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CFB BOILERS IN MULTIFUEL APPLICATION

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Abstract.

Fuel flexibility characteristic for CFB boilers plays an important rule in industrial and utility size applications. Possibility to use wider range of fuels that has been long time considered as by-products or wastes and possibility to design boilers able to operate with alternative fuels is an important factor that improves fuel delivery security and plant economy. Presented article is based on similar publications that present Foster Wheeler's experience in design and delivery of the CFB boilers for wide range of coals and cofiring by- products of crude oil refining and coal processing. Aspects of biomass cofiring will be also presented.

1. Fuel flexibility introduction

Concerning increase in the market prices and in many cases problems to secure constant delivery of high quality fuels investors and plant owners are continuously looking for technology that will be more and more "flexible" in terms of the alternative fuels that could be used in mixture as the addition to main fuel or separately to become main energy source for power generation. This paper will briefly present Foster Wheeler's experience in this area and outline technical solutions applied in existing CFB units. The conceptual engineering development will be also briefly presented.

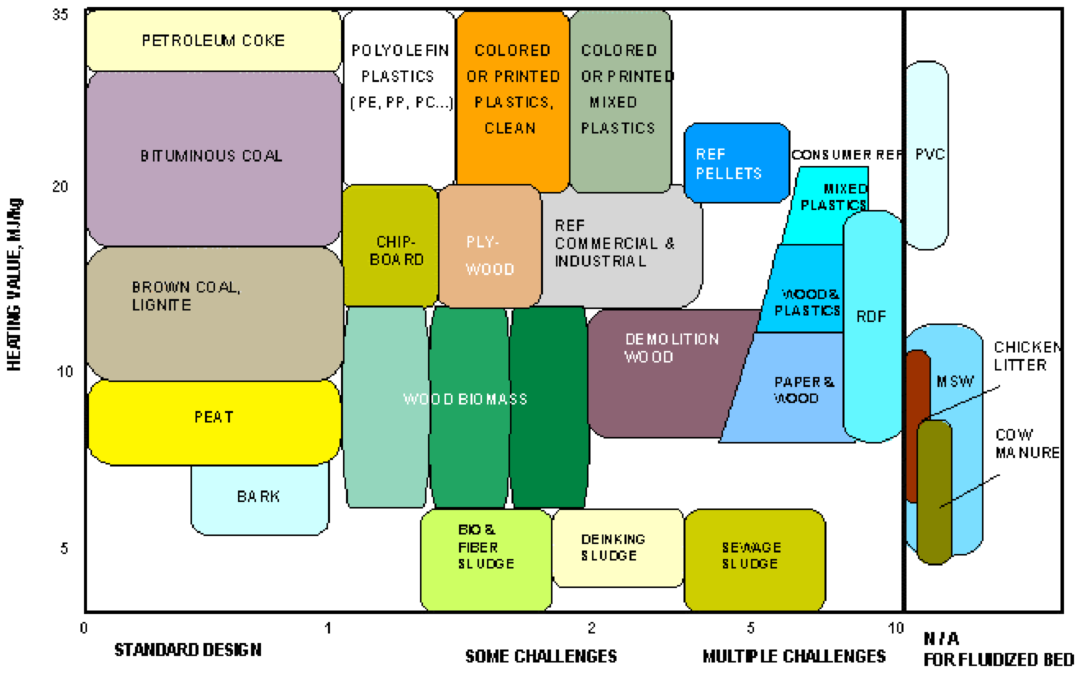

Figure 1 : Fuels available for CFB

2. Aspects of biomass cofiring

Biomass co-firing is one of the most popular requirements that are given in front of the boiler suppliers. Typically it relates to combustion in one boiler of main fossil fuel (e.g hard coal) together with biomass, which contributes in the mixture, is various percentages. Naturally biomass can be used alone as main source of energy but factors like its availability and transportation costs play an important rule in plant's economy. That is seriously limiting feasibility of large-scale power plants operation. Cofiring biomass with the main fuel replaces fossil fuel with a renewable fuel and cuts CO_2 emissions. In addition, cofiring typically reduces SO_x and NO_x emissions. Cofiring of biomass in a boiler with high steam parameters will also give higher power generation efficiency compared to smaller units employing moderate steam cycles.

When biomass is fired in a large unit with high steam parameters, special attention has to be paid to ash properties with regard to slagging and corrosion. The low ash melting characteristics and often elevated chlorine levels typical for biofuels have to be considered in boiler design. These problems can be solved by cofiring biomass with fossil fuels, such as peat, coal, or lignite with significantly "safer" ash properties. The appropriate level of biomass to achieve acceptable boiler availability and maintenance costs has to be determined case by case. The amount of slagging and corrosion depends on the properties of both the biomass and the coal used, as well as boiler design in the case of retrofitting an existing boiler for biomass cofiring.

Two options are available for cofiring: direct co-combustion of biomass and coal in a CFB furnace, or gasification of biomass in a CFB gasifier and combustion of the resulting product gas in a pulverized coal furnace. This paper however will concentrate on direct combustion. Foster Wheeler's experience in CFB based gasification process that is also an energy efficient method of biomass utilization will not be described however should be considered as an attractive alternative depending from project specific requirements.

What makes biomass an attractive opportunity for all energy producers from small scale industries up to large scale utility plants?

First of all biomass is a clean, renewable energy source. Emissions from biomass are lower than for fossil fuels. Replacing fossil fuels with biomass can result in a considerable reduction in net carbon dioxide emissions, which contribute to the greenhouse effect. It is important to realize that biomass cofiring in with compliance with planned CO2 emission trading policy that will directly lead to pro environmental actions from power producers.

