Achievable combustion efficiency with Alstom CFB boilers for burning discarded coal

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Synopsis

The key driver for choosing a circulating fluidized bed (CFB) boiler is the ability to burn a wide range of fuels with highly efficient combustion while meeting low emission requirements. Reduced sorbent and water consumption compared with pulverized coal (PC) plants and the ability to deal with corrosive fuel constituents while still meeting local regulations make a CFB boiler-based power plant particularly attractive.

CFB-based power generation is particularly relevant in coal mining areas. During mining, a portion of the roof and floor material may be extracted along with the coal seam in order to create adequate working height for the equipment and miners. Therefore, run-of-mine coal which comes directly from the mine contains impurities. The raw coal can undergo a washing or screening process in order to improve its quality by reducing the ash content in the fuel in order to sell it on the export market or to comply with domestic customer requirements. The coal discarded from the washing process usually has a high ash content and difficult mechanical properties resulting from the initial properties, the mining, and the coal cleaning processes. It can contain a large volume of stones or can be very fine as a result of the washing treatment. To create value from burning this discarded coal, the boiler supplier has to meet several technical challenges in developing the appropriate design.

This paper highlights the performance achieved with Alstom's CFB boilers developed for power generation over the last two decades to extract value from discarded coals. Emile Huchet Power Plant is the first 125 MW_e CFB unit developed for burning coal slurries (called *schlamms* in France). The Emile Huchet discarded coal fuel is a very fine high-ash residue with an average particle diameter by mass (d_{50}) of around 80 μm as received from the washing plant. The paper describes the performances and the basic design of the CFB boiler to manage such a fine fuel.

The performances of two other CFBs of approximately 300 MW_e output in operation in the USA and PR China are also mentioned to demonstrate the capability of this technology to burn either low-volatile bituminous or anthracite waste coals. The significant issues experienced during commissioning are reported, and the conceptual choices for burning such fuels are mentioned.

Keywords

CFB, performances, discarded coal, coal mines.

Introduction

Fluidized bed combustion boilers and plants have been in successful operation for many years in capacities ranging from 50 to 350 MW_e. Steam generators with circulating fluidized bed (CFB) combustion have found acceptance throughout the world over the past few years, in particular for power generation, but also as industrial power plants and combined heat and power stations.

The reason for this success is twofold: (1) air quality regulatory requirements are now considerably more demanding, and a CFB can generally meet such requirements without back-end flue gas cleaning equipment, and (2) fluidized bed combustion allows much more fuel flexibility than conventional pulverized coal boilers: a single CFB boiler can burn not only different types of coal and biomass, but also various sludges and production residues.

Choosing a CFB boiler also makes sense for captive power plants located near to coal mines and operated with residues of low-grade coals that have no market value. Alstom Power's fuel-flexible CFB boilers are well suited to meet the technical and economical requirements under these circumstances.

The Baima project in the People's Republic of China

Alstom Power Boilers was awarded the contract for supplying the first 300 MW_e CFB boiler, one of the world's largest CFB boilers, in China's Sichuan province. The contract was signed in July 2002 and came into force in April 2003.

The contemplated fuel was challenging, consisting of local anthracite with high ash and high sulphur content. High combustion efficiency was required, together with low emissions without back-end flue gas cleaning, such as sulphur oxide scrubbers or selective catalytic reduction of nitrogen oxide emissions.

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The Chinese customer has also selected Alstom's CFB technology for developing its domestic CFB-based 300 MW_e class fleet. Alstom has subsequently transferred this technology to the three major Chinese boiler manufacturers as well as several Design Institutes.

The plant, known as 'Baima CFB Demonstration Power Plant', has been in commercial operation since April 2006. Test campaigns were conducted to optimize performance, including limestone consumption and carbon burnout. In 2007 a dedicated programme was implemented to allow the power plant to be operated in automatic mode despite significant fluctuations of coal quality. The performance tests were passed in 2007.

Boiler design

This 1025 t/h natural circulation CFB boiler was designed to fire a Chinese anthracite coal at the steam conditions shown in Table I. The anthracite coal has a relatively low volatile matter content (8.5 per cent by weight as received) and high ash content (35 per cent as received). The lower calorific value is 4 420 kcal/kg (18.5 MJ/Kg). A detailed analysis is given in Table I.

The emission requirements for the gases discharged at the stack are also shown in Table I. No flue gas back-end cleaning equipment is required.

The design utilizes the concepts developed and well proven by Alstom over several years of successful operation at the French Provence and US Red Hills plants.

It provides for a dual-grate (pant-leg) furnace, four high-efficiency cyclones, and four external fluidized bed heat exchangers (FBHEs) – two for bed temperature control and two for reheat steam temperature control[1]. The arrangement of the CFB boiler is shown in Figure 1.

Potential (uncontrolled) sulphur dioxide levels in the flue gas are close to 10 000 mg/Nm³ (at 6% O_2 dry gas) for the design coal and 14 000 mg/Nm³ for the higher sulphur coal. SO_2 emissions must be lower than 600 mg/Nm³ when burning the design coal, so the required sulphur capture efficiency is close to 94 per cent. Sulphur capture is performed by injecting limestone into the furnace through four ports located in the return ducts from the seal pots to the furnace. The calcium carbonate ($CaCO_3$) content of the limestone is within 90 to 92 per cent.

