47 th International Energy Agency
Workshop on Large Scale CFB
Zlotnicki , Poland October 13th 2003

Recent ALSTOM POWER Large CFB and Scale up aspects including steps to Supercritical .

Jean-Xavier MORIN

ALSTOM

WHY CFB TECHNOLOGY IS A PROMISING OPTION

The fluid bed combustion process facilitates power production firing a wide range of fuels while meeting stringent required emissions limits. The current trend of cost effective, environmentally sensitive solid fuel steam generation has created a need for continued scale-up of the CFB option to continue to meet these demands.

CFB technology has demonstrated an unparalleled ability to achieve low NOx production without the need for post-combustion equipment such as SCR. This is possible due to low combustion temperatures (1550-1650° F / 845-900° C) and the staging of air by application of secondary air admission zones. Furthermore, CFB technology has exhibited a fuel flexibility with an ability to burn waste materials and fuels previously deemed uneconomical and/or impossible to handle by conventional boiler firing system technologies. Currently, based on its demonstrated scale-up ease, low emissions capabilities and fuel flexibility, CFB technology is a serious option for many customers for their mid-sized (300-450 MWe) and larger (400-600 MWe) utility unit applications.

In addition , thanks to its ability to cope with oxygen firing, the CFB process appears as a suitable technology route to implement efficient CO2 capture systems able to meet Kyoto Protocole requirement with CO2 sequestration or to meet Enhanced oil recovery requirements .

The proper design of the combustor and the appropriate scale up figures are the key to success for such technology where Alstom has the widest range of experience with large CFB units in operation respectively under construction .

THE MAJOR SCALE UP TECHNICAL CHALLENGES

Scale-up of CFB technology has steadily progressed over the last decade. As units are scaled up in size, maintaining the bed dynamics similar to small CFBs requires more engineering expertise. Bed fluidization, air distribution in the combustor, and fuel feed distribution are extremely critical to obtain the same process requirements as for smaller CFBs. The major scale-up technical challenges are with four major components of CFBs: the combustor, the cyclones, the backpass, and the fluid bed heat exchangers.

Combustor

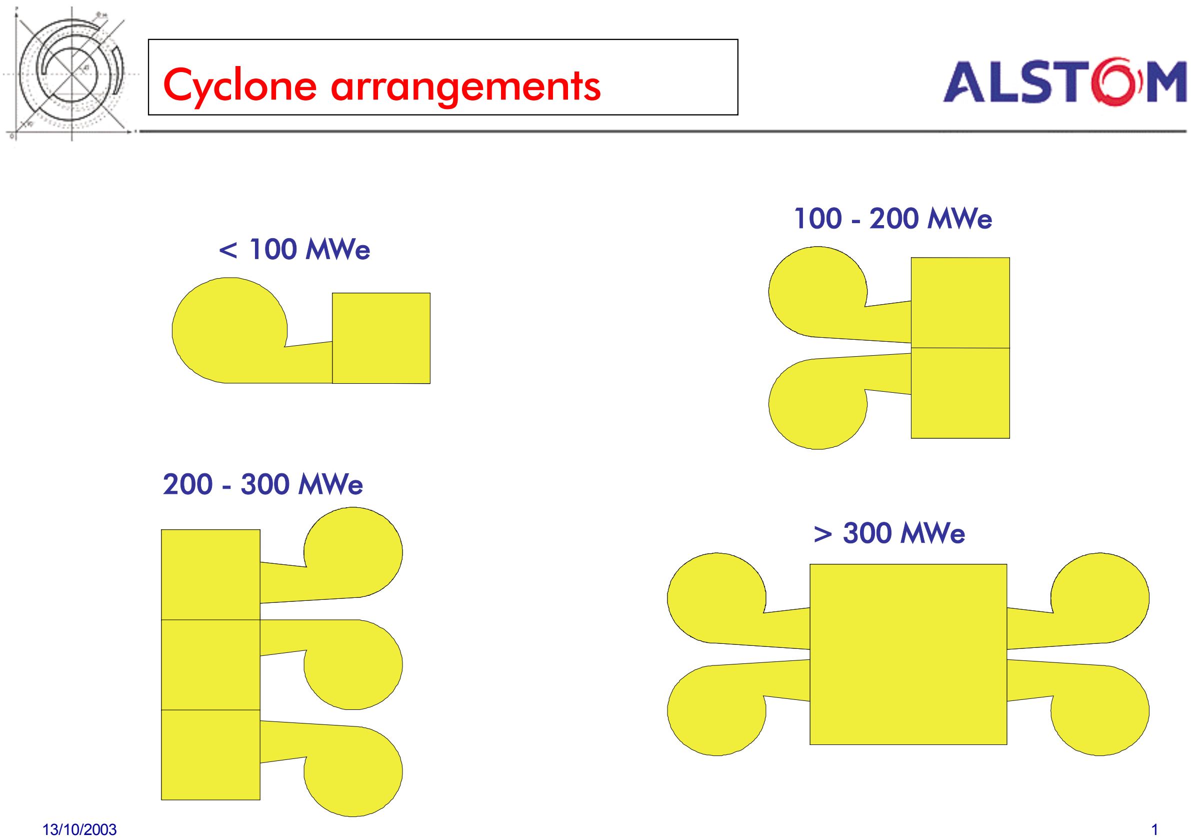
Careful consideration is given to the geometry of the combustor as this impacts fuel, air, and sorbent mixing. In scaling-up CFB design from existing units, ALSTOM increases the combustor height only slightly to ensure the solids pressure profile, and therefore heat transfer to the waterwalls is within our proven experience and knowledge base. The lower furnace design used by ALSTOM enables the fuel, air, and sorbent to mix in an area that is roughly one-half of the overall combustor plan area. As the unit size increases, the depth of the unit remains constant to ensure good mixing of fuel, air, and sorbent in the lower furnace. The width of the unit increases and cyclones are added as required to maintain gas velocities at optimum levels . As units increase in size to a point where four (4) cyclones are required, the combustor design changes to a pant-leg .