From the other hand biomass is also an indigenous resource, which is not subject to world price fluctuations or the supply uncertainties of imported fuels. Some countries have favorable conditions for growing biomass and a large potential for increasing power generating capacity based on biomass. Wood and other types of biomass are used as fuels basically because they are cheaper than other fuels and are locally available. A lot of biomass is available as by-products from other activities, such as pulping, sawmilling, plywood, chipboard production and agricultural production Wood is the most commonly used biomass in energy production. Wood fuel can be produced from forest residue, recycled demolition wood, or energy wood plantations. The most commonly used wood for power production comes from the forest products industry, such as pulping, sawmilling, and plywood and chipboard production. In these cases, wood fuel consists of bark, offcuts, branches, and stumps.

Agricultural residues,are the other main source of agricultural biomass fuels. In some countries these materials are important in the domestic sector, but can also provide an important fuel for industrial energy production.

As a fuel, biomass is of lower quality than fossil fuels, such as coal and oil. Biomass has a typically high moisture content, which results in high gas volume during combustion. As a result, boilers need to be larger, and will operate at lower efficiency than those designed for coal. This has an effect on investment and operating costs, and has to taken into account in fuel pricing.

Biomass contains alkalis such as sodium and potassium, which lower the softening and fusion temperature of the ash produced in combustion. Lower ash fusion temperature results in the slagging and fouling of heating surfaces. Alkali levels vary in different types of biomass; as a rule of thumb, alkali levels are higher in the case of young and fast-growing biomass. The effect of alkalis on boiler design and operation has to be evaluated case by case. Boilers can be designed to accept low ash fusion temperatures, but this typically calls for a somewhat larger investment than would be needed otherwise. When it is possible to cofire biomass with coal, the high content of inert ash in coal dilutes the harmful components of biomass ash , thereby reducing or stopping slagging and fouling.

Biomass may also contain chlorine, which, together with alkalis, can induce corrosion in superheater tubes if high steam temperatures are used. All biomass is not problematic in respect of chlorine and superheater corrosion, however, and each case should be studied for chlorine corrosion potential. Again, cofiring coal and biomass will help here. As biomass ash is diluted with the larger mass of coal ash, the ash fusion temperature increases, and the slag becomes less aggressive, reducing high-temperature chlorine corrosion. Foster Wheeler's solution to high-temperature corrosion is based on its Intrex™ superheater located in the solids return flow from the solids separator. Chlorine content is much lower here than in the flue gas heat recovery area, and corrosion rates are significantly lower as a result.

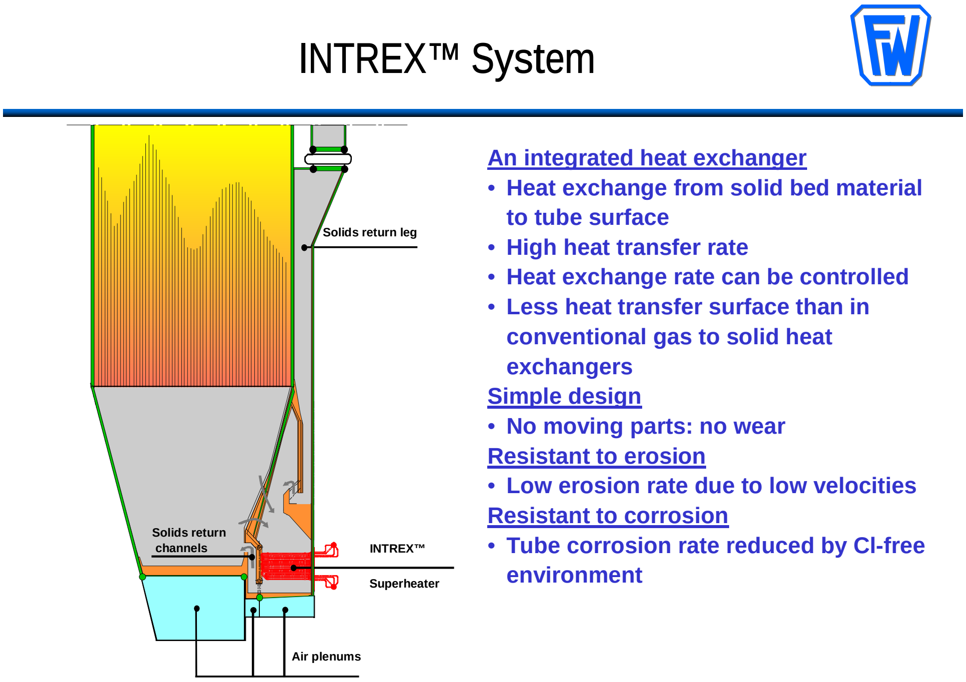

Figure 2 : INTREX type heat exchanger is a standard design when high temperature corrosion is considered (e.g biomass fired boilers)

3. Experiences with Co-combustion of Biomass and Coal

Foster Wheeler is the leading supplier of CFB technology and has a number of references for coal and biomass combustion. In Thailand, for example, Foster Wheeler has supplied seven CFB boilers that burn both domestic and imported coals and simultaneously cofire biomass. The first CFB unit in Thailand started up in 1993 and has successfully burnt local lignite together with bagasse pith and sludge from a local paper mill

