Technology comparison of CFB versus pulverized fuel firing for utility power generation

by J. Utt* and R. Giglio*

Synopsis

Recent developments in circulating fluidized bed (CFB) once-through supercritical technology (OTSC) have enabled this technology to be offered as a utility-scale alternative competing head-to-head with pulverized fuel (PF) OTSC offerings. One clear example is the CFB supercritical unit at the Łagisza Power Plant in Poland, owned by PoludniowyKoncernEnergetyczny SA (PKE). This unit has now been in commercial operation for three full years, exhibiting very good performance, and has validated Foster Wheeler's performance model at this utility scale as well as for units in the 600 MW_e and 800 MW_e size ranges offering net efficiency of ~43 per cent (LHV basis). This operating unit has also proven the use of the world's first FW/BENSON™ vertical-tube OTSC low mass flux technology. Since the Łagisza original international tender specified OTSC PF technology, it is important to note that the alternative selection of CFB OTSC technology over conventional PF technology is of historic significance, not only for the validation of the CFB supercritical platform as a viable alternative to conventional PF technology, but it also positions the CFB OTSC with fuel flexibility for offering of sizes up to and including 800 MW_e units.

This paper explores the differences between CFB OTSC technology and standard PF OTSC in utility power generation. Selection criteria, fuel burning range in both technologies, and other selection drivers are discussed. Economic analysis of both technologies, based on existing cases, is also provided. Also discussed are the technical advantages and uses of each technology. Foster Wheeler has recently been awarded a contract for four units of CFB OTSC technology, which utilizes a 2 on 1 configuration of two 550 MW_e CFB OTSC boilers on two single 1000 MW_e turbines. Essentially this provides a fuel-flexible low-emissions alternative to a 2 × 1000 MW_e solid fuel power block.

Keywords

OTSC CFB technology, OTSC PF technology, comparing PC and CFB economics, pulverized fuel, low mass flux, supercritical CFB, sub critical CFB, supercritical PF/PC, sub-critical PF/PC, PC versus CFB, high-efficiency steam cycle, fuel flexibility, power plant case assumptions, fuel arbitrage, wide range of fuels, variations in fuel quality, low fuel quality, low fuel costs, low emissions.

Introduction

Coal-fired power plants account for over 40 per cent of all electricity generation globally. Some countries have even higher percentages of coal-based electricity generation, as shown in Table I.

In today's global utility power generation industry the most widely used technology for large-scale utility coal-fired steam generators has been pulverized fuel firing so-called 'steam' quality coal. These pulverized fuel (PF) boilers fire coal in differing configurations including wall firing, corner firing, and in some cases for low-volatile fuels, arch firing.The coal fired in these boilers is generally a high- to medium-quality bituminous coal, which in many cases is beneficiated through some type of washing.

Foster Wheeler has designed and supplied over 130 000 MW of the type of solid-fuel steam generators discussed in this paper. These units include (a) sub-critical and supercritical pulverized fuel/coal (PF/PC) wall-fired steam generators firing high- to medium-quality bituminous, sub-bituminous coals, (b) sub-critical and supercritical arch-fired units firing low-volatile anthracite, and (c) sub-critical and supercritical circulating fluidized bed (CFB) steam generators firing a wide array of solid fuels, including all coals, petroleum coke, biomass, waste coal, and oil shale to name a few.

Table I

Coal in electricity generation

South Africa 93%	Poland 92%	PR China 79%
Australia 77%	Kazakhstan 70%	India 69%
Israel 63%	Czech Rep 60%	Morocco 55%
Greece 52%	USA 49%	Germany 46%

Source: IEA 2010

* *Foster Wheeler Global Power Group.*

 This paper was first presented at the, Industrial Fluidization South Africa Conference, 16–17 November 2011, Cradle of Humankind, South Africa.

There have been three significant milestones related to utility steam generators achieved by Foster Wheeler in the last few years. The first came in 2009 with the successful completion and commercial operation of the world's largest and first supercritical CFB, the Łagisza 460 MW_e CFB OTSC BENSON vertical tube design in Poland. The project was originally specified as a PF unit but the supercritical CFB was selected as an alternative due to the CFB's ability to burn a wider range of fuels, which favourably impacted the life cycle economics. The second is the Longview 760 MW_e supercritical PF BENSON vertical ribbed tube (VRT) design, which has recently been put into successful commercial operation in Madisonville, Virginia in theUSA. The third is the recent contract awarded for four 550 MW_e supercritical CFB BENSON vertical units to be supplied to Korea Southern Power Company (Kospo) for their Samcheok Green Power project in South Korea. This project features a '2 on 1' configuration of two each 550 MW CFB units on a single 1000 MW turbine with two separate 1000 MW power blocks. The significance of the Samcheok Project is that it was awarded based upon the favorable environmental features and economics of the CFB units in straight-up competition with two single 1000 MW PC units on two single 1000 MW_e turbines.