The combustion of the fuel, sulfur capture, and heat transfer to the combustor walls and in-combustor surface are a result of fluidization of the bed. The bed material is fluidized by primary air, which is introduced into the combustor through a nozzle grid in the floor.The location of the secondary air along the front and rear walls aids in combustion as well as creates conditions to minimize NOx formation.

The proper design of the combustor and the appropriate scale up figures are the key to succes for such technology where Alstom has the widest range of experience with large CFB units in operation respectively under construction .

Cyclones

Cyclones in a CFB separate the entrained particles from the flue gas leaving the combustor and return the hot solids to the combustor. The high recycle rate of the cycle ensures a uniform temperature in the combustor. The efficiency of the cyclone impacts the capture rate of the fines fraction of the solids entering the cyclone. This in turn affects limestone utilization and carbon burn-up. In scaling-up, a point is reached where the cyclone size gets so large that limestone utilization and carbon burn-up are negatively impacted. Scale-up to larger size cyclones has been gradual. Optimization of the cyclone collection efficiency has been achieved, as a result of ALSTOM knowledge and extensive laboratory research, through changes to the inlet and outlet duct design, and to the vortex finder length and location. As the unit size increases, cyclone size is increased or cyclones are added as required to maintain optimum gas velocities.



Fluid Bed Heat Exchangers (FBHEs)

Recirculated ash from the furnace can be directed from below the cyclone hopper at temperatures of 1550-1650° F (845-900° C) to a bubbling fluidized bed heat exchanger for the purpose of performing additional boiler heat duty. Solids are diverted using a water cooled ash control valve to a series of heat exchanger bundles which can perform superheater, reheater, and/or evaporator duties. As CFBs get larger in size, the combustor surface-to-volume ratio decreases and it is not always possible to perform the required heat duty in the furnace and backpass. The FBHEs allow incremental duty by passing a sufficient amount of recycle solids into the bundles. An inherent benefit of using a FBHE is the relatively high heat transfer rate from the hot solids to the tube bundles. By standardizing tube bundle arrangements and by utilizing a modular approach, an increase in unit size can be accommodated without developing new FBHE designs.

FEATURES OF 3 RECENT LARGE SCALE ALSTOM CFB

1- RED HILLS 2 x 250 MW CFB

Supported by Provence 250 Mwe operation, Alstom was awarded the Red Hills contract. Red Hills is a lignite fired 440 MW (net) power plant located in Choctaw County, Mississippi. It is owned by Choctaw Generation Limited Partnership, a wholly-owned subsidiary of Houston-based Tractebel Power, Inc. (TPI), which operates the plant. TPI is a wholly owned subsidiary of Belgium-based TRACTEBEL, the Energy division of the French corporation Suez. The entire output of the Red Hills Power Plant is sold to the Tennessee Valley Authority (TVA) under a 30 year purchase and operating agreement. Lignite fuel from an adjacent surface mine is provided by the Mississippi Lignite Mining Company, a unit of the North American Coal Corporation under a 30 year lignite sales agreement.

Red Hills CFB Design

The plant EPC contract was awarded to BECHTEL Power Corporation, which placed the CFB boilers contract with ALSTOM. ALSTOM was able to meet the required stringent emissions levels without any back-end cleaning equipment and could offer a very low guaranteed limestone consumption, as well as demonstrate the satisfactory operation over several years of the 250 MW CFB boiler in Provence (France), the only reference of that size operating at the time. The Red Hills plant configuration is based on a single 500 MWe class steam turbine harnessed to two identical 250 MWe class CFB boilers. Commercial operation commenced on April 1, 2002.

The Red Hills Boiler detailed parameters are listed in annex 1 . The main steam parameters are 753 t/h 568 °C / 540 °C.