.Table 1: References of the Foster Wheelel CFB's co-firing biomass

Delivery year	Customer/Site	No. of Units	Capacity MWe	Capacity MWt	Fuels
1981	Länsi-Suomen Käynnissäpito Oy Kauttua, Finland	1	20	65	Peat, wood, coal
1983	Patria Papier & Zellstoff Ag Frantschach, Austria	1	15	55	Brown coal, bark
1985	Jämtkraft AB Östersund, Sweden	1	0	25	Wood chips, peat, coal
1985	Stora Fors AB Fors, Sweden	1	15	56	wood residue, peat, coal
1985	Metsä-Sellu Oy Äänekoski, Finland	1	25	76	Peat, wood residue, coal
1987	Lenzing AG Lenzing, Austria	1	25	94	Brown coal, sludge, bark
1988	Black River Partners Fort Drum, New York State, U.S.A.	3	18	56	Coal, anthracite, wood
1989	P.H. Glatfeller Co. Spring Grove, Pennsylvania, U.S.A.	1	40	132	Coal, wood
1989	Kainuun Voima Oy Kajaani, Finland	1	95	240	Peat, wood residue, coal, sludge
1989	Caledonian Paper plc Irvine, Scotland, United Kingdom	1	15	43	Coal, bark
1990	Rumford Cogeneration Co. Boise Cascade, Rumford, Maine, U.S.A.	2	45	130	Coal, wood
1990	Vaskiluodon Voima Oy Seinäjoki, Finland	1	125	299	Peat, coal
1990	Enso Oy Varkaus, Finland	1	50	150	Bark, wood residue, coal
1990	Solvay Österreich GmbH Ebensee, Austria	1	10	38	Coal, wood residue
1992	Midtkraft Power Company Grenå, Denmark	1	24	77,5	Straw, coal
1992	Karlstads Kommun Tekniska Verken Karlstad, Sweden	1	25	90	Wood residue, coal
1994	Fortum Engineering Kokkola, Finland	1	30	97,5	Peat, coal
1996	Thai Kraft Paper Industry Co., Ltd. Wangsala, Thailand	1	50	140	Lignite, sludge, bark
1997	Indah Kiat Pulp & Paper Corporation Perawang, Indonesia	2	50	171	Coal, bark, wood, sludge
1997	Sonoco Products Co. Hartsville, South Carolina, U.S.A.	1	12,5	37,4	Coal, bark, waste paper plastic, stoker ash
1997	P.T. Riau Andalan Pulp & Paper Corp. Kerinci, Indonesia	1	110	314	Coal, bark
1998	National Power Supply Co. Ltd Tha Toom, Thailand	2	150	370	Anthracite, rice husk, bark
1998	Mysore Paper Bhadravathi, India	1	20	71	Lignite, bagasse pith, sludge
1998	Frantschach Energo A/S Steti, Czech Rebuplic	1	50	176	Brown coal, bark, sludge
2001	Lycksele Energia AB Lycksele, Sweden	1	15,5	46,5	Wood residues, peat, bark, coal
2001	Västerås Energi AB Vesterås, Sweden	1	58,7	157	Wood resisdues, peat, coal
2005	Stora Enso Kvarnsveden Borlänge, Sweden	1	36	130	Bark, sediment sludge, biosludge, coal

The boilers are of Foster Wheeler's second-generation design. The main difference between this and earlier designs is that the round cyclone of the traditional CFB boiler has been replaced by a solid separator, which is integrated with the furnace.

The separator is joined to the furnace without expansion joints. The solids separator and the solids return channels are fabricated using cooled, straight membrane panel walls. Thick, insulating refractory is not required in the design, only thin refractory for protection against wear. The main benefits of the design are its compact size, a cooled structure that recovers heat, and a low maintenance requirement, which allow flexible, reliable, and economical operation.

A by-product from the nearby Advance Agro pulp and paper mill, eucalyptus bark and an agricultural residue, rice husk, have been cofired with anthracite. The bark has a fairly high chlorine content.

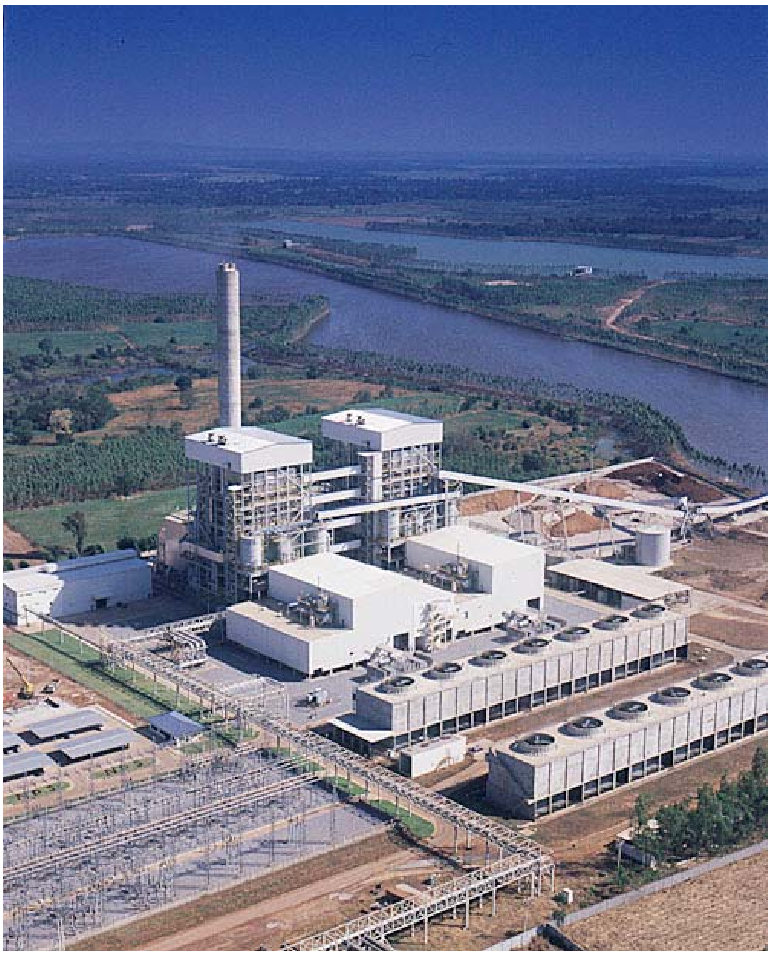

Figure 3: NPS Power Plant, Tha Toom (Thailand)

To reduce the risk of superheater corrosion, the amount of biomass has been limited to 10-15% of heat input. Bark is mixed with rice husks to give a dryer biomass with a higher heating value.