The 250 mg/Nm³ NO_X emission limit has already been achieved at other Alstom units. However, two major challenges for the Baima project in terms of performance were combustion efficiency and limestone consumption. Test campaigns conducted with a low-rank fuel at the French

Table I

Baima CFB boiler main data

Steam conditions at MCR	
Main steam flow t/h	1025
Main steam pressure bar	174
Main steam temperature °C	540
RH steam flow t/h	844
RH steam pressure bar	37
RH steam temperature °C	540
Feed Water temperature °C	281
Emissions levels	
SO_2	600 mg/Nm³ at 6% O_2
NO_X	250 mg/Nm³ at 6% O_2
Particulates	100 mg/Nm³ at 6% O_2
Fuel analysis, % by weight	
Volatile matter	8.55
Fixed carbon	49.2
Ash	35.27
Moisture	7.69
Sulphur	3.54 to 4.30
LHV Kcal/kg	4420
LHV MJ/kg	18.5

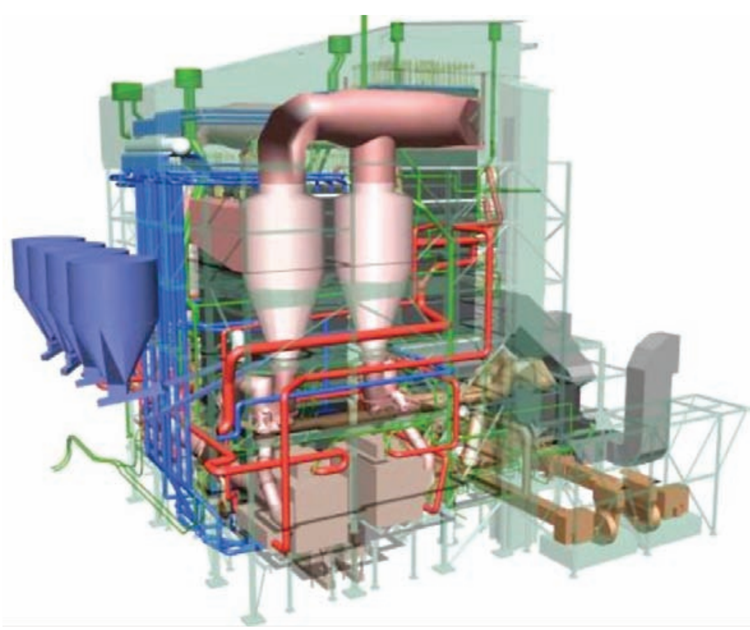

Figure 1—Baima CFB Arrangement

Provence 250 MW_e CFB power plant had demonstrated the ability to maintain the NO_x emissions below the limit by adjusting the combustion temperature and in particular the air staging.

To achieve the high performance required, Alstom implemented the following basic design principles:

- Maintain a uniform furnace temperature within the range 880°C–900°C, at which the limestone reactivity has proven to be maximized and the carbon burnout near the expected figure
- Ensure adequate evaporative duty by means of furnace water walls and extended walls located in the furnace; superheat or reheat heating surfaces were moved into the external fluidized beds
- Design of the cyclone and the inlet duct to achieve the highest possible capture efficiency. Several designs were tested on a cold flow model. The selected design was able to retain the fine particles of lime and carbon in the solids loop and hence improve the performance by increasing circulating solids residence time. Furthermore, high capture efficiency leads to an increase in the circulating ash flow, ensuring a high heat transfer and a uniform temperature in the furnace as well as good contact between CaO particles and SO_2-rich flue gas for optimum sulphur removal
- Air staging in the bottom part of the furnace was carefully adjusted for burning anthracite based on Alstom's previous experience. The ratio of primary air rate flow to total air flow was increased. Secondary air was properly distributed around the furnace enclosure and in the core of furnace through air ports located on the both sides of internal walls (pant-leg furnace arrangement) and over two levels
- Coal was injected with the limestone in the return ducts from the seal pots to the furnace to allow pre-mixing with the circulating ash before entering the furnace. Return ducts were arranged to create a circulating ash flow at the entrance of the furnace, on the centre line of the fluidization grate. This arrangement takes advantage of the high momentum balance of circulating ash to achieve good penetration and mixing of all the solids along the furnace grate. Uniform distribution of coal and limestone was achieved and matched the air distribution
- Bed inventory was also increased, compared to that of other commercial CFB units burning higher-rank fuel.

Performance and lessons learned

Performance tests were carried out in June 2007 and demonstrated the outstanding combustion and emissions performance as reported in Table II.

The heat loss due to the unburned carbon is less than 3 per cent on a low heating value basis.

Commissioning was, however, challenging as the coal supplied for the plant was far from meeting the contractual coal specification. Whereas the contractual ash content was specified within 30 to 40 per cent, the actual ash content was very often higher than 50 per cent. This caused problems in the bottom ash removal system and the coal crushing system, but not in the combustion process itself, demonstrating the tolerance of the CFB to such difficult conditions.

Figure 2 highlights the ash content over an operating period of seven consecutive days in July 2007. Average ash content was close to 50 per cent and sometimes above 60 per cent.

A large amount of stone in the raw coal caused rapid wear of the hammers in the secondary crusher. The expected coal particle size distribution, important for achieving the design conditions, has never been reached. Thirty per cent (by weight) of particles were larger than 3 mm, with a maximum size around 15 mm and a d_{50} of 1 to 2 mm. Hence, coarse particles had to be extracted from the fluidized bed ash coolers (FBACs), but the high amount of ash, including many oversized particles, led to a buildup of coarse ash inside the FBAC tube bundles and reduced heat exchange. The ash temperature at the FBAC discharge was excessive, triggering trips of the downstream mechanical ash conveyors.