The emissions limits are met using solely primary measures :

Sulfur Dioxide (SO_2), Mg/Nm³ at 6% O_2 dry (Max 95% capture) :325

Nitrogen Oxides (NO_x), Mg/Nm³ at 6% O_2 dry : 260

Carbon Monoxide (CO), Mg/Nm³ at 6% O_2 dry : 260

Volatile Organic Compound (VOC), Mg/Nm³ at 6% O_2 dry :3.7

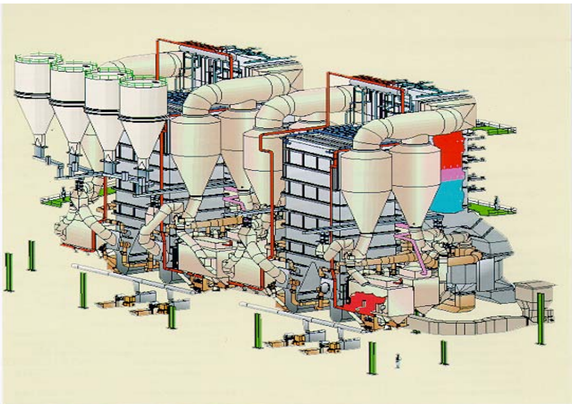
The Red Hills Fuel detailed data are listed in annex 1.The design fuel is a low BTU locally mined lignite . The maximum nitrogen content imposed special design precautions in order to stay within the contract NOx emissions limit. A particular feature of this lignite is the high calcium content in ash, capable under proper design and operating conditions to contribute significantly to the sulfur capture, thus decreasing the added limestone consumption. ALSTOM experience gained at Provence in respect to inherent sulfation of calcium ash proved to be very helpful in optimizing the total limestone consumption. Special lab testing was conducted by ALSTOM at the tender stage to assist the Owner in optimizing its sorbent consumption and sourcing.

Red Hills Boilers Layout.

Each boiler loop features a single water wall cooled furnace, with a refractory lined ‘pant-leg’ bottom, four cyclone separators, and four external fluidized bed heat exchangers (FBHE), two for bed temperature control containing the medium temperature superheaters and two for reheat steam temperature control containing the finishing reheaters. This design avoids attemperation for reheat control and improves the cycle efficiency. The flow of solids passing through each FBHE is regulated automatically by a water cooled ash control valve, whereas the balance of solids is re-circulated to the bottom of the furnace through seal pots.
The pressure parts not enclosed in the loop, i.e., from top to bottom high temperature finishing super-heaters, low temperature re-heaters and economizers, are located in a backpass linked to the cyclones by two large flue gas ducts, each serving two cyclones.

Recent ALSTOM Large CFB’s
Red Hills CFB : General arrangement

ALSTOM



- **Pant leg design**
- **4 cyclones**
- **4 FBHE’s**
- **4 x 50 % FBAC**
- **4 Fuel feeds to seal pots**
- **3 x 50 % limestone injection systems**

13/10/2003 2

Red Hills Combustion Process.

Owing to its high volatile matter content, lignite is very reactive and can therefore be fired at a relatively low temperature even for a CFB. Various tests were performed, which demonstrated that a combustion temperature of 830° C (1526° F) was the optimum in respect to inherent sulfur capture, limestone consumption and NOx emissions. This high fuel volatility also allowed ALSTOM to base its design on a lower than standard excess air, i.e., 17%. Sulfur capture is achieved through inherent capture by the fuel bound calcium and injection of prepared and dried limestone in the furnace. Sulfur capture efficiency as well as NOx emissions vary greatly with bed temperature; therefore the ability to control such temperature with FBHEs is an advantage. This solution has added advantage in the case of the particular configuration of this plant: two reheat boilers harnessed to a single turbine. Whenever both boilers are operating at different loads, such as during start-up periods, the FBHE design provides the ability to control the reheat steam temperature within the boiler control range.

Red Hills Reheat temperature control

is accomplished without using water injection. This design also provides flexibility for load following: both boilers are operated at equal loads between 100% and 75% turbine load. Then one boiler load is reduced down to its minimum and the other one increased as may be necessary, to reach 50% turbine load. Below 50% turbine load one boiler only is kept in operation, down to 15% turbine load. Special care was taken in the design of the lignite feeding system, which is sized for 4 x 50% system capacity. Fuel is injected in the four solids ducts downstream of the seal pots to ensure an homogeneous distribution of the fuel in the furnace, an important point for this reactive fuel. This fuel-feeding design has proved to have a very positive effect on boiler control in case of individual feeder trip. Boiler guaranteed thermal efficiency (HHV) is 82.4%, which translates into an aggressive 94% on LHV, a high figure when considering the 41.75% moisture content of the lignite.

Red Hills Separation System.

The cyclone sizing and geometry, which includes the design of the inlet duct, is at the heart of ALSTOM CFB combustion technology-- the capture efficiency of the separation system is the decisive factor in maintaining the bed density, retaining the fine particles in the loop, particularly the fine, calcium rich particles. A high bed density in turn ensures a high heat transfer and an even temperature in the furnace, a high contact between CaO particles and SO_2 rich flue gas for optimum sulfur capture efficiency and of course the best possible combustion by keeping the fuel particles in the furnace for the longest possible time. It also has a beneficial impact on NO_x emissions.

Red Hills Air and Flue Gas System.

Primary air is injected through two identical grids of special fluidizing air nozzles located at the bottom of each leg of the furnace. The role of the primary air is to lift the bed of particles and to fluidize it. The secondary air is injected through numerous ports at two levels above the grid. The role of the secondary air is to ensure the strong agitation of the particles as well as their mixing necessary to the process. The ratio of primary to secondary air has a strong influence on NO_x emissions, and special care was taken in selecting the most appropriate ratio. Fluidizing air is also injected in the four FBHEs and seal pots.