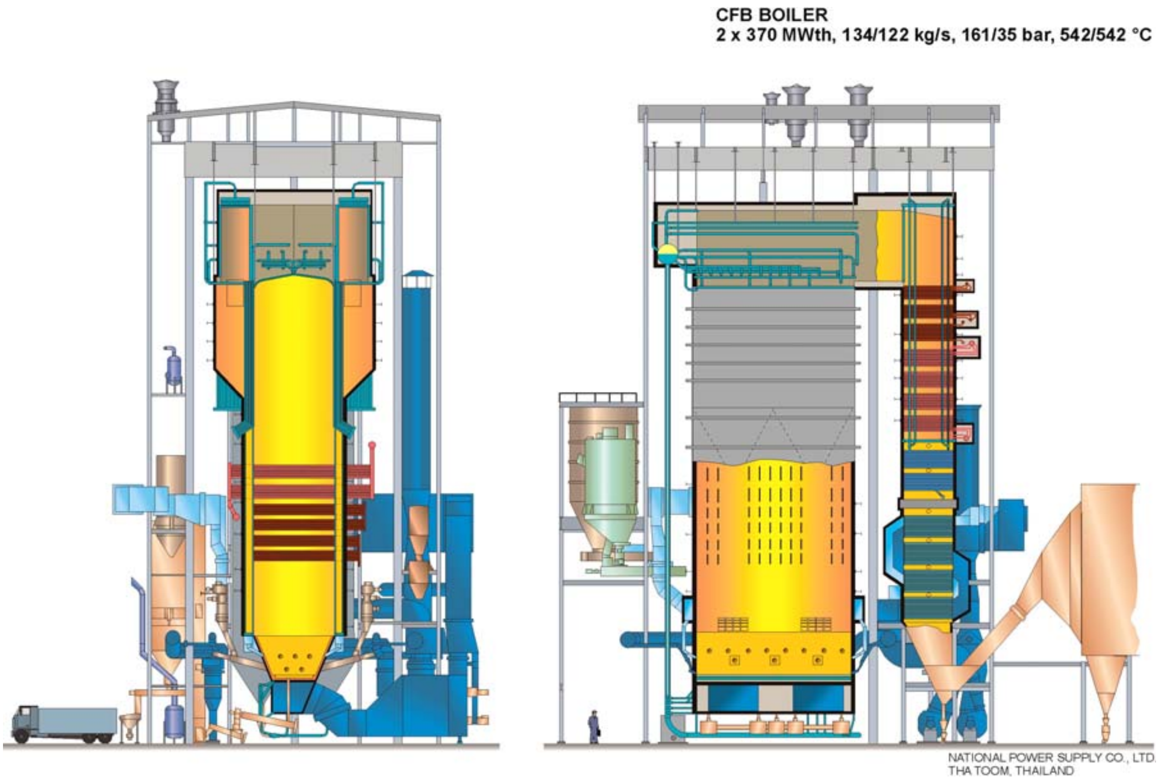

Figure 4: The cross section of the Compact CFB Boielrs.
Foster Wheeler delivered two units with capacityof 370MWth each.

Despite the considerable and uneven variations in the moisture of the mixture, the high heat capacity of the circulation solids in the CFB furnace and the stability of coal firing, together with the advanced control system, allow these variations to be handled without impairing operations.

The fuel handling system consists of two parallel coal lines in the coal yard, with coal pile reclaimers and a screening and crushing station. Coal is transported via long belt conveyors to the boilers, where there are two silos and two feeding lines for both boilers. Biomass equipment consists of an unloading hopper in the biomass yard and belt conveyors, which transport biomass into two separate silos at the boiler.

Biomass is mixed with coal in a mixing screw and fed into the furnace via a chain conveyor, robbing screws, rotary feeders, and forced screws. A four-field electrostatic precipitator, installed before the stack, is used for fly ash removal; ash is transported by truck to an ash yard. The 120 meter-high concrete stack has two flues, one for each unit.

Table 2: Analysis of the fuels used at NPS

		Hongai # 8 Anthracite	Australian Jellinbah-anthracite	Chinese Hebi-anthracite	Eucalyptus bark	Rice husk
Total moisture	%	9	10	9	58	13
Ash (as rec.)	%	12	12	14	2.5	14.8
Volatile (dry)	%	4.8	13	13		
LHV (as rec.)	MJ/kg	27.8	26.0	26.0	5.0	12.7
Ultimate (MAF)						
C	%	92.5	88.2	88.1	48.8	46.2
H	%	3.4	3.8	4.6	5.8	6.9
O	%	2.1	5.3	5.5	44.9	44.8
N	%	1.4	1.9	1.5	0.4	0.8
S	%	0.6	0.8	0.3	0.02	1.3

Since the boilers were designed to fire two very different fuels, anthracite and biomass, some challenges had to be overcome during the commissioning period. The boilers were started on pure anthracite to simplify basic tuning of the control loops. After smooth operation with anthracite had been achieved, tuning for biomass cofiring followed.

The performance values of the boilers are presented below. Due to the high moisture in the biomass, the boiler load is limited to 80% MCR load when burning the maximum permitted proportion (50% by energy) of biomass. This limitation is linked to the capacity of the ID fan and gas velocities in the boiler. The high moisture content of the biomass feed also has an effect on overall efficiency, due to higher stack loss. However, the availability of low-cost biomass has made the co-combustion of biomass economically viable.

