as the Hitachi-Naka No.1 boiler by considering the appropriate design countermeasures and the special combustion properties of U.S. coals.

References

1. N. Shinotsuka et al.: Application of High Steam Temperature Countermeasure in High Sulfur Coal- Fired Boilers, Electric Power 2003
2. T. Abe et al.: Design and Operating Experience of Supercritical Pressure Coal Fired Plant, Electric Power 2003
3. Y. Fukuda et al.: Application of High Velocity Flame Sprayings for the Heat Exchanger Tubes in coal Fired Boiler, Int. Thermal Spraying Conf. May, Osaka, 1995
4. K. Saito et al.: Reliability of Supercritical Boiler and its Advantages, Electric Power 2004
5. Y. Shimogori et al.: Experience in Designing and Operating the Latest Ultra Supercritical Coal Fired Boiler, Power-Gen Europe 2004