A MAJOR STEP FORWARD---THE SUPERCritical CFB BOILER

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ABSTRACT

Since the start-up of a coal-fired, 30 MW_\text{e} bubbling fluidized bed boiler in the US at Rivesville, West Virginia in 1977, fluidized bed boilers have grown steadily in size, matured into a circulating fluidized bed (CFB) configuration, and now offer utilities enhanced performance, high reliability, and the ability to burn a wide variety of fuels. Having built the Rivesville demonstration unit and the world’s largest CFB boilers, Foster Wheeler has been a pioneer in this effort. The largest units now in operation, with a nominal 300 MW_\text{e} capacity, are located at Jacksonville Electric Authority’s Northside Generating Station These began operation in 2002 and can fire coal or petroleum coke in varying proportions.

Although CFB technology was previously viewed by some as being limited to relatively small sizes and serving only a niche ‘hard-to-burn’ fuel market, it is obvious that CFBs have grown to meet the power industry’s need for large-scale power generation, minimum stack gas emissions, and fuel flexibility.

The next step in the evolution of CFB technology has been the move to advanced steam cycle conditions to maximize plant efficiencies. In February 2003, the Polish utility
Poludniowy Koncern Energetyczny S.A. awarded Foster Wheeler a contract to build the world’s first CFB boiler operating at supercritical steam conditions---a 460 MWe unit to be built at their Lagisza station. In addition to operating at supercritical pressure (27.50 MPa/3989psig main steam throttle pressure) with superheat and reheat steam temperatures of 560°C and 580°C (1040°F and 1076°F) respectively, the CFB will incorporate BENSON Vertical Low Mass Flux Once-Through Technology developed by Siemens Power Generation of Erlangen, Germany. This technology allows the boiler to operate with reduced pressure drop, thus minimizing auxiliary power demand and increasing plant efficiency. In addition, tube flow characteristics are typical of drum-type units, where an increase in heat flux translates automatically into an increase in tube side flow rate. The latter is very important, as it protects tubes against over-temperature under the worst upset conditions, without having to resort to mechanically complex, high pressure drop designs.

This paper describes the 460 MW_e supercritical CFB boiler, Siemens Low Mass Flux Once Through Technology and its advantages for a CFB design, and presents the results of design analyses investigating the effects of varying furnace conditions, both steady-state and loss of fuel feed, on tube water/steam flow distributions and evaporator outlet temperatures.

INTRODUCTION

The Kyoto Protocol, regardless whether it is fully ratified or not, has been the catalyst for a number of changes in the energy generation industry. Debate on future energy management for power stations and what types of energy should be used continues to be quite intensive, and has resulted in a lot of new research and development work. One focus of this debate has been on carbon dioxide (CO₂) emissions and how to reduce them. As a result, coal remains somewhat unpopular, due to the perception that coal-fired plants pollute the atmosphere and generate higher emissions of CO₂ than gas-fired technology. Flue gas cleaning technologies have made major improvements here. The capture and sequestration of CO₂ is not yet an economic technology when burning coal. The industry nevertheless needs to use coal as one of its fuel sources; and the only feasible method of
reducing CO2 in the near and medium term when utilizing coal is to emit as little CO2 as possible, by increasing plant efficiency.

Modern power plants are designed for high efficiency, not only for economical reasons but also for environmental reasons, such as reducing fuel usage, the quantity of ash generated, and cutting the level of pollutants emitted. Increasing efficiency also means lower emissions of CO2. Supercritical steam parameters have been applied as a first step to achieving these goals. Most of the large European thermal power plants fired on fossil fuels, such as coal and brown coal, that have been commissioned over the last decade have incorporated supercritical steam parameters In order to achieve even higher efficiencies, steam temperatures and pressures are being continuously increased as much as the metals used in boiler tubes and turbine blades allow.

The larger plants built recently have been based on pulverized coal (PC) technology, and much development of this technology has taken place. However, circulating fluidized bed (CFB) technology has emerged as a growing challenger. CFB boiler technology based on natural circulation has reached utility scale over the last decade. The largest units in operation at the moment are two 300 MWe boilers operated by Jacksonville Electric Authority (JEA) in Jacksonville, Florida, capable of burning either 100% coal or 100% petroleum coke or any combination of the two.