Cofiring biomass has also reduced boiler emissions, particularly in the area of SO_2 emissions, thanks to the low sulfur content of the biomass used. Achieving the permit level for SO_2 does not require limestone addition when using low-sulfur coals.
High availability has been achieved since the start-up of the boilers. Operation has been trouble-free and there has been only a marginal increase in maintenance costs resulting from biomass feeding and handling equipment. The co-combustion of biomass has had a positive impact on plant economy and the environment. As biomass is a local fuel source, it has also created employment opportunities in the surrounding area and thus enhanced the local economy.

Table 3: Operational parameters of NPS boilers

		Design	Hongai	50% Hongai + 50% biomass by energy
Boiler load	% MCR	100	100	80
Main steam flow	kg/s	134	134	107
Temperature	°C	540	540	540
Pressure	bar, g	161	156	156
Fuel		Hongai # 8		Hongai # 8 + biomass mixture
Moisture	% a.r.	8	7.2	47.5
Ash	% a.r.	12	11.5	5.0
Volatiles	% DAF	8	5.4	53
Sulfur	% dry	0.7	0.52	0.1
LHV as received (a.r.)	MJ/kg	27.79	28.3	9.3
Fuel flow	kg/s	14.41	13.75	6.1+29.8
Limestone	kg/s	-	-	-
UBC loss of HHV	%	2.5	2.5	1.7
UBC in ash	%	14.4	12.3	9.6
Boiler efficiency	%	91.7	92.0	90.3
Emissions				
Flue gas O_2 in backpass	%-wet	3.32	2.87	2.5
SO_2 (6 % O_2 dry)	ppm-dry	397	339	25
NO_x	ppm-dry	180	34	30
CO	ppm-dry	200	118	110

4. Petroleum coke

When various refining processes produce significant quantities of by-products like petroleum coke (petcoke) that is offered in the market it has become interesting opportunity for power producers. When various refining processes produce significant quantities of by-products like petroleum coke (petcoke) that is offered in the market it has become interesting opportunity for power producers.

Figure 5: Petroleum coke is not any more just refinery by-product it has become reliable and economic fuel for many power producers(photo www. fwc.com)

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As crude oil is refined, lighter fractions, or products, such as gasoline and jet fuel are driven off, leaving a residual oil of relatively little value. In refineries with cokers, this residual oil is processed further to yield additional amounts of light products, along with petroleum coke. Because parameters of petcoke depend from the source of the crude oil that ultimately provides the feedstock for the coking process. A CFB steam generator firing petroleum coke must be able to accommodate wide variations in these characteristics with no deterioration of efficiency or environmental performance.

Petroleum coke (both fluid and delayed) is a fuel that has long been considered an ideal partner to the circulating fluidized bed combustion technology.

Some of the main advantages are:

- High combustion efficiency.
- Excellent combustion stability over a wide boiler load range.
- High sulfur content provides enough bed material through addition of limestone for sulfur capture.
- Very low emissions possible.
- Relative insensitivity to low-melting temperature vanadium compounds.

There are benefits related to CFB combustion that have to be considered when petcoke is planned to be the main or additional fuel for the plant. The fuel introduced in a CFB steam generator is burned as it mixes with other material, such as limestone sorbent and ash, in an upward flow of gas. The highly turbulent and effective mixing of with air results with uniform temperature throughout the furnace and the long residence time of fluidized material in the furnace contribute to high combustion efficiency. Efficiency is enhanced by typical for CFB boilers solid separators that are returning a very high percentage of ash and unburned carbon back to the furnace.

The CFB process currently utilized by Foster Wheeler for petcoke firing is characterized by the presence of a pronounced bed in the first few feet of the furnace and a relatively lean solids freeboard above this region. Foster Wheeler’s process is also unique in that the distinctive bed-fluidizing regime is characterized by relatively coarse sorbent-particle distribution and comparatively low primary-furnace-zone gas velocity. This provides optimum conditions for minimizing emissions and maximizing carbon burn-up. In general, Foster Wheeler’s CFB design philosophy offers:

- Higher solids residence time due to the deep, pronounced bed in the lower furnace
- Lower solids loading through the heat-recovery area as a result of the coarser bed and a high-efficiency cyclone
- Low erosion potential in the furnace and cyclone entrance because of leaner freeboard operation
- Good and predictable thermal performance
- Simplified controls.

These features add up to predictable operation over a broad range of conditions; efficient fuel burn-out and limestone utilization; low sulfur-oxide (SOx), nitrogen-oxide (NOx), and carbon-monoxide (CO) emissions; and simpler, low-cost construction.
These design and operating features underlie the superiority of CFB technology for firing a fuel with the characteristics of petcoke that were mentioned earlier. The low volatile content of petcoke is accommodated by the substantial inventory of hot solids within the furnace of a Foster Wheeler CFB unit. These hot solids provide a constant source of ignition energy and allow the steam generator to operate over a wide range of loads without concern. Fuel burn-out has been shown to be very high with very low CO levels under all operating conditions.

A number of problems related to the nature of petroleum coke can occur if appropriate design parameters are not used for the cyclone, loop-seal, and heat-recovery area in CFB units that will operate with this fuel. For example, tests have shown that the loop-seal system between the cyclone and furnace is particularly susceptible to pluggage, which is a hard build-up of circulating ash mainly in the horizontal run of the loop-seal. Similar deposits can also occur on the cyclone walls. These deposits are predominantly CaSO4, CaCO3, and CaO, along with small amounts of char, vanadium, nickel, and iron. They have been found to result from a combination of insufficient loop-seal fluidization and chemical-reaction sintering in certain areas of the loop-seal system. However, appropriate design can virtually eliminate pluggage and associated maintenance costs. Testing has also shown that limestone sizing and composition are also important factors in the formation of such deposits. New tests developed by Foster Wheeler can help to select the limestone best suited for a CFB facility that will be firing petcoke.

Careful boiler design and limestone selection can thus prevent problems that may be caused by firing coke, as demonstrated by the performance achieved at many commercial CFB facilities provided by Foster Wheeler.