Although modification of the FBACs would have probably fixed the issue, the plant owner decided to remove the FBACs and to replace them by rotary ash coolers (RACs). The replacement took place in September 2007. Since October 2007, when the four RACs were put into operation, there has been no trouble in the ash extraction system, even though the thermal performance of the coolers was lower than expected. Cooler thermal capacity was improved during the planned outage in July 2008 by increasing the RAC length by approximately 20 per cent.

Table II

Performance tests results

Baima performance tests Date	BECR Perf test 1 26 June 2007	BECR Perf test 2 27 June 2007	Design BECR
Coal quality stability	Good	Good	Good
Coal LHV MJ/kg	15.38	16.49	18.5
Ash %	43.5	40.5	35.3
LHV boiler efficiency % (corr)	> 93	> 93	< 92
Added Ca/S (corr)	< 1.5	< 1.7	< 2.0
Sulfur capture %	> 95	> 94	> 94
SO_2 emission mg/Nm³ at 6% O_2 dry	< 600	< 600	600
CO emission mg/Nm³ at 6% O_2 dry	< 150	< 130	NA
NO_x emission mg/Nm³ at 6% O_2 dry	< 100	< 100	250

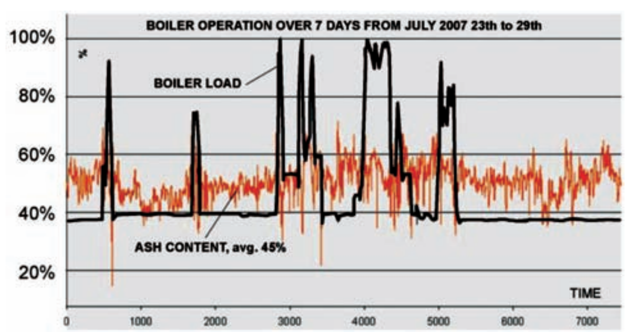

Figure 2—Coal ash content vs time

Each RAC was installed in same footprint of the FBAC, which was dismantled.

The inlet of the ash cooler was kept through the cone valve, and a vent to the flue gas duct was installed.

The water quality and pressure were taken into consideration, and this led to use of a thick shell for the cooler. Figure 3 shows the design principle of the RAC. Such coolers are widely used in PR China.

The boiler was able to operate when the FBACs were replaced with RACs. However, coarser particles in the bed caused some erosion of the water walls at the junction with the refractory lining. A kick-out was installed by the client over one metre of tube wall and the erosion rate dropped significantly.

Due to the high silica content in the fly ash, together with the ash in the flue gas, a low flue gas velocity was chosen in the heat recovery back-pass. No tube erosion was observed.

The CFB boiler was designed with a four-sector regenerative air heater, with one sector for the primary air located between two sectors dedicated to secondary air. These sectors are in contact with the remaining fourth sector through which the flue gas passes.

The soot-blowing system was not as efficient as expected, and some ash was entrained in the air stream. Control dampers, secondary and primary air ducts, and the fluidizing nozzles were eroded, and some of the fluidizing nozzles were replaced three years after the start of commercial operation. The design of the sealing joints, as well as the location and number of soot-blowers, needs to be carefully considered when choosing a regenerative air heater.

An additional challenge was to handle the variability of the coal quality while operating the CFB-based power plant in automatic mode. Coal flow varied from 120 t/h to 200 t/h for the same power output of 300 MW over 1 hour, as illustrated by a control room display capture in Figure 4.

If the unit is operated under boiler-follow mode, the main steam pressure is controlled by the coal feeders. Changes in electrical power demand, acting simultaneously on the HP turbine throttle valves and on the boiler load demand through a feed-forward controller, required close attention from the operators as the unit responded quickly.

If the coal quality was fluctuating too much, the unit was operated under turbine-follow mode.

In this case, electrical power demand drives the speed of coal feeders. The main steam pressure is then controlled by the HP turbine throttle valves.

It was possible to control the main and reheat steam at the rated temperatures while the boiler was operated between 100 per cent and 50 per cent MCR (Figure 5) and with a main steam pressure set point from 120 to 170 bar.