For CFB technology to be considered a viable technology for meeting the power generation guidelines established by the United States Department of Energy Road Map, it has to be designed with supercritical steam parameters. This step has now been reached by Foster Wheeler, following the award of a contract by the Polish utility, Poludniowy Koncern Energetyczny S. A. (PKE), in February 2003 to build the world’s first CFB boiler operating at supercritical steam conditions, a 460 MWe unit to be built at their Lagisza station.

Prior to winning the contract, Foster Wheeler had carried out extensive development work on the mechanical design issues involved and understanding the process conditions affecting heat transfer, flow dynamics, carbon burnout, gaseous emission suppression, hydraulic flows, etc.. Various methods and equipment, such as bench-scale test rigs, pilot
plants, field testing at operating units, model development, design correlations for conventional boiler design, and simulation employing semi-empirical models or more theoretical models have been used for developing and successfully implementing design criteria for larger units.

The Foster Wheeler supercritical once-through boiler (OTU) employs a licensed application of Siemens’ low mass-flux BENSON vertical once-through technology. It also employs the results of work performed under an EU-funded program aimed at further developing OTU CFB technology; that program known as High Performance Boiler (HIPE), began in 2002 under the Community’s 5th Framework, and involves Foster Wheeler Energia Oy from Finland, Siemens AG from Germany, the Technical Research Center of Finland, and Energoprojekt Katowice from Poland. The BENSON system, together with some test results from the HIPE program, along with a design description of Foster Wheeler’s 460 MW_e unit, are discussed below. The advantages of using low mass-flux OTU technology for a CFB boiler are described in general.

**SIEMENS BENSON LOW MASS-FLUX VERTICAL ONCE-THROUGH (OT) TECHNOLOGY**

With a total of more than 1,000 units delivered over many years to the power generation industry, the BENSON boiler is the most commonly used type of once-through boiler. It operates at power levels up to 1,300 MW_e, steam pressures up to 350 bar, and steam temperatures up to well over 600°C. More than a quarter of units operate at supercritical pressure.

BENSON technology is centered on an evaporator design and has been licensed by Siemens since 1933. It is a once-through design suitable for sub- and supercritical pressure and variable pressure operation. Steam generators using the BENSON design incorporate features that are critical to economic success on today’s competitive power markets. These features include:
➢ a highly efficient water/steam cycle, as a result of supercritical pressures and high steam temperatures
➢ insensitivity of steam output and steam temperature to fluctuating fuel properties
➢ the capability for rapid load changes, due to variable-pressure operation and short start-up times, thanks to thermoelastic design.

The extensive worldwide use of the BENSON boiler is the result of ongoing efforts to develop the technology. The expanded knowledge base obtained through detailed studies, particularly of the heat transfer mechanisms within furnace tubes, has made an important contribution to this effort. New evaporator designs will continue to improve operating behavior and make boiler manufacturing more cost-effective.

The BENSON Low Mass Flux design is unique. Earlier furnaces were designed with spiral-wound tubes, and operating experience has been built up with several hundred boilers extending over more than 30 years. A new development started in the 1980s in the form of vertical evaporator tubing with low mass flux, based on the use of rifled tubes, as shown in Figure 1.

Figure 1 BENSON Boilers – Concepts for Water Walls.

Heat transfer in a rifled tube is very good, especially during evaporation, since centrifugal forces transport the water fraction of the wet steam to the tube wall. The resulting wall
wetting results in excellent heat transfer from the wall to the fluid. This has the following advantages over smooth tubes:

- No deterioration of heat transfer, even in the range of high steam quality
- Very good heat transfer, even at low mass flux
- Only a slight increase in wall temperature in the case of film boiling near critical pressure
- Potential for increased heat transfer by optimizing rifling geometry.

The Siemens high-pressure test rig – the largest in the world, with an electrical heater capacity of about 2,000 kW – was used to generate more than 200,000 data points in an investigation of standard commercial rifled tubes and tubes with modified rifling geometry. Changes to the rifling geometry permit significant improvements in heat transfer to be achieved, as can be seen in Figure 2.