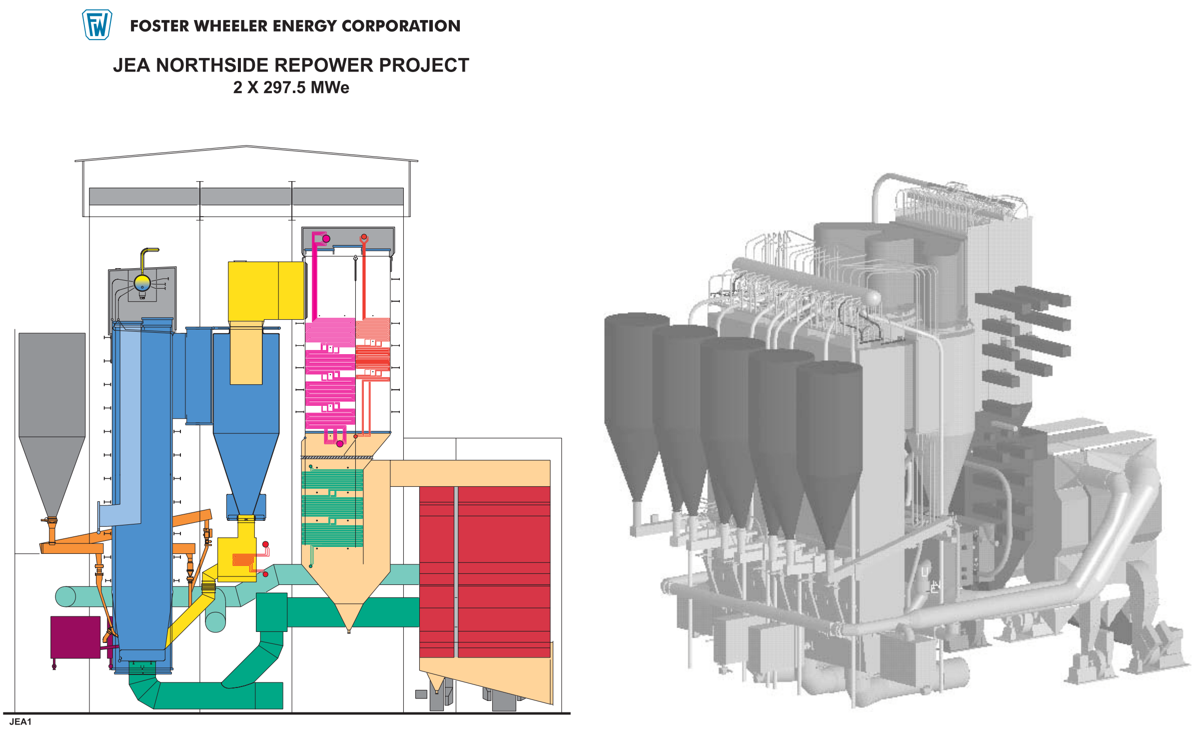

Figure 6: The 300 MWe class CFB boiler designed to fire 100% bituminous coal and 100% high sulfur petroleum coke (cross-section and 3D model)

Emissions achieved in JEA show good environmental performance of the boiler. To optimize overall plant performance, the JEA project incorporates a polishing SO2 scrubber. The CFB boiler provides over 90% SO2 capture via limestone injection, with the remaining capture from a semi-dry polishing scrubber via injection of lime. Overall SO_2 capture is over 98%.

Although CFB boilers can achieve 98% SO_2 removal, limestone utilization is reduced as removal efficiencies exceed 90-95%. The polishing scrubber allows reducing the overall sorbent use, such that the savings in operating cost (sorbent, ash disposal) could offset the capital and operating costs of the polishing scrubber.

Table 4: Design fuels of JEA Project

Steam Conditions at Turbine Throttle @MCR

Flow, SH/RH, lb/hr (ton/hr)	1,993,591/1,773,263	(906 /806)
Pressure, SH/RH, psi (bar))	2500/547.7	(172 / 37.7)
Temperature, SH/RH °F (°C)	1000/1000	(538 / 538)

Fuel Analysis:	Coal			Coke		
	Min.	Max.	Design	Min.	Max.	Design
C, %wt	59.0	72.0	68.6	78.0	89.0	79.0
H	3.9	5.3	4.6	3.2	5.8	3.6
O	3.0	9.8	4.11	0.1	1.8	0.3
N	0.8	1.6	1.3	0.4	2.0	1.0
S	0.5	4.5	3.3	3.0	8.0	6.7
Ash	7.0	15.0	12.8	na	3.0	0.4
H_2O	na	13.0	5.2	na	15.0	9.0
Volatiles	30.0	36.0	35.6	7.0	14.0	9.0
HHV, btu/lb.	11,600	na	12,690	13,000	na	14,000
(Kcal/kg)	(6,445)		(7,050)	(7,220)		(7,780)

Although CFB boilers can achieve 98% SO_2 removal, limestone utilization is reduced as removal efficiencies exceed 90-95%. The polishing scrubber allows reducing the overall sorbent use, such that the savings in operating cost (sorbent, ash disposal) could offset the capital and operating costs of the polishing scrubber. However, another consideration in the decision to add the scrubber was the enhanced environmental performance regarding trace elements provided by the scrubber. While this benefit cannot be quantified, JEA decided the added capital cost was justified.

Table 5: JEA – the achieved emissions.