For each boiler unit, combustion air is supplied by the following fans:

- one 100% primary air fan, the primary air balancing between both legs being achieved through dampers
- one 100% secondary air fan
- two 50 % fluidization air fans for the external beds.9
- four 25% fluidization air blowers for the seal pots.

Flue gases are extracted by one induced draft fan downstream of the bag filter.
The single air preheater is a regenerative, vertical axis Ljungström, and therefore heats up both the primary and the secondary air.

Red Hills Ash System.

The ash, composed of the lignite ash, CaO and $CaSO_4$, is extracted at the bottom of the furnace through plug valves controlled by the furnace DP. This device is designed to allow the furnace DP which measures the bed density, to vary between set limits. The bottom ash is cooled in 4 x 50% water cooled fluidized bed ash coolers. There are other smaller points of extraction of bed ash located at the external heat exchangers. Ash extraction at this relatively cold place slightly improves the boiler thermal efficiency. Bottom ash composition and particle size distribution are the same as the bed and are therefore relatively coarse, as the heaviest particles tend to remain in the bottom part of the furnace; while the fly ash escaping the cyclones is very fine, d50 □20 m, and is collected at the hoppers of the bag filter.

Red Hills Limestone System.
Limestone is pneumatically fed through 3 x 50% injection points. The particles size distribution (PSD) is an important factor in the sulfur capture process efficiency, together with carefully controlled temperature and high cyclone efficiency.

Red Hills Operating Results
During the provisional acceptance tests, both boilers achieved their performance (steam characteristics, emissions, efficiency).

- **Main Combustion Parameters**

The fuel burned (differed from the design lignite. It is worth noting that the sulfur content of this lignite was below the design value, but the inherent Ca/S ratio was higher than the design coal. The calcium bound into the fuel is under organic form, and therefore less reactive than the added limestone. Injected limestone has a purity of 80.5%, very close to the design value of 80%.

- **Operating Conditions**

During the provisional acceptance tests, both boilers were operated at the conditions shown below :
- Excess Air 14% - 18%
- Furnace Temperature : (838-841°C)

- **Efficiency.**

During these tests, steam characteristics were achieved (568°C /540°C). Actual measured efficiency proved to be higher than the guaranteed figure on all the tests (3 per boilers), greater than 82.6% (HHV) against the guaranteed 82.4%. The unburned carbon in fly ash and bottom ash are very low (This is the result of:

- High reactivity of the fuel
- High cyclone efficiency leading to very fine and consequently more reactive particles in circulation (D50~120µm)

- **Red Hills Unburned Solids in Ash**

Carbon in Fly Ash 0.04 – 0.61 %
Carbon in Bottom Ash 0.07 – 0.25 %

- **Low Load Operation.** ALSTOM'S FBHE arrangement, coupled with a very reactive fuel such as Red Hills lignite, allows a very low load control point. During commissioning, some low load tests were performed. At 35% load with both boilers in service, superheat and reheat design steam temperatures were achieved – which is significantly better than the required steam temperature control range of 70-100% load.

- **Red Hills Emissions Performance**

All guaranteed emissions were achieved.

  - **SO2 and Ca/S.** During these tests, the sulfur capture efficiency achieved was >95%, resulting in emissions that were between 0.013 lb/MMBtu and 0.100 lb/MMBtu. This was well below the regulation limit of 0.25lb/MMBtu. Limestone flows were below the guaranteed values.

  - **NOx Emissions.** NOx emissions were achieved without any back-end cleaning equipment (SNCR or SCR). The basic design of the pantleg furnace with FBHEs, associated high efficiency cyclones and intense air staging results in excellent NOx reduction conditions. The Nox emissions measured were < the guarantee of 0.2lb/MMBtu.

  - **Volatile Organic Compounds (VOC).** It was demonstrated that VOC emissions were below 0.8 ppmC eq. C3H8 @ 6%O2 dry FG. The level of emissions is well below the guaranteed conditions (0.0058 lb/MMBtu ~3.7ppm) and demonstrates the high combustion rate of these CFB boilers.

2- SEWARD POWER PLANT 2 x 292 MW CFB

When Reliant Energy broke ground in 2001 for the 521 MW net output Seward Power Plant in East Wheatfield Township, Indiana County, Pennsylvania, it not only began construction of the first major coal-fired power plant to be built in the state in 20 years, but also one of the first new, solid-fuel based merchant plants to be built in the United States.

The base loaded plant will be fueled by Pennsylvania's western coal-mining region and supply its power to the mid-Atlantic region's PJM Interconnect. It will be powered by two 292 MW (gross output) circulating fluid bed (CFB) boilers supplied by ALSTOM that will burn local waste coal – a significant environmental issue in its own right – while meeting stringent state and federal clean air emissions standards. When the new plant begins commercial operation in 2004, it will replace an existing, 50-year-old, 196 MW power facility that will be shut down in late 2003. Due to the combination of CFB technology and other emissions control equipment, the air emissions will decrease even though the new station will be capable of producing more than twice the electricity of the old plant.