A vertical tube arrangement on the one hand, and rifling on the other, allow a design with very low mass flux. This low mass flux changes the flow characteristics of a once-through system. Increased heat input to an individual tube leads to increased throughput for the tube concerned, instead of reduced throughput, as might be expected. This flow behavior – typical of drum boilers – is known as a natural circulation or positive flow characteristic.

The advantages of a vertically tubed furnace can be summarized as follows:

- Mass flux reduction from 2,000 to 1,000 kg/m²s, with a similar flow characteristic to that of drum boilers
- Cost-effective fabrication and assembly
- Low minimum load and simple start-up
- Reduced slagging and erosion on furnace wall due to parallel gas flow
- Reduced evaporator pressure drop.

The BENSON low mass flux design was first tested in the Farge 420 MWₜ supercritical power plant, using a few small test sections. The first coal-fired boiler with an evaporator based on the Siemens low mass flux design was built in Yaomeng, China, and has now been in successful operation since mid-2002. The boiler – a repowering project at a 300
A Major Step Forward – The Supercritical CFB Boiler

MW power plant – incorporates the special challenge of a center water wall with heat input from both sides and configured parallel to the water walls. Despite the large variations in heat input between the outer water walls and the center water wall, the temperature variations at the outlet of the water wall heat exchange surfaces are negligible.

CFB plants incorporating once-through boilers rated up to 100 MWₑ have been in operation for many years. The state of the art when these plants were constructed featured a relatively elaborate riser–downcomer system for the water walls. The largest CFB plants to date, rated in the 300 MWₑ range, are designed with drum boilers. However, once-through operation and elevated steam conditions up to approximately 600°C and 300 bar are required to make CFB technology a real competitor to pulverized coal firing for large plants.

**Figure 2** Rifled tubes reduce wall temperatures or allow mass flux reduction.

Table 1 shows the references for CFB BENSON boilers with vertical riser-downcomer systems and PC BENSON Boilers with low mass flux installations.
As part of the EU HIPE research program, an evaporator concept for a 460 MW<sub>e</sub> CFB plant was elaborated, based on the Siemens low mass flux design. Fluid mechanics analysis have been performed, as well as heat transfer measurements in the BENSON test rig using rifled tube, such as that used in the intermediate water walls (wing walls) of a combustor subject to heat input from both sides.

Due to the differing geometries and heat inputs involved, the evaporator had to be subdivided into a number of systems, configured in parallel. The individual mass flows and the corresponding outlet temperatures from the water wall sections were then determined. The effects of variations in heat input and the loss of a fuel feeder on the temperatures were also investigated.

<table>
<thead>
<tr>
<th>Power Plant</th>
<th>Type</th>
<th>Flow (kg/s)</th>
<th>Temp. (°C)</th>
<th>Pressure (bar)</th>
<th>Contractual Date</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW Duisburg*</td>
<td>CFB</td>
<td>75</td>
<td>535</td>
<td>140</td>
<td>1983</td>
<td>Babcock Borsig</td>
</tr>
<tr>
<td>Bayer Leverkusen 1</td>
<td>CFB</td>
<td>2 x 39</td>
<td>580</td>
<td>140</td>
<td>1984</td>
<td>Burmeister+Wain</td>
</tr>
<tr>
<td>Bayer Leverkusen 2</td>
<td>CFB</td>
<td>2 x 39</td>
<td>580</td>
<td>140</td>
<td>1988</td>
<td>Burmeister+Wain</td>
</tr>
<tr>
<td>Berlin Moabit</td>
<td>CFB</td>
<td>91</td>
<td>540</td>
<td>190</td>
<td>1986</td>
<td>Burmeister+Wain</td>
</tr>
<tr>
<td>KW Farge Test Loop</td>
<td>PC</td>
<td>300</td>
<td>535</td>
<td>250</td>
<td>1996</td>
<td>Babcock Borsig</td>
</tr>
<tr>
<td>Yaomeng (China)</td>
<td>PC</td>
<td>278</td>
<td>545</td>
<td>164</td>
<td>2001</td>
<td>Mitsui Babcock</td>
</tr>
</tbody>
</table>

Table 1    BENSON references for CFB with a vertical riser-downcomer-system and PC boilers with vertical tubing. Note that SW Duisburg* has horizontal evaporator tubing.