Fuel	**50/50 Coke/Coal**	**80/20 Coke/Coal**
Load % MCR	95.3	96
Fuel HHV, kcal/kg	7461	7825
Fuel S %wt	5.34	3.70
Emissions		
SO2 (Stack), mg/nm3	135	84
SO2 Removal (overall) %	98.8	98.9
SO2 (Boiler), mg/nm3	294	167
SO2 Removal (Boiler) %	97.4	97.8
NOx, mg/nm3	102	18
CO, mg/nm3	22	18
Dust, mg/nm3	5.9	3.5
Fluoride, kg/hr	0.119	0.2
VOC, kg/hr	< 0.05	<6.4

Foster Wheeler has the most experience firing petroleum coke in CFB boilers either alone or in combination with coal. Foster Wheeler CFB boilers are in service as depicted below. This is important to note that petcoke has been used in together with variety of coals staring from anthracites up to higher volatile bituminous coals.

Table 6: Petroleum coke experience.

CFB experience in petroleum coke firing

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Del. year	Customer	MWe	MWth	Fuels
1984	OCI, Inchon, Republic of Korea	25	97	Petroleum coke, coal
1985	California Portland, California, USA	20	59	Coal, petroleum coke
1988	FT. Howard Paper Co., Rincon, Georgia, USA	32	98	Petroleum coke, bituminous coal
1988	Hyundai Oil Co., Seosan, Republic of Korea	25	94	Petroleum coke, oil
1988	Sunkyong Fibres, Suwon, Republic of Korea	25	105	Petroleum coke, bituminous coal, oil
1988	Omi-Kenshi, Hyogo, Japan	4	28	Semi anthracite coal, bituminous coal, petroleum coke, oil
1988	YFU, Taipei, Taiwan, R.O.C.	30	103	Bituminous coal, petroleum coke
1988	Stockton Cogeneration Facolity, California, USA	50	165	Coal, petroleum coke
1988	Black River Partners, Fort Drum, New York, USA	3 x 17	3 x 56	Coal, anthracite, petroleum coke
1989	Sunkyong Fibre, Ulsan, Republic of Korea	45	160	Bituminous coal, oil, petroleum coke
1989	Mt. Poso Cogen., Co., Bakersfield, California, USA	50	164	Bituminous coal, petroleum coke
1990	Rumford Cogen., Co., Maine, USA	2 x 40	2 x 130	Coal, oil, petroleum coke
1990	University of Northern Iowa, Iowa, USA	15	36	Bituminous gob, petroleum coke
1991	City of Manitowoc, Wisconsin, USA	20	77	Petroleum coke, bituminous coal, tire derived fuel
1991	UDG-Niagara Inc., Niagara Falls, New York, USA	50	149	Bituminous coal, petroleum coke, shredded tires
1992	NISCO, Lousiana, USA	2 x 120	2 x 285	Petroleum coke
1995	Steel Authority, Orissa, India	15	45	Coal, petroleum coke
1995	Fort Howard Paper Co., Savanna Mill, Georgia, USA	32	98	Petroleum coke
1995	Northampton Energy Project, Pennsylvania, USA	100	276	Anthracite culm, petroleum coke
1996	Taiheiyo Cement, Oita, Japan	29	69	Bituminous coal, semi anthracite coal, petroleum coke, RDF, TDF
1998	Petropower Talcomuaro, Chile	67	180	Petroleum coke
1998	Rain Calsining, Visag, India	25	82	Petroleum coke
1999	Zhenhai Sinopec, Ningbo, P.R.C.	2 x 50	2 x 160	Petroleum coke

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CFB experience in petroleum coke firing

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Del. year	Customer	MWe	MWth	Fuels
2000	Bay Shore Power Co., Ohio, USA	180	460	Petroleum coke
2001	Taiheiyo Cement Co., Ltd., Niigata, Japan	149	341	Bituminous coal, petroleum coke, RDF
2001	JEA, Florida, USA	2 x 300	2 x 689	Petroleum coke, bituminous coal
2001	Sinopec Jingling, Jingling, P.R.C.	2 x 50	2 x 156	Coal, petroleum coke
2002	Sinopec Shanghai, Jinshan, P.R.C.	2 x 75	2 x 218	Petroleum coke, bituminous coal
2004	Zhenhai Refinery, Ningbo, P.R.C.	2 x 100	2 x 293	Bituminous coal, petroleum coke
2005	Taiheiyo Cement Tosa, Kochi Plant, Japan	150	341	Semi anthracite coal, petroleum coke
2005	Sumito Osaka Cement Co., Ltd., Kochi Plant, Japan	62	152	Semi anthracite coal, petroleum coke
2006	Corn Products International Inc., Illinois, USA	130	376	Bituminous coal, petroleum coke
2006	Yanshan Petrochemical Corp., Beijing, P.R.C.	2 x 75	2 x 218	Petroleum coke, bituminous coal
2007	Maoming Petrochemical Corp. Maoming, P.R.C.	2 x 100	2 x 293	Bituminous coal, petroleum coke, oil shale

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5. Coal Slurry in CFB

When one comes to the terms of fuel flexibility it is also important to look for the technical solutions that allow utilizing energy sources that have been considered for the long time as the wastes, low-grade residues like these produced during coal processing. The techniques in coal processing vary from coal mine to coal mine, however there is one common thing with these different methods: they are continuously creating enormous amount of coal wastes varying from fine and dry screening waste to huge sedimentation ponds of coal mud or slurry.