Trend to higher efficiency generation

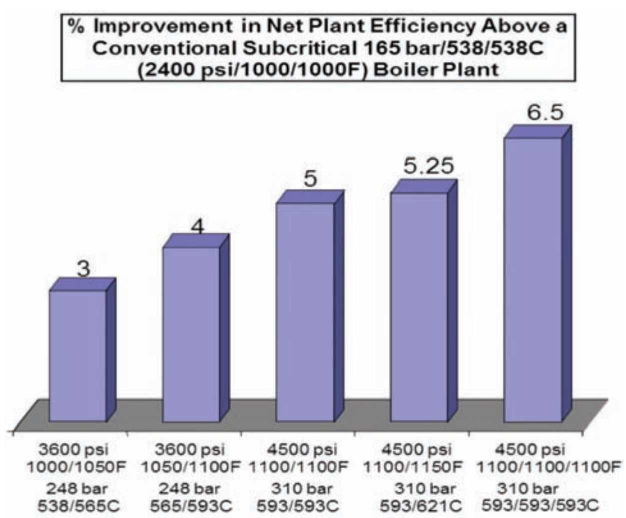
In today's expanding coal generation markets, the trend is to install larger 660 MW to 1000 MW single or multiple PF units with once through supercritical (OTSC) technology with steam pressures approaching 300 bar and temperatures around 600°C. The advantage of using increasingly higher efficiency steam cycles is to improve net plant heat rate, which essentially produces the same amount of electricity with reduced fuel usage, reduced emissions to the atmosphere (CO_2, SO_X, NO_X, Hg, and dust), while also reducing operation and maintenance (O&M) cost. Figure 1 illustrates the improvement in net plant heat rate as the steam temperature and pressure is increased from sub-critical to supercritical conditions.

Technology comparisons

The differences between the PC and the CFB are shown in Figure 2 for a supercritical design. Although the heat recovery areas of the boilers are similar, with the exception of the reheat steam temperature control scheme, major differences can be seen in the furnace sections. One major difference is that the CFB utilizes a continuous hot solids return system to the furnace, which offers many advantages. The CFB hot solids circulating system acts as a thermal 'flywheel' which increases solids retention time, resulting in good carbon burnout and homogeneous heat flux throughout the furnace and return system. A couple of key benefits of this thermal flywheel effect are:

a) Capability of burning a wider range of fuel
b) Ability to tolerate variations in fuel quality on a 'real-time' basis.

This alone favourably affects the variable O&M economics. While the PC uses rotating mills and transport air to deliver fuel to multiple levels of burners to fire the pulverized fuel, the CFB boiler uses startup burners for initial warm up, then when reaching a solid fuel temperature permit the solid fuel is gravity-fed to the units with virtually no flame present. The combustion temperature remains fairly constant between 875–925°C.



Source: FW Internal Modeling

Figure 1—Improvement in net plant heat rate with increasing steam temperature and pressure

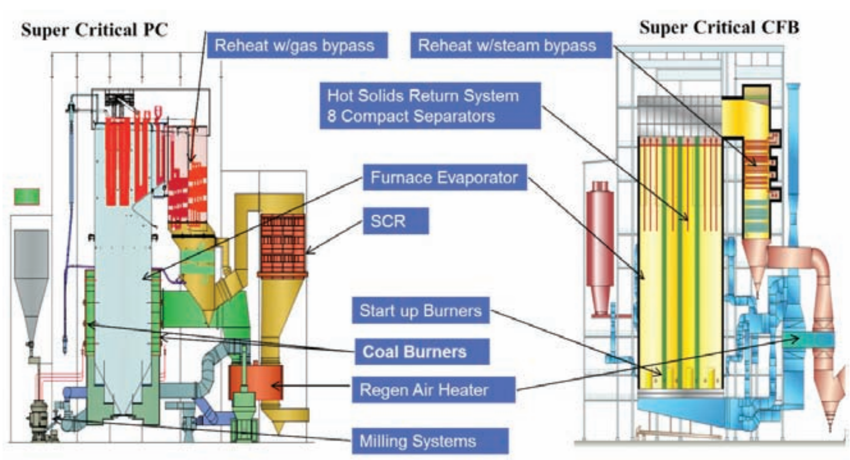


Figure 2—Comparison of the features of the largescale OTSC PC and OTSCCFB

The difference in combustion temperature between the boilers is dramatic, as shown in Tables II and III. The lower combustion temperature in the CFB generates much less thermal NOx, while also producing a more even temperature profile in the furnace compared to the PC unit.