The selection of a relatively low design mass flux – between 400 kg/m²s and 700 kg/m²s depending on the type of tube – yields a good positive flow characteristic for all tubes, for the smooth tubes in the front, rear, and side walls, as well as for the rifled tubes in the intermediate walls (wings walls).

This means that even large variations in heat input are evened out by the adjustment of individual mass flows, which takes place automatically as a result of the self-regulating characteristic. At full load, the differences between the highest and lowest individual tube
temperatures at the evaporator outlet are only 35 K, even in the event of the loss of a fuel feeder, as shown in Figure 3. Further investigations performed for partial load conditions (75% and 40%) yielded even lower temperature differences.

Thanks to the low mass fluxes, the evaporator pressure drop between the point of distribution to the individual systems and the separator inlet only amounts to 2.7 bar at full load. This makes a major contribution to reducing the auxiliary power requirement.

![Figure 3 Outlet temperatures of the evaporator tube segments. Note that only one half of the furnace is shown.](image)

CFB technology imposes stringent requirements on water wall tubing. The high ash loading in the combustor requires the use of tubing running parallel to the flue gas/ash flow. Wound tubing, such as that usually implemented in the furnaces of pulverized coal-fired boilers, is not feasible for the combustor. In addition, some variations in heat input must be assumed. The combustor walls feature zones of greatly differing heat input, especially in the upper section. As a result, several sections in the ash discharge area are provided with lining. Higher-output plants require intermediate water walls, with heat input to both sides, where necessary.

In the CFBs constructed to date as once-through boilers, the combustor has been implemented using a system of risers and downcomers, each featuring a complex
redistribution of the water/steam mixture after each pass. Thanks to the BENSON low mass flux design, an evaporator concept is now available that fulfills the above requirements and is cost-effective, thanks to its inherent simplicity. Medium flows take place in parallel through all tubes in one pass, and no distribution of water/steam mixture is required. There are only negligible variations in temperature between the tubes at the outlet from the combustor, as variations in heat input are evened out by the positive flow characteristic. The relatively low heat flux in the combustor compared to that in the furnace of pulverized coal-fired boilers allows smooth tubes to be used for the water walls subject to single-sided heat input. In addition, the suitability of the evaporator system for variable-pressure operation meets all power plant requirements with regard to operating flexibility.

COMBUSTION-SIDE STUDIES WITH THE LOW MASS-FLUX OTU CFB

The CFB process also has a number of other merits when applying supercritical OTU technology. The nature of CFB combustion results in low and uniform heat flux throughout the entire furnace, due to relatively low combustion temperatures, no distinct flame with high temperature and high radiation, and uniformity of furnace temperature resulting from the circulating solids acting as a buffer. In pulverized coal firing, the burner flames cause a high temperature zone, resulting in high heat fluxes locally and higher temperatures in the boiler tubes. Figure 4 illustrates the heat flux for a CFB boiler compared to a PC boiler, and the difference is significant. Figure 4 also shows how the heat flux develops along the height of a furnace.

Understanding heat flux characteristics is of utmost importance, and requires a thorough understanding of the combustion process in a furnace, including the release of heat in the combustion process, heat transfer, and gas and flow dynamics. Foster Wheeler has concentrated on testing and measuring these issues in bench-scale test rigs, pilot plants, and operational units, and developing empirical and semi-empirical models for use in combination with more theoretical models to create simulation tools to assist in CFB furnace design.
Boiler combustion behavior and its influence on heat flux and heat transfer can now be modeled accurately in a three-dimensional model. The model combines fundamental balance and momentum equations and empirical correlations. Theoretical equations are used for those phenomena for which the governing equations are defined and acceptable. Empirical correlations are used for phenomena for which the theoretical equations are not known or the theory is too complex, resulting in unacceptable computing times.

The most important phase in the development of these models and correlations has been validation, using measurements taken in real conditions. For validating a three-dimensional model, the standard measurements for defining overall mass and energy balance are
required, but are insufficient in themselves. Profile measurements have been carried out in various parts of the furnace, and measurement locations extended well inside the furnace. It is also essential to know more about fuel and limestone behavior in areas such as attrition and fragmentation.