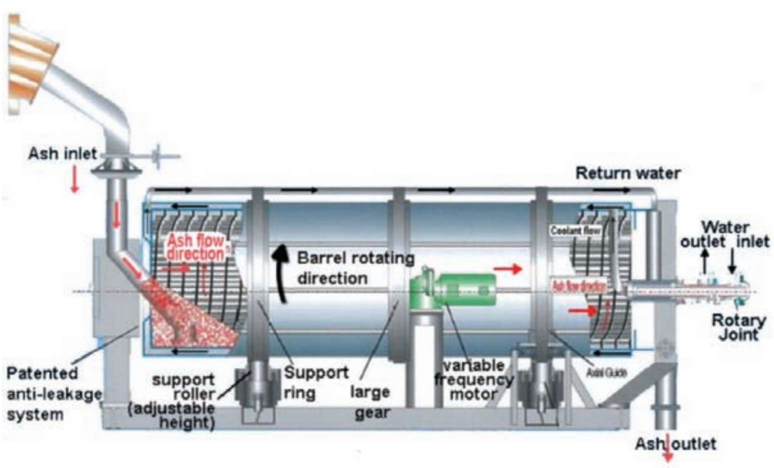

Figure 3—Rotary ash cooler

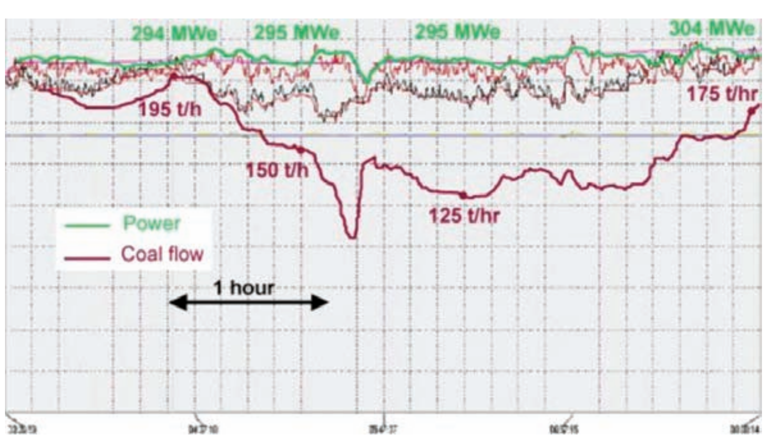

Figure 4—Power generation remains stable despite huge variations in coal flow

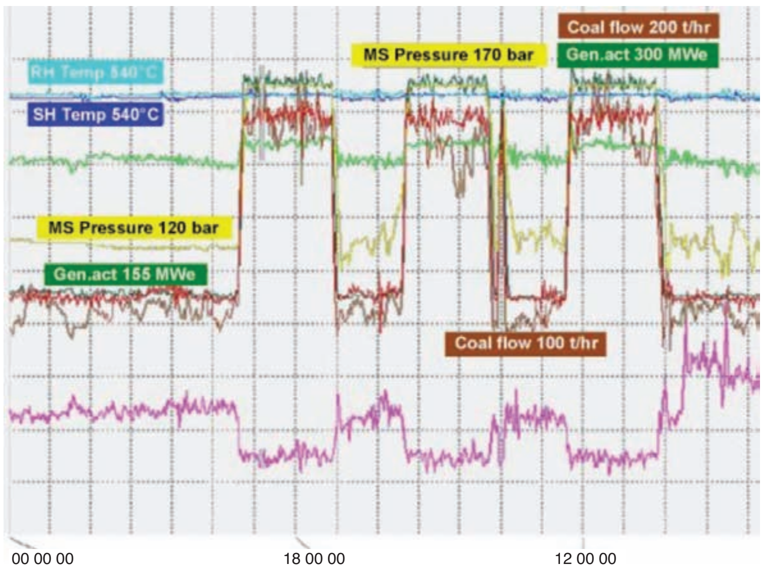

Figure 5—Main and reheat steam temperatures are kept under tight control despite large load swings

Despite the challenges raised by such variable coal properties, the bed temperature was kept at around 880°C, good combustion and good sulphur capture were achieved.

The Emile Huchet project in France

Up to the 1990s Charbonnages de France (CdF), then a state-owned company, and Alstom had teamed up to develop large coal-fired units. CdF operated coal mines and associated power plants such as the Emile Huchet power plant in the east of France. CdF was closed in December 2007 and today E-On and SNET (Société Nationale d'Electricité et de Thermique) own and operate this power plant.

Emile Huchet is a captive power plant close to coal mines and burns low-grade coal residues. It is located in Carling in the Lorraine coal basin, and has a total installed capacity of around 1100 MW_e. It burns either so-called '*schlamms*', a by-product from coal washing plants with no market value, or coal slurry, which is *schlamms* conveyed with water from coal washing plants via pipelines to the power plant. Both *schlamms* and slurry are then filtered and dried before being sent to the pulverized-coal boilers.

When the project to replace the 125 MW_e pulverized-coal boiler, unit 4, came up in 1987, CdF and Alstom had to face several technical challenges:

- Meeting the SO_2 end NO_x emission limits, in compliance with the clean coal combustion regulations
- Efficiently burning the *schlamms*, currently pre-dried for use in PC boilers
- Avoiding, as far as possible, energy-intensive drying of the *schlamms* and slurry
- Creating value from the enormous amount of *schlamms* accumulated in settling ponds over decades.

CFB technology was deemed the most promising way to meet all these challenges. SO_2 emissions would comply with regulatory levels thanks to the sulphur removal achieved by injection of limestone in the furnace. NO_x emissions would also be in line with regulations, as the typical low CFB combustion temperature avoids thermal NO_x emissions.

The key challenge was to efficiently burn a mixture of two fuels: *schlamms* as dried fuel with a lower heating value of about 5 000 Kcal/kg (21 MJ/Kg) and a coal slurry as wet fuel with 33 per cent water content, half of the *schlamms's* lower calorific value, and producing a significantly higher flue gas volume.

Due to the coal mining process, the *schlamms* are very fine. This raises a challenge in managing the solids inventory, which must be maintained high enough in the furnace to achieve the required performances. In this respect, the cyclone design is critical.

Boiler design

This 367 t/h natural circulation CFB boiler was designed to fire the local residues at the steam conditions shown in Table III. The residue is a medium-volatile bituminous coal characterized by a high ash content (30 to 45 per cent on a dry basis) and 33 per cent moisture content, along with a 5 000 kcal/Kg (42 MJ/Kg) for the dried *schlamms* and 2 500 kcal/kg (21 MJ/Kg) lower calorific value for the slurry. The detailed analysis is given in Table III.

Another key property of the coal residues is the fineness of product. The average particle diameter by mass (d_{50}) was within the range 75 to 250 μm and the maximum size did not exceed 3 mm. Obviously no crushing system was needed. The actual particle size distribution (PSD) of the fuel was completely at variance with what the CFB industrial process requires. Furthermore, solid fuel fragmentation with time makes the issue worse. The technical challenge was to design cyclones to keep the maximum quantity of particles in the furnace, for two reasons. Firstly, bed material should not escape the cyclone; otherwise make-up is required to maintain the bed inventory. Sand was contemplated for this purpose, but it is expensive and leads to potential erosion issues. The second reason was to maximize the coal particle residence time in the furnace to secure the highest combustion efficiency.