The comparison of the attributes in Tables II and III shows why many utitlities favour the CFB as a technology choice, especially in today's utility generation climate given the concerns for carbon emissions balanced against the economics of power made available to meet regional demand.

The difference in the heat flux profiles between the two technologies is shown in Figure 3. The heat flux comparison illustrates the difference in design requirements for evaporator tube cooling of the CFB versus the PC. Both units utilize Foster Wheeler's BENSON low-mass flux evaporators, although there is less tube–to-tube differential temperature in the CFB, which reduces heat stresses to the boiler tubes and enhances the long-term reliability. The graphic shown below the heat flux graphics plots the heat flux input of the CFB compared to the percentage of PC wall-fired and PC arch unit heat flux as a function of furnace height. The peak fluxes of the PC units are in the burner zones, while the CFB heat flux is fairly constant throughout the furnace.

Drivers to consider

PC - steam coal readily avaiable

A good example of drivers that would influence the selection of a PC over a CFB would be high availabilty of a local steam-quality low-sulphur coal with relatively relaxed emission

Table II

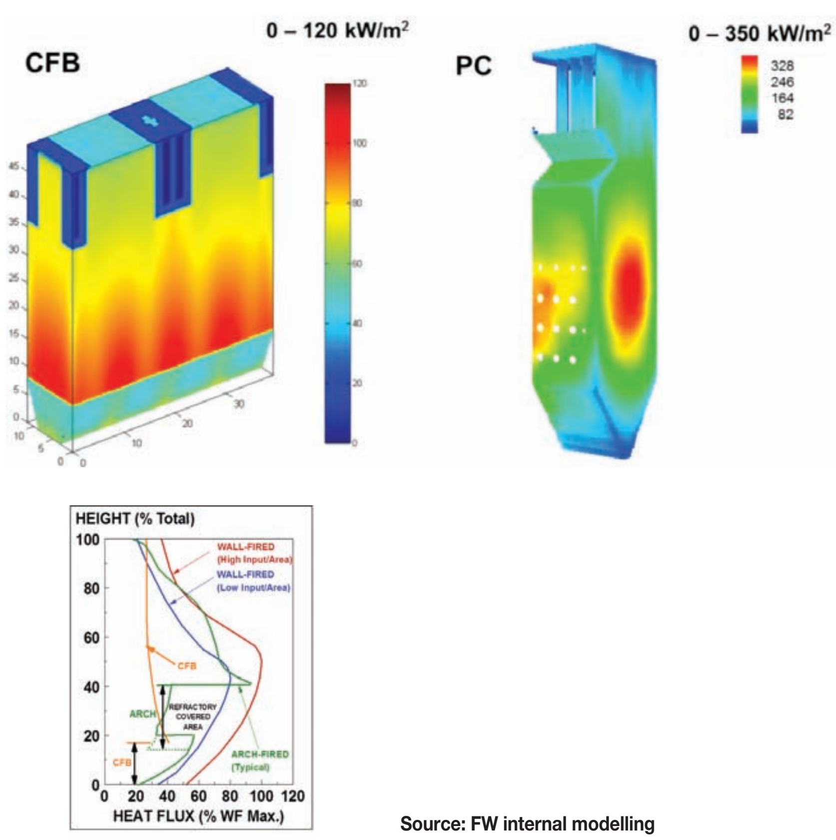
PC attributes

- Combustion temp 1300–1400°C
- In-furnace soot blowers normal practice
- Melting ash could cause potential slagging in furnace
- Fast burn
- Open flame
- Achieving reasonable NO_x levels require low NO_x burners with SCR
- No sulphur retention in the furnace
- Greater possibility of heat-related tube damage due to higher temperature differentials between water and flame and high heat flux in the burner zone
- Sensitive to sudden changes in fuel quality

Table III

CFB attributes

- Combustion temperature 850–900°C
- No furnace slagging
- No furnace soot blowing
- NO_x formation reduced due to staged combustion – SNCR add- on simple
- SO_2 retention simple by adding limestone into the furnace
- SO_x capture
- Flue gas temperature profile homogenous throughout the furnace lowers stress