An extensive program has been conducted to measure heat transfer and heat fluxes, combustion profiles, and other issues in large-scale units. One part of the total program has been the measurements carried out under an EU-supported project, ‘In Furnace Process in a 235 MW$_e$ CFB Boiler’, in one of the units at the Turów power station in Bogatynia, Poland. The partners in the project have been the plant, Technical University Hamburg-Harburg, Czestochowa Technical University, the Technical University of Ostrava, Chalmers University of Technology, and Foster Wheeler Energia Oy. A more detailed description of the development of the models is presented in /1/.

The heat flux is relatively uniform in the furnace, as seen in Figure 4. This also applies for the temperature. However, as there are occasional inconsistencies in operation, such as feeder trips, it is of interest to investigate these situations. If a boiler is sensitive to such disturbances, some partial overheating or imbalance could occur. This has been studied extensively for a CFB boiler in the 400-500 MW$_e$ size range. In the case of a corner feeder tripping, as described in Table 2, when the other feeders have to pick up the load, not very much happens to the heat flux or the combustion temperature. Figure 5 shows the heat flux and the differences, while Figure 6 shows the temperature distribution and the difference. For illustrative purposes, the colors show a large difference, but in fact the numerical changes are very small.

<table>
<thead>
<tr>
<th>Case 1:</th>
<th>Basic case.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uniform fuel feeding to all the feeding points.</td>
</tr>
<tr>
<td>Case 2:</td>
<td>Fuel feed stopped to feeding point at front-right corner.</td>
</tr>
<tr>
<td></td>
<td>Feed rate to other feeders increased equally.</td>
</tr>
</tbody>
</table>

**Table 2** Heat flux distribution cases.
Figure 5 Heat flux comparison between Case 1 and Case 2, front and right wall
**Figure 6** Gas temperature comparison between Case 1 and Case 2

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
<th>Scale [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in gas temperature [°C] (Case 2 – Case 1):</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case 1 – Case 2</th>
<th>Scale [°C]</th>
</tr>
</thead>
</table>
The difference in gas temperature is close to 25 °C at its maximum point, but this does not have a very significant influence on heat flux. Figure 7 presents the percentage change at different horizontal locations on the furnace walls at an elevation of approximately 6 meters from the grid. The heat flux changes gradually from the front to the back of the furnace. Such percentage changes have no significant impact on wall metal temperatures. The change is in the order of a few degrees.

![Figure 7 Percentage change in heat flux in the horizontal direction when one fuel feeder trips.](image)

Various kinds of operational modes, as well as the overall sensitivity of a boiler and its combustion process, can be studied using this kind of tool, as has been done, and is still being done in respect of the Lagsiza project.

**ADVANTAGES OF A SUPERCRITICAL OTU CFB BOILER**

One general feature of Siemens’ low mass-flux BENSON OTU technology is that it results in a lower water/steam side pressure drop. This reduces feed water pump power consumption, thereby reducing the plant net heat rate.

Other advantages of an OTU CFB include the fact that a low and uniform heat flux makes boiler tubes insensitive to overheating, as earlier discussed. As the combustion temperature
is relatively low in a CFB, i.e. 850-880 ºC (1562-1616 ºF), there is no slagging or fouling of the furnace water walls and, hence, no deterioration of heat transfer.

In addition, the following general advantages should be mentioned:

- fuel flexibility
- multi-fuel capability
- low emissions without the need for secondary clean-up

One inherent feature of a CFB boiler is its insensitivity to variations in fuel composition. In many cases, coal or brown coal from the same mine varies widely in terms of heat value, ash content, and moisture. Such variations do not materially affect the combustion temperature, due to the thermal wheel that the circulating solids create, i.e. the solids act as a buffer against any variations in fuel characteristics and the amount of fuel present in the unit is only a few percent of the total amount of bed material. The relatively uniform combustion temperature provided by the CFB results in a uniform heat flux and even temperatures in the boiler tubes.

Multi-fuel operation is another inherent feature of a CFB unit. When firing several different fuels, heat fluxes will also be low and uniform, due to the buffer characteristics of the circulating solids. These are clear advantages for a plant owner, as fuel property variations and fuel availability will not become an issue, giving owners a larger degree of freedom to use the most economical fuel source. This is increasingly important, as many plant owners rely on imported coal or coal from various mines.