Table III

Emile Huchet unit 4, CFB boiler main data

Steam conditions at MCR		**Fuel analysis %**	***Schlamms***	**Slurry**
Main steam flow	367	**Proximate**		
Main steam pressure	133	Volatile matter	21.19	11.79
Main steam temperature °C	540	Fixed carbon	45.05	25.06
RH steam flow t/h	338	Ash	25.76	30.15
RH steam pressure bar	30	Moisture	8.00	33.00
RH steam temperature °C	540	**Ultimate**		
Feed Water temperature °C	242	C	52.27	29.08
		H	3.50	1.95
		N	0.58	0.32
		S	1.66	0.92
Emissions levels		O	8.23	4.58
SO_2	330 mg/Nm³ at 6% O_2	LHV kcal/kg	4 850	2 500
NO_X	300 mg/Nm³ at 6% O_2	LHV MJ/Kg	20.3	10.5

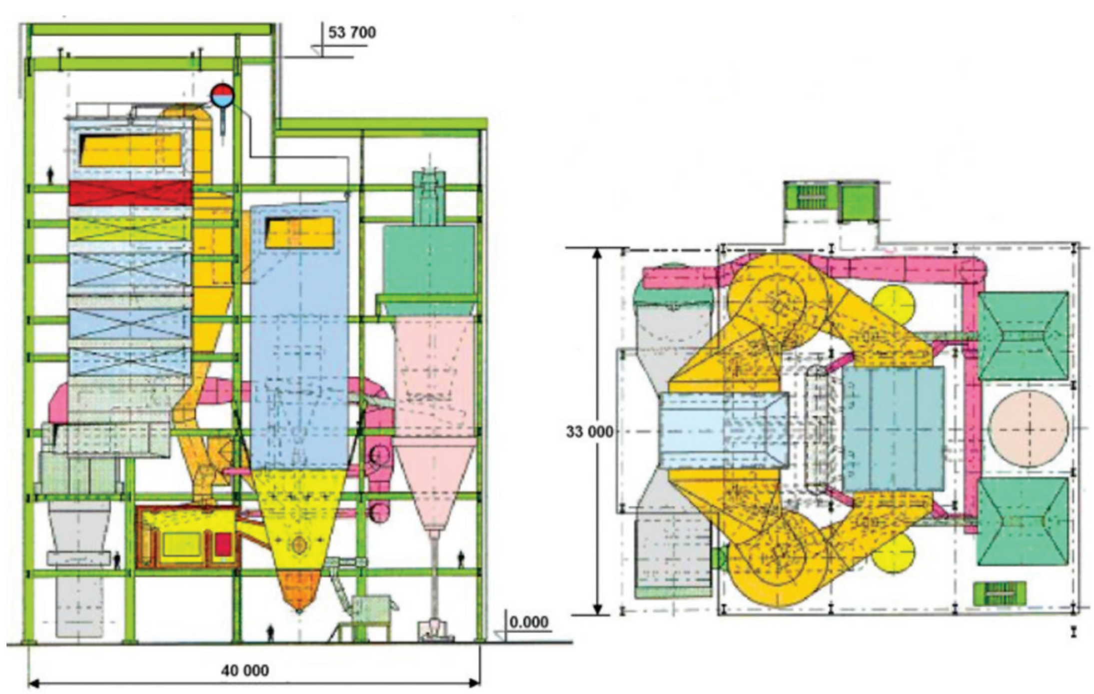

Figure 6—Emile Huchet 125 MW_e CFB arrangement

- ➤ Potential (uncontrolled) sulphur dioxide levels in the flue gas are close to 4500 mg/Nm³ (at 6% O_2 dry gas). To achieve the required 330 mg/Nm³ SO_2 emission, the sulphur removal rate must be close to 92.5 per cent. Sulphur capture is performed by injection of limestone through several ports located in the bottom part of furnace. The limestone actually delivered on site was finer than recommended, with a d_{50} of 50 μm and a maximum size not greater than 600 μm
- ➤ Air staging in the bottom part of the furnace was implemented to mitigate the NO_X emissions. During the design phase, the primary air flow was set up at 40 per cent of the overall air flow, whatever the fuel. Cap nozzles were chosen to distribute the primary air over the fluidizing grate
- ➤ The conceptual design is based on a furnace with a single grate, two cyclones, and two external fluidized bed heat exchangers – one for the control of the bed temperature and one for reheat steam temperature control. The arrangement of the CFB boiler is shown in Figure 6.
- ➤ *Schlamms* were injected in the return ducts from the seal pots to the furnace to allow for pre-mixing with the circulating ash before entering the furnace. Return ducts were arranged for obtaining a circulating ash flow at the furnace entrance onto the centre line of the fluidization grate
- ➤ Coal slurry was injected at about one metre above the fluidizing grate through six separate lines, each including a variable positive-displacement pump and a slurry gun with air-assisted atomization

- Bottom ash was cooled in fluidized bed ash coolers (FBACs)
- The cyclones were designed to operate with a flue gas velocity in the barrel close to 5.5 m/s at the maximum continuous rating when burning coal slurry. This led to an internal diameter of 8 m. The cyclones were laid out on the lateral sides of the furnace and shifted towards the heat recovery back-pass. This layout provides a long connecting duct from furnace to barrel and the required duct angle, both enhancing the pre-collection of the particles impinging the duct extrados (Figure 6)
- A test campaign was launched on a cold flow model to validate the selected design. This cold flow model is still used to validate the design of ongoing projects or to develop new concept of separators
- Several designs of cyclone with different layouts were investigated. Figure 7 highlights the main results.
- Two air heaters were supplied, one tubular air heater for the heating of primary air and a regenerative air heater for the secondary air.