ALSTOM supplied the Seward plant with two Circulating Fluid Bed Boilers, each capable of firing Pennsylvania waste coal To meet Pennsylvania's air emissions standards, the plant will use an assortment of back-end emissions control technologies. Specifically, the CFB technology will be combined with selective non-catalytic reduction (SNCR) equipment (aqueous ammonia) for enhanced Nox reduction, as well as ALSTOM's unique flash dryer absorber (FDA) system to further optimize the plant's SO2 emissions. The gases discharged from the unit will meet the project emissions requirements as shown below .
The SEWARD CFB boiler detailed data , along with the emissions requirements are shown in annex 2 .

Seward FDA.
The Seward project uses ALSTOM's patented flash dryer absorber (FDA) system to reduce the plant's SO2 emissions. The Seward installation will be one of the first U.S. power.16 plants to use the FDA system, which basically integrates several flue gas desulfurization functions into one unit. The overall sulfur removal efficiency of the CFB and FDA is 95%, with approximately 80% removal in the CFB and the remaining 15% in the FDA. A unique feature of the FDA system is its ability to use ash (which contains surplus lime) supplied by the CFB (via the flue gas stream) for further sulfur dioxide absorption downstream. The system comprises the FDA reactor followed by a fabric filter.

The FDA system was evaluated favorably when compared to both conventional dry FGD andwet FGD alternatives. Compared to conventional dry FGD systems equipped with rotary atomizers or dual fluid nozzles, the FDA process minimizes the need for sophisticated and/or special equipment. There is no rotary atomizer with its high-speed machinery, nor are there any dual fluid nozzles requiring compressed air. Power requirements for the FDA recycle/reagent mixers are much lower than for the corresponding items in a conventional dry FGD system.

The FDA system was also evaluated favorably with respect to its ease of maintenance. All equipment requiring operator attention is placed near ground level, in an enclosure common with the fabric filter. A comparison with a wet FGD system showed lower costs for the FDA since a wet system would require a more expensive wet stack and a separate dust pre-collector (ESP or FF) for fly ash removal.

3- BAIMA 300 MW CFB

Baima is an anthracite fired 300 MW power plant being built in the Sichuan province of the People's Republic of China for Sichuan Baima CFB Power Plant Co., Ltd. It is a Demonstration Plant for large capacity CFB boilers and a Transfer of Technology for the Chinese domestic use .

In selecting CFB technology for Baima, the Owners gain certain specific operational and cost advantages compared to the downshot pulverized coal boilers traditionally used to fire Chinese anthracites. The first advantage is in term of minimum load without oil support, usually referred to as « technical minimum. » The technical minimum guaranteed for BAIMA is 40%. PC boilers firing anthracite have in many cases a higher technical minimum. The difference entails considerable fuel oil savings during part load operation. Post-combustion equipment (such as SO2 scrubbers and SCRs) would be mandatorily installed downstream of a PC boiler, but are here avoided, thus positively impacting CFB investment cost and ease of operation. Furthermore, SCRs consume ammonia for NOx reduction, while there is no need for this in the CFB combustion process. Another significant advantage is fuel flexibility: CFB boilers can accommodate the considerable variations in fuel quality which are likely to happen over the plant's life.

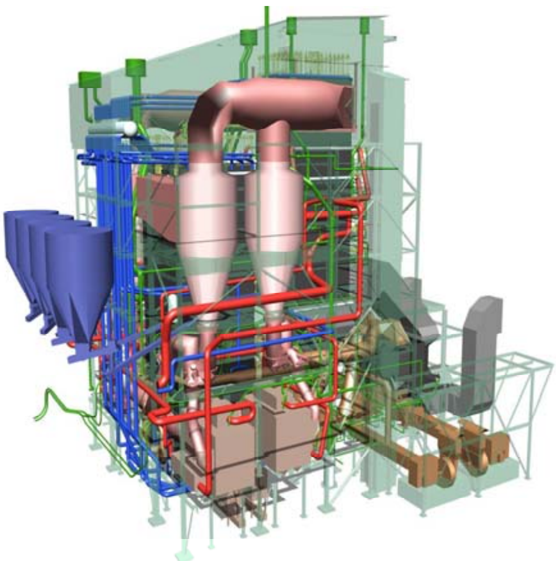
This 1025 tonnes/hr natural circulation CFB boiler is designed to fire a Chinese anthracite coal at steam conditions as shown in Table 10. The anthracite coal can be characterized by a relatively low volatile matter content (8.5% as received) and a high ash content (35% as received). The lower calorific value is 18495 KJ/Kg (7950 BTU/lb). The detailed analysis is given below. The gases discharged at the stack will meet the emissions requirements as shown berlow, without any post-combustion cleaning equipment for NOx or SOx. The boiler thermal efficiency, including the heat credits, is higher than 91% (LHV).

The design itself utilizes the concepts developed and well proven by ALSTOM over several years of successful operation at the PROVENCE and RED HILLS plants, i.e. a pant-leg furnace, 4 high efficiency cyclones and 4 External Heat Exchangers, 2 for bed temperature control and 2 for reheat steam temperature control.