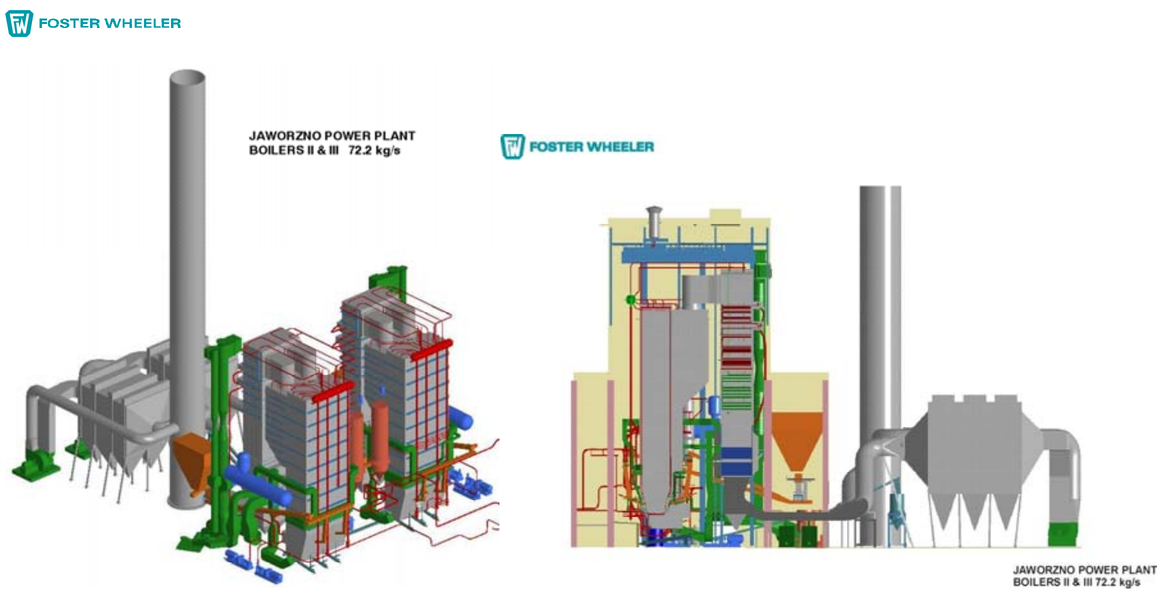

Figure 7: Jaworzno CFB boiler designed to fire 100% Bituminous Coal and mixture of Bituminous Coal and Coal Slurry (cross-section and 3D model)

When designing a CFB boiler for low-grade coals there are several items to be taken into account: velocities in the furnace and back pass must be selected so that potential erosion from the high ash load in the flue gases will be avoided, and the fuel handling equipment must be specially designed for handling coals with high moisture content. Even the steam cycle must be tailored for low-grade coal firing. Very often the low-grade coals and coal wastes have significantly high alkaline and chlorine content which can cause fouling and high temperature metal corrosion in final superheaters. To address these concerns, Foster Wheeler has successfully introduced the INTREX™ heat exchanger as the essential part of the boiler design.

Figure 8:Coal slurry requires specific handling equipment but its cost effective energy source when fired in CFB boilers

Performance of Jaworzno Boilers

Overall performance of the boilers including emissons was verified during the guarantee tests. Guarantee tests for 100% coal firing were carried out in February 2000 and for co-combustion of coal and coal slurry in November 2000. Tests were performed over the whole load range.

Table 6:Coal and coal slurry analysis during the performance tests.

		100 % Coal	Co-combustion of Coal and	
		Coal	**Coal**	**Coal slurry**
Coal origin		**Jan Kanty**	**Ziemowit mine**	**Sobienski mine**
Heat value, LHV	MJ/kg, as fired	19.1 – 20.4	18.1 – 18.8	8.1 – 9.0
Volatiles	%, dry ash free	41 – 42	38 – 39	39 - 40
Moisture	%	21 – 25	14.6 – 15.3	35.1 – 38.4
Ash	%, as fired	11 – 12	21.4 – 22.6	27.9 – 28.4
Sulphur	%, as fired	1.0 – 1.6	1.1 – 1.2	0.5 – 0.6
Chlorine	%, in dry solids	0.01 – 0.05	0.32	0.01

During 100% coal tests coal moisture content has been slightly higher and ash content lower than designed. During slurry tests coal was taken from the other mine and the analysis is as per design. Slurry moisture content had to kept slightly higher than design in order to ensure trouble free and reliable pumping of slurry.

Table 7:Performance test data of Jaworzno boilers.

	Guaranteed		Achieved	
			K3	K2
Capacity	72,2	Kg/s	73,6	73,4
Steam temperature	540	°C	540,5	540,1
Steam pressure	13,7	MPa	13,68	13,71
Boiler efficiency	89,83	%	91,3	90,3
Own consumption	5300	kW	5177	5082
Limestone consumption	4,5	t/h	2,66	2,4
Slurry share in the fuel input	50	%	45,4	50,6
Dust	50	mg/Nm^3	7,36	6,46
NO_x	470	mg/Nm^3	248	217
SO_2	560	mg/Nm^3	557	558
CO	310	mg/Nm^3	62	74

The problems that occurred during boiler operation were mainly caused by slurry feeding system caused by improper slurry quality(impurities like stones, metal objects and pieces of wood) have caused many blockages and some equipment damages in the piping at the receiving station and at the end of the feeding line i.e. in slurry lances. Later more attention has been paid for the quality of incoming slurry to avoid disturbances.

Selection of atomizing media. Originally, steam atomizing was used in the coal slurry lances for the even distribution of slurry into the furnace. Steam line from the low pressure header was quite long and that caused partly condensation of steam. Water drops in steam caused significant erosion in the lances and even in the refractory of the furnace near the inlets of the lances. Steam atomizing was replaced by pressurized air atomizing and the erosion problems have been reduced clearly.

Individual equipment problems hydraulic valves at the receiving station have been damaged and they have been replaced. One reason for these equipment problems can be stones and metal scrap coming with slurry although line is equipped with stone traps to remove biggest particles.

6. Conclusions

The CFB combustion features make this technology an ideal partner for wide range of power producers starting from small and average units up to utility scale projects. The impact of fuel prices, availability and quality will be continuously forcing power business to look for fuel flexibility as one of the most important factors to be considered for retrofits and completely new projects. The aspects of plant economy and security of constant fuel delivery are improving feasibility studies for future projects.

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