Performance and lessons learned

The Emile Huchet CFB boiler has been in commercial operation since 1990 after passing the performance tests at maximum continuous rating (MCR) as reported in Table IV.

The heat loss due to the unburned carbon is less than 1.5 per cent on a LHV basis with *schlamms*, and somewhat higher with coal slurry. The carbon content in the fly ash does not exceed 6 per cent.

The boiler can be operated properly with a mixture of *schlamms* and coal slurry. The combustion temperature in the furnace can be set within the range 850–860°C—whatever the fuel mix—by controlling the heat pick-up in the external fluidized bed heat exchangers.

Though the fuel and limestone were very fine, the amount of fly ash leaving the cyclones has never exceeded 70 per cent of the overall ash produced by the coal and the limestone.

High solids concentration was measured in the upper part of furnace, leading to a high solids flow in circulation in the furnace–cyclone–seal–pot loop. This promoted some ash build-up and plugging in the cones of the cyclones. The primary air flow was reduced when operating with slurry in order to reduce the ash loading at top of furnace and hence operate the boiler under safe conditions.

The pressure drop in the fluidizing nozzles in the furnace was too low, thus promoting ash back-sifting. A few holes of the inner tube were plugged to create a sufficient pressure drop of around 45 mbar at MCR.

Thermal performance of the ash cooler and ash extraction capacity were improved by moving the location of the ash

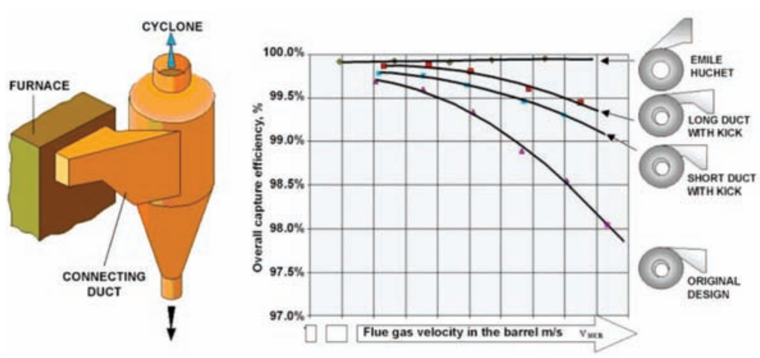

Figure 7—Overall capture efficiency in relation to the general layout

Table IV

Performance tests results

Fuel	Guarantees		Performance test			
	Schlamms	*Slurry*	*Schlamms*		Slurry	
Main steam flow t/h	367		369	374	375	375
Main steam temperature °C	541 +/-3		539	539	540	543
Hot reheat steam temperature °C	539 +/-3		542	543	543	543
Boiler efficiency % LHV	89.3	86.5	89.4	90.2	86.2	87.5
Unburnt carbon loss % LHV			1.4	1.2	2.55	1.71
SO_2 mg/Nm³	<330		53	142	139	145
NO_x mg/Nm³	<300		245	292	109	101
Ca/S Mol ratio	<2.5		1.8	0.7	1.8	1.7
Fly ash - bottom ash split % - %	-		70/30	60/40	62/38	58/42
Unburnt carbon in fly ash %	-		6.0	5.6	5.0	3.8
Unburnt carbon in bottom ash %	-		1.2	1.0	0.4	0.4

vent to the back of the FBAC. This allows reduction of the internal ash recirculation between the ash cooler and the furnace via the vent and the discharge pipe from the furnace to FBAC.

The CFB solid management software developed by Alstom for the calculation of solids flows in the CFB system has shown excellent consistency (Figure 8) with the field test data. This tool is currently used for setting up the expected capacity of ash extraction systems as well as the ash flow in circulation in the furnace, which is required to calculate heat transfer factors and performances.

The Seward project in the USA

Pennsylvania in the USA is a major coal area, with reserves of approximately 100 billion tons prior to mining. Since the beginning of the 19th century, 25 billion tons have been mined. The balance is still underground, as extraction no longer makes economic sense. Approximately 350 Mt of discarded coal have resulted from mining. Seward, located in a bituminous coal basin in Indiana County, was a mine-mouth coal washing plant, feeding a 200 MW_e power station, built in 1921.

However, the environment has suffered. The vintage power station had released huge amounts of nitrogen as well as sulphur oxides and particulates, at a time where public awareness of the detrimental consequences on air quality had not yet been translated in regulations.

Further, approximately 2 Mt of waste coal resulting from the mining process has been left on the site, and hundreds of millions more are within 80 km reach. Lixiviation has promoted acidic mine drainage (AMD) from waste coal piles, thus polluting the soil and the nearby Conemaugh river.

Pyrite, or iron disulphide (FeS_2), is commonly present in coal and the adjacent rock strata and is the compound most associated with AMD. Water is also a principal component of the AMD problem, functioning as a reactant in pyrite oxidation, as a reaction medium, and as a transport medium for oxidation products. Pyrite, oxygen, and water form sulphuric acid and ferrous sulphate. Oxidation of ferrous iron (Fe^{2+}) produces ferric ions (Fe^{3+}). When the ferric ions react with water, they form an insoluble ferric hydroxide [$Fe(HO)_3$], known as 'yellow boy', and more acid is produced.