The BAIMA CFB boiler detailed data , along with the emissions requirements are shown in annex 3 .

Recent ALSTOM Large CFB's
BAIMA - China 300 MW CFB : General Data

ALSTOM



- **Customer: State Grid Comp. / Sichuan Electric Power Corp**
- **Fuel: Anthracite**
- **Commissioning: 2006**
- **Steam Conditions:**
  - ➩ **Capacity: 1025 t/h**
  - ➩ **Pressure: 175 bar (2542 psig)**
  - ➩ **SH/RH Temperature: 540/540°C (1004/1004°F)**
- **SO2 : 600 mg / Nm3 (> 95%)**
- **NOX : 250 mg / Nm3**

13/10/2003 5

SUPERCRITICAL 600 MWe CFB BOILER DESIGN

Increasing the efficiency of fossil fuel fired power plants will be one key option to significantly contribute to the reduction of world-wide CO2 emissions. PC fired boilers achieve lower CO2 emissions largely by using supercritical steam conditions and elevated feedwater, superheater and reheater outlet temperatures. Conservative estimates show 8 % reduction in CO2 emissions when changing from drum-type natural circulation to supercritical sliding pressure water-steam design.

A major step in developing supercritical CFB technology was ALSTOM's participation in a program launched by EDF, targeting 600 MWe supercritical CFB power plants. This program included a detailed design study where special emphasis was given to the following items:

- Scale-up from 4 cyclones to 6 cyclones. This included detailed cold flow studies as well as CFD analysis to optimise the flow approach into the different cyclones

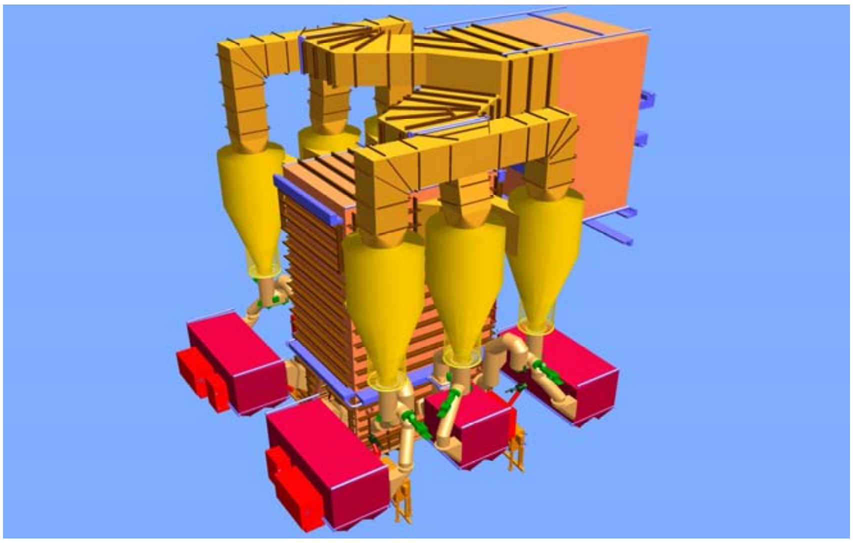
- Scale-up of FBHE sizes. The key objective was to determine the flow pattern within FBHEs to predict the behaviour when increasing the dimension beyond existing dimensions.

Components design with special emphasis on minimizing the amounts of refractory required. The cold flow studies for 3 parallel cyclones revealed that separation of ashes and gases starts in the cyclone inlet duct. It is of key importance to arrange the inlet ducts in a way that the pre-separated particles are led to the outer wall of the inlet duct at an early stage. Also the length and direction of the inlets ducts relative to the furnace outlet were addressed, as they also impact the cyclone separation efficiency.

Further stages of development include investigations of appropriate waterwall designs for different types of fuels, analysis of system requirements for dynamic behaviour, and approaches to further increase cost effectiveness of the supercritical CFB design. These investigations have paved the way for the commercial introduction of supercritical CFB plants in the 450 - 600 Mwe size range.

600 MW CFB STUDY
3D View

ALSTOM



13/10/2003 23

Scale-Up Principles. The scale-up strategy for a large CFB boiler with 6 Cyclones is the following :

- the use of a pant-leg lower furnace design is required to ensure proper combustion conditions.
- Three cyclones and up to 3 FBHEs are located on each pant-leg side.
- Downstream of the cyclones the flue gases are led to the steam cooled backpass via two overflow ducts.
- An optimized arrangement of the cyclones and their respective inlet ducts ensures that gas and solid loading of the cyclones will be within a proven range. The equal gas/solids distribution in combination with the high separation efficiency of the cyclone ensures that enough hot ashes can be extracted from the loop seals under all operating conditions to supply the connected FBHEs with the required heat.

Once-Through Concept. Supercritical once-through boilers which operate under sliding pressure conditions are subject to a wide range of fluid conditions in the evaporator. Depending on the location along a furnace tube and depending on the boiler load, the water-steam conditions range from supercritical conditions throughout the whole combustor to subcritical conditions starting with sub-cooled water at the inlet to two-phase mixtures and superheated steam flow in the upper furnace part.