A CFB boiler generates low levels of gaseous emissions without the use of additional flue gas cleaning equipment. The cost of flue gas desulfurization (FGD) and selective catalytic reduction (SCR) systems can be very significant. In addition, an SCR system requires ammonia injection, and the catalyst must be replaced on a regular basis. A CFB produces more ash, since in-furnace sulfur reduction is not as efficient as an FGD. On the other hand, limestone can be used directly and lime is not required. The cost of lime is typically several times higher than the cost of limestone. The end-product of a CFB is always dry and there are no wet discharge streams.
Even though the CFB operates at a much lower temperature than a pulverized coal-fired unit, the high particle residence time and turbulent mixing provided by the hot circulating solids to enhance carbon burnout and in, practice, the two units operate with similar combustion efficiencies. The CFB, however, can operate with a lower flue gas exit temperature which enhances boiler efficiency. The reason for this lower flue gas temperature is the economizer, which can be used more effectively in a CFB. The water temperature can be raised in the economizer while still maintaining the appropriate steam/water ratio by weight in the furnace tubes, as the heat fluxes are lower than in a pulverized coal-fired unit. The \( \text{SO}_2 \) content in CFB flue gas is also significantly lower than in a PC, since sulfur capture takes place in the furnace. This results in a lower acid dew point and flue gas can be colder without cold end corrosion.

While more auxiliary power is needed for fluidization, no mills are required and there is no additional flue gas pressure drop due to FGD and SCR units, and no water consumption, as in a FGD. The power demand of these components are more or less equal to the power needed for fluidization.

Overall, CFB boiler technology offers so many advantages that it can be expected to be utilized more and more in future large-scale power generation based on coal or brown coal.

**THE 460 MW \(_e\) ONCE-THROUGH CFB LAGISZA PROJECT**

The first company to benefit from utilizing a OTU CFB with supercritical steam parameters will be the Polish utility, Poludniowy Koncern Energetyczny S.A. (PKE). Located in southern Poland, PKE is the largest utility in Poland, operating eight power plants within a 50 km radius from Katowice. The company has installed capacity of over 4,795 MW\(_e\), which is approximately 17% of Poland’s total generating capacity. In addition, the company has over 2,000 MW\(_{th}\) of district heating capacity, which accounts for 16% of the local heat generating requirements of the Katowice area.

PKE solicited quotations for a 460 MW\(_e\) once-through supercritical, coal-fired boiler plant in October 2001. The bidding process was split into two phases and specified for two
alternative combustion technologies: pulverized combustion and CFB combustion. Foster Wheeler submitted proposals for both alternatives, based on Siemens’ BENSON technology with vertical tubing and low mass flux.

The first-phase proposals, submitted at the end of February 2002, were based on preliminary turbine conditions. During the second phase, the turbine conditions were specified in greater detail and the formal proposal submittal took place at the end of October 2002.

The scope of Foster Wheeler’s bid included the boiler island, supplied as an EPC delivery: engineering and design, civil works and foundations, boiler house enclosure with steel structures, boiler pressure vessels with auxiliary equipment, main steam piping to the turbine and re-heated steam piping, coal bunkers and fuel feeding equipment, electrostatic precipitator and cold end flue gas heat recovery system, erection, construction, start up, and commissioning. A coal slurry system was included in the proposal as a possible later option.

Foster Wheeler was selected as the boiler supplier, on the basis of either PC or CFB combustion, on December 30, 2002. A detailed evaluation of both technologies, including associated investment and operational costs, began in January 2003, conducted by two groups, comprising PKE personnel, Polish energy industry engineers, and professors from a number of technical universities. Both groups concluded that CFB was the best alternative. The selection of the technology was announced on February 28, 2003.

Engineering work on the boiler began immediately, on March 1 and is continuing.