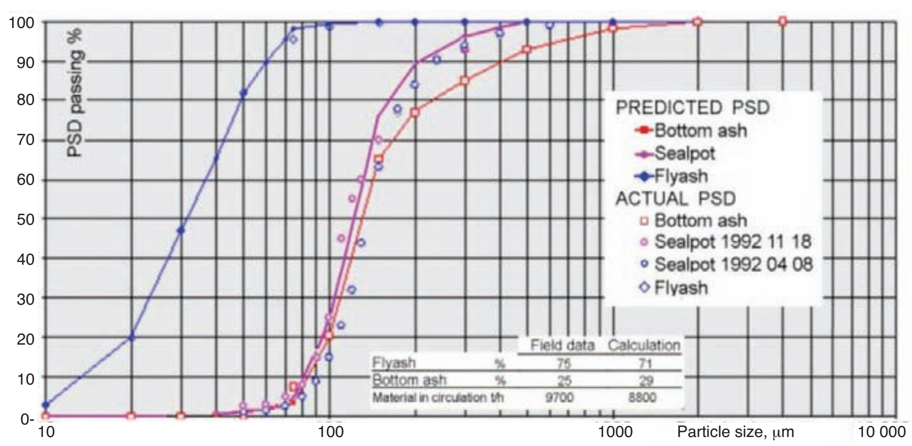

Figure 8—Actual vs predicted particle size distributions at Emile Huchet

Figure 9—The Seward Power Station

Figure 10—A 100 m high discarded coal pile

The above reactions produce elevated concentrations of insoluble ferric hydroxide [Fe(HO)$_3$], dissolved sulphate (SO_4^{2-}), and acid (H^+). Secondary reactions of the acidic water dissolve many other constituents associated with coal deposits, including manganese, aluminium, zinc, and trace metals such as arsenic, cadmium, and mercury[2].

Finally, abandonment of the mines has triggered an unemployment issue, thus jeopardizing the future of the local community.

These facts drove the promotion of the remediation of Seward site through construction of a state-of-the-art power station, capable of efficiently burning the enormous amount of waste coal available, while limiting the environmental impact of combustion. Circulating fluidized bed boiler technology was the answer to such challenge.

Reliant Energy awarded to Alstom Power and Duke/Fluor Daniels an engineering procurement and construction contract for a 590 MW$_e$ gross/521 MW$_e$ net power station. Construction started in June 2001, and commercial operation started in November 2004, a very tight schedule.

Boiler design

Two 872 t/h natural circulation CFB boilers (Figure 11) were designed to burn a bituminous waste coal at steam conditions shown Table V. This coal has a low volatile matter content (11 per cent by weight design basis, but can vary from 9 to 30 per cent). Ash content is high (51 per cent), as well as sulphur (2.75 per cent). Calorific value is quite low at 12.8 MJ/kg. The detailed analysis is given in Table V.

The emission requirements for the flue gas discharged at the stack are also shown in Table V.

The general layout of the CFB boilers is based on a three-bay arrangement. The first bay includes the furnace, which is fed with coal through eight ports located on the front wall. The second bay includes the three aligned cyclones (Figure 12) and external fluidized bed heat exchangers (FBHEs). The third bay is the heat recovery boiler, which hosts the low temperature superheater, reheater, and economizer. There are two FBHEs, one is located under – and

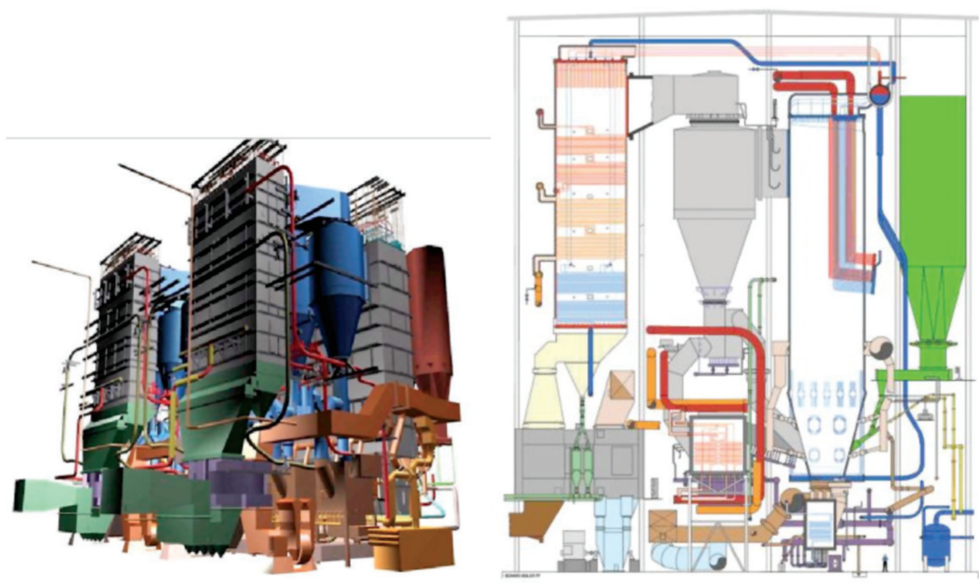

Figure 11—3D view and elevation of Alstom CFB boiler at Seward

Table V

Seward CFB boiler main data

Steam conditions at MCR		Design coal analysis	
Main steam flow t/h	872	Carbon % wt AR	29.32 (25–35)
Main steam pressure Bar	174	Volatile matter %	11 (9–30)
Main steam temperature °C	541	Sulphur %	2.75 (2–4.25)
RH steam flow t/h	796	Ash %	51 (25–58)
RH steam pressure bar	47	Moisture %	8.7 (7–12)
RH steam temperature °C Feed Water temperature °C	540 264	Heating value MJ/kg	12.8 (11.6–14)
Emission levels			
SO_2	780 mg/Nm³ at % O_2 (sulphur removal 95%)		
NO_X	130 mg/Nm³ at 6 % O_2		
Particulates	40 mg/Nm³ at 6 % O2		

Figure 12—Cyclone arrangement at Seward

receives ash from – the outer cyclone. The second is located under – and receives ash from – the central cyclone. The remaining outer cyclone does not feed any FBHE.