For once-through boilers, the flow regime and flow distribution, the cooling conditions and the pressure loss within the evaporator are clearly differentiated from the conditions for natural circulation boilers. The key differences between these systems are the waterwall design, the dynamic behaviour and the start-up system.

Waterwall Design. The two major considerations for the waterwall design for once-through furnaces are to sufficiently cool the waterwall tubes under all operating conditions and to minimize tube temperature differences between furnace tubes. ALSTOM’s preferred solution for the CFB furnace waterwalls is a parallel arrangement of all waterwall tubes using small tube diameters to keep the mass flow within acceptable limits.

System Requirements for Start-up and Shut-down. To ensure sufficient mass flow through the evaporator tubes during part load and start-up, a start-up system must be installed. The start-up system is closely integrated with the circulating system and has the same structure as for traditional PC fired once-through steam generators. It is commonly based on a circulating pump in stand-by mode to provide sufficient cooling flow during start-up and low load operation only.

Once-through boilers contain only about 40 % of the water in the evaporator system in comparison to drum-type boilers. This fact, in combination with the high amount of heat that is stored in the circulating ashes as well as in the refractory of the furnace and cyclone, requires special attention to prevent overheating of pressure parts during shut-down, especially black-out conditions. Besides proper material selection for the relevant pressure part areas, a main design criteria is to minimize the heat that is stored within the refractory by minimizing the refractory masses. Typically this is achieved by using thin refractory lining for the cyclones and ducts and cooling the refractory by a steam or water cooled substructure. The cooling of the superheater heating surfaces during shut-down or black-out conditions is performed by the remaining steam from the system. The time that sufficient cooling steam flow is available can be expanded by reducing the pressure in the water / steam system. During black-out an independently operated emergency boiler feedwater pump may be beneficial for improving the cooling but it is often not mandatory. The reheater heating surfaces are cooled by steam from the HP bypass system in a conventional manner.

OXYGEN FIRING IN CFB TECHNOLOGY

ALSTOM teamed-up with the Department of Energy's National Energy Technology Laboratory (DOE NETL) to conduct a comprehensive study evaluating the technical feasibility and economics of alternate CO_2 capture technologies applied to "greenfield" coal-fired electric generating power plants. This work entailed conducting a test program that studied pertinent combustion performance and bed dynamics in ALSTOM's 4-inch inner-diameter fluidized bed combustion facility. The impact of potential bed agglomeration due to increased particle surface temperatures associated with high O_2 combustion environments was of particular concern. Three fuels were selected for this study. Each fuel was subjected to a parametric series of combustion tests, with and without the presence of the limestone sorbent. Oxygen (O_2) concentrations in the combustion gases ranged from 21% to 70% (by volume) with the balance of gas being CO_2. Results from various oxy-fuel firing of three fuels were compared to those obtained similarly from air firing in the same test apparatus.

Testing two coals and one delayed petroleum coke in air and O_2/CO_2 combustion volume mixtures containing up to 70% O_2 (in CO_2 balance) and other prevailing conditions led to the following conclusions:

- Slagging-induced bed de-fluidization problems could be obviated as long as the bed was kept fully fluidized at all times.
- High O_2 combustion mediums improved overall fuel combustion efficiencies, which, hence, improved carbon loss in the fly ash.

Added emission benefits offered by Oxyfuel firing over air firing in Circulating Fluidized Bed (CFB) boilers included:

- CO_2 in the flue gas was highly concentrated (up to ~90% vs.~15%), thus making the processing of this stream – to achieve the required CO_2 purity for Enhanced Oil Recovery application – relatively cheaper.
- Typically low NOx emissions in combustion-staged air-fired CFBs were further reduced due primarily to elimination of thermal NOx.
- SO_2 emissions reductions of up to 90% with sorbent utilization were not negatively impacted as long as the bed temperature was not allowed to increase.

The addition of limestone to the combustion process to control sulfur dioxide emission did not adversely impact the overall combustion efficiency of each fuel, although is appeared to cause an increase in NOx for the medium volatile bituminous coal.

CHEMICAL LOOPING COMBUSTION WITH CO2 CAPTURE

The CO2 Capture project (CCP) and the European Commission are supporting a project by BP (UK) , Chalmers University of Technology (Sweden) , Consejo Superior de Investigationes Cientificas (Spain) , Vienna University of Technology (Austria) and ALSTOM (France) to prove the concept of chemical looping combustion technology for boiler applications to facilitate the capture of CO2. The work runs from January 2002 to December 2003 and covers the development of the particles that will act as oxygen carriers , fluidisation and modelling investigations , study of the design and economics of a future industrial unit and the demonstration of a laboratory scale chemical looping combustor .
See references .

CONCLUSION

ALSTOM's recent projects and R and D programs have demonstrated important benefits of utility-scale CFB plants. These benefits include:

- Fuel flexibility, with the ability to use economical waste, high-sulfur and hard-to-burn fuels
- Unsurpassed ability to minimize NOx production through in-furnace control and, when required, the effective utilization of SNCR for meeting extreme emission limits
- Ability to meet stringent requirements for other emissions, including very high sulfur capture
- Design flexibility
- Proven technology, with comparative ease of scale-up.