The CFB design was found more economical in the following areas:

- Total plant investment cost was lower, as the wet scrubbing and SCR systems that are essential for a PC-based solution could be eliminated.
- Plant performance was better. Net plant efficiency using CFB technology and an advanced flue gas cooling system was approximately 0.3% better that the PC solution.
- Fuel flexibility will provide a useful safety margin for the future. The unique multi-fuel capability inherent to CFB technology provides a wide fuel range and the
additional possibility of using opportunity fuels. The basic design allows for using wet coal slurry, sourced from local mines, for up to 30% of fuel needs. Up to 50% granulated coal slurry and up to 10% biofuel can be easily adopted during the project or at a later date.

The time schedule of the project is as follows:

- Contract signing  December 30, 2002
- Start basic engineering  March 1, 2003
- Effective date of the contract  October 1, 2003
- Mechanical completion  February 28, 2006
- Commercial operation  September 30, 2006

The fuel for the project is characterized as bituminous coal sourced from 10 local coal mines, with a maximum sulfur content of 1.4% on an as-received basis, with a chlorine content of 0.4% in dry fuel. Figure 8 describes the fuel range of the project.

The emissions of the unit will meet the latest requirements of the European Community’s Large Combustion Plant Directive (see Table 3).

<table>
<thead>
<tr>
<th>Emission (6% O_2, dry)</th>
<th>mg/m^3n</th>
<th>lb/MMBtu</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO_x</td>
<td>200</td>
<td>0.15</td>
</tr>
<tr>
<td>SO_2</td>
<td>200</td>
<td>0.16</td>
</tr>
<tr>
<td>Particulates</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3** Emissions at the Lagisza plant.

NO_x emissions into the solids separator could be further reduced using ammonia injection. This option can be included in the future, if required, with very few changes to the pressure part structure.
BOILER DATA AND DESIGN

The Lagisza CFB boiler was dimensioned according to the data in Table 4 below:

<table>
<thead>
<tr>
<th></th>
<th>kg/s</th>
<th>klb/hr</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum continuous steam flow</td>
<td>359.8</td>
<td></td>
<td>2856</td>
</tr>
<tr>
<td>Minimum continuous steam flow</td>
<td>143.9</td>
<td></td>
<td>1142</td>
</tr>
<tr>
<td>HP steam pressure at turbine inlet</td>
<td>27.50</td>
<td>psig</td>
<td>3989</td>
</tr>
<tr>
<td>HP steam temperature at turbine inlet</td>
<td>°C</td>
<td>°F</td>
<td>1040</td>
</tr>
<tr>
<td>Cold reheated steam flow</td>
<td>306.9</td>
<td></td>
<td>2436</td>
</tr>
<tr>
<td>Cold reheated steam pressure</td>
<td>MPa</td>
<td>psig</td>
<td>792</td>
</tr>
<tr>
<td>Cold reheated steam temperature</td>
<td>°C</td>
<td>°F</td>
<td>598</td>
</tr>
<tr>
<td>RH steam temperature at IP turbine inlet</td>
<td>°C</td>
<td>°F</td>
<td>1076</td>
</tr>
<tr>
<td>Feed water temperature</td>
<td>°C</td>
<td>°F</td>
<td>553</td>
</tr>
</tbody>
</table>

Table 4  Boiler data for the Lagisza 460 MW<sub>e</sub> boiler.

The boiler’s general layout was based on the conventional in-line arrangement that has been applied in the 2 x 150 MW<sub>e</sub> NPS units in Thailand and in units 4 – 6 of the Turów power plant. Figure 9 shows the schematics of the boiler. A more detailed description of the design and a comparison with the Turów units can be found in /2/.
CONCLUSIONS

Historically, CFB technology has tended to be considered a technology for niche applications, such as hard-to-burn fuels. That is not the case any more, however, and the technology is now challenging conventional pulverized coal technology. Significant enhancements in terms of both scale and efficiency have been made. Advantages such as fuel flexibility, multi-fuel capability, and emission control without the use of secondary systems are of great importance for plant owners in today’s very competitive environment. The use of BENSON Low Mass Flux technology to create a ground-breaking once-through supercritical CFB design reduces the pressure drop on the steam/water side, ensures low and uniform heat flux, and prevents the type of tube overheating that has been experienced in the past in conventional plants. With the Lagisza 460 MW<sub>e</sub> project, CFB technology is about to enter a major new stage in its development, and even larger boiler sizes are already under development.
REFERENCES