Most of the SO_2 formed during the combustion of sulphur in the fuel is captured in the furnace – provided that the combustion temperature is strictly under control – by the calcium oxide generated by the calcination of the limestone in the furnace. At Seward, this in-furnace process ensures 70 per cent desulphurization efficiency. However, the sulphur content of the waste coal is typically 2.75 per cent, which gives a potential sulphur oxide of 12 000 mg/Nm³ at 6 per cent oxygen. The sulphur oxide permit limits were 780 mg/Nm³ at 6 per cent oxygen or 95 per cent sulphur removal, whichever is the most stringent.

That could be achieved by injecting more limestone in the furnace. A more cost-efficient option was to implement Alstom's proprietary NID™ dry scrubber. This system – fully integrated between the boiler and the fabric filter – takes advantage of the unreacted lime in the fly ash escaping the CFB boiler. This back-end treatment includes a reactor where the flue gas stream is submitted to further SO_2 absorption by the injection of reactivated lime, a fabric filter for collecting the ashes, and a mixer where the lime in the ashes is reactivated by water injection before re-injection into the reactor. SO_2 acid gas in the flue gases reacts with the lime during intense contact in the reactor. The dust, with its reacted components and captured sulphur, is collected in the fabric filter and then falls into hoppers. The end product is discharged from the filter hopper and pneumatically conveyed to a silo.

Due to a combustion temperature lower than in conventional pulverized coal boilers, the emissions of nitrogen oxides are low enough in a CFB to comply with regulatory emission limits, unless they are especially stringent, as in Pennsylvania. Alstom has implemented a selective non-catalytic reduction denitrification. Aqueous ammonia is injected into the flue gas, where it thermally reduces the NO_x in the flue gas stream to form nitrogen (N_2) and water vapour. At Seward, the aqueous ammonia is injected in the CFB inlet and – preferentially – outlet gas ducting. This provides good mixing and dispersion of the reagent.

Performance and lessons learned

Overall, compared to the old 1921 power plant, NO_x, SO_2, and particulate matter are reduced by 74 per cent, 85 per cent, and 90 per cent respectively. Heat discharge to the river has also been limited by using an air-cooled condenser.

A combination of non-symmetrical design and significant variations in waste coal blends supplied to the boiler have triggered some unbalanced operations in the furnace:

➤ Unbalanced SO_2 concentration in the furnace, excessive limestone consumption
➤ Unbalanced heat pick-up in the furnace
➤ Excessive release of CO
➤ Less than expected desulphurization in the NIDTM dry scrubber.

These were remedied by implementing the following tuning:

➤ Biasing the fuel to the furnace area where the cooled ash is discharged from the external beds
➤ Biasing the secondary air accordingly while increasing the secondary air rate on the front wall of furnace
➤ Increasing the humidity in the flue gas at the entrance of the NID™ dry scrubber.

This challenging tuning allowed the issues to be resolved and to secure emissions below the maximum allowable limits.

The coal blends also show an unexpectedly high content of coarse particles such as stones. Accumulation of these in the first chamber of the FBAC leads to decay of thermal performance and a higher ash discharge temperature. This was successfully remedied by adding an extraction screw to the FBACs, thus removing the coarse particles and keeping fluidization going.

Proper introduction of the coal was also challenging, because of the high clay content. Along with moisture, this is a sure recipe to promote build-up of large chunks of coal in the coal chutes. This increased coal chute plugging and disturbed operation. Several fixes were implemented, in particular air blowing at various locations from coal silos to chutes.

The official performance tests conducted in August 2005 show compliance with the guaranteed performances.

It is estimated that Seward will consume more than 40 Mt of waste coal from stockpiles in Cambria, Somerset, and Indiana Counties over its first 15 years of service. It is anticipated that over its entire lifetime, Seward will consume up to 100 Mt of waste coal in Pennsylvania, i.e. 30 per cent of the total.

The alkaline ashes — 300 t/h — are removed from the plant and returned to many of the waste coal sites to neutralize acids remaining in the soil, thus mitigating AMD.

The beneficial influence to the environment is enormous.

Conclusion

Circulating fluidized bed (CFB) combustion technology has proven its ability to efficiently burn a wide range of fuels while being friendly to the environment. It has proven successful for the combustion of sulphur- and ash-rich coals, such as low bituminous coal or anthracite, as well as residues of coal mining operation.

In-furnace desulphurization allows compliance with most current environmental regulations. For more stringent requirements, or to optimize operating costs, the proprietary NID™ dry scrubber can be proposed. In either case, the water consumption is negligible, a significant advantage in a world where water is becoming a scarce resource.

The high-efficiency Alstom cyclone technology has proven successful in dealing with the ultrafine discarded coal coming from coal washing plants at Emile Huchet. Operating experience in Emile Huchet, Baima, and Seward has allowed Alstom to accumulate unique expertise in the design of CFBs capable of successfully burning discarded coals. Unexpected — but unavoidable — coarse particles such as very large stones are also handled through appropriate boiler design and proper selection of material handling technologies.

CFB ashes can be used to mitigate acidic mine drainage issues in coal mine areas.

CFB-based power generation is the technology of choice to be installed near coal mining areas. It can create value from otherwise discarded coal, and considerably mitigates the detrimental impact of coal mining on the local and regional environments.

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