CFB technology is currently an attractive option for plant owners considering mid-sized (300-450 MW) and larger utility unit applications .
Further development of the CFB technology with supercritical steam parameters is a major R&D program in Alstom. The purpose of this R&D activities is to check the capabilities of this challenging technology as well as to ensure Alstom in offering such a technology for commercial application while providing proven and reliable equipment to the customers.

In a context of CO_2 capture and trading , CFB technology could be adapted to oxygen firing to appear as a suitable candidate for the zero emissions power plant of this century .
On a longer term , chemical looping combustion appears also as a candidate for the zero emissions power plant .

References

- ALSTOM'S LARGE CFBS and RESULTS , J-C Semedard , S Devroe , J-M Lemasle , M.M Marchetti , T.S. Czarnecki , FBC 17 th , Jacksonville 2003
- Design Considerations of the 2 * 150 Mwe Formosa Heavy Industry Corporation CFB Boiler and NID system . C Tsiou , J Pisano , A Wiktorsson, S Ahman , FBC 16 th , Reno 2001
- Bench scale Fluidised Bed Combustion Performance of Solid fuels in O_2/CO_2 Environments , Nsakala ya Nsakala , R.D. Mc Whinnie , 20 th Pittsburgh Coal Conference , September 2003
- Chemical looping Combustion for CO_2 capture , P Hurst , J Boden , M B Wilkinson , M Simmonds , NETL conference , May 2003 .

A N N E X 1

Table 1 – RED HILLS – Boiler parameters

Superheated Steam Flow t/h	753
Superheated Steam Pressure Bar Bar(g)	181
Superheated Steam Temperature °C	568
Reheated Steam Flow, t/h	649
Reheated Steam Pressure at Boiler Outlet bar(g)	36.5
Reheated Steam Temperature °C	540

Table 2 – RED HILLS – Performance Fuel

Performance Fuel Specification	Design	Range
Moisture	41.75	(37.45 – 49.58)
Ash	14.64	(6.09 – 23.19)
Volatile Matter	23.49	(19.84 – 27.15)
Fixed Carbon	19.54	(15.48 – 23.59)
Sulfur	0.58	(0.19 -1.25)
Higher HeatingValue, as received, Kcal/kg	2940	

ANNEX 2

Table 3 – SEWARD– Boiler parameters

MCR 100 % Superheated Steam Flow t/h	871.8
Superheated Steam Pressure bar(g)	173.7
Superheated Steam Temperature °C	541
Feedwater Temperature at Boiler Inlet °C	264
Reheated Steam Flow t/h	795.7
Reheated Steam Pressure at Boiler Outlet bar(g)	47.1
Reheated Steam Temperature °C	541.12

Table 4– SEWARD – CFB Emissions Requirements

Performance Fuel Specification	**Design**	**Range**
Sulfur Dioxide	(SO2) lb/Mbtu	From 40 – 100 % MCR : 06
Nitrogen Oxides	(Nox) lb/Mbu	From 40 – 100 % MCR : 015
Carbon Monoxide	(CO) lb/Mbtu	From 70 – 100 % MCR : 0.15
Volatile Organic Compound	(VOC) lb/Mbtu	From 40 – 100 % MCR : 0.005
Ammonia concentration	Ppm dry at 3 % O2	From 40 – 100 % MCR : 10
Opacity at stack inlet 10 %	Particulate Matter lb/Mbtu	From 40 – 100 % MCR : 0.01

Table 5– SEWARD – Performance Fuel Specification (Design /Range)

Ultimate Analysis %		**Range**
Carbon	29.50	(25 – 35)
Hydrogen	2.09	(1.5 – 3.0
Nitrogen	0.92	(Max 1.8 lb/Mbtu)
Sulfur	2.75	(Max 7.0 lb/Mbtu)
Ash	50.98	(25 – 58)
Oxygen	5.06	4.0 – 7.0
Chlorine	0.13	-
Total Moisture	8.70	(Max 7.0 lb/Mbtu)
Higher Heating Value, as received, Kcal/kg	3055	(2780 – 3333)

Table 6– SEWARD – Limestone Specification

Chemical Compositon, Wet Basis, % Weight	
CaCO3	82.0
MgCO3	7.5
Moisture Max	4
Inerts	6.5

ANNEX 3

Table 7– BAIMA – Boiler Design Parameters

Main steam flow t/h	1025
Main steam pressure bar (g)	174
Main steam temperature °C	540
Reheated Steam Flow t/h	843,93
Reheated Steam Pressure bar(g)	37
Reheated Steam Temperature °C	540
Feed Water temperature °C	281.19

Table 8 – BAIMA – Design Fuel Analysis

Ultimate Analysis, %	Design Coal	Check coal
Carbon 29.	49.2	44.2
Volatile matter	8.55	9.35
Sulfur	3.54	4.3
Ash	35.27	38.1
Moisture	7.69	9.5
Lowing Heating Value KJ/kg	18495 (design)	17040 (check)

Table 9 - BAIMA – Guaranteed Emsision @ 6 % 02, dry

SO2	600mg/Nm3
N0x	250/NM3

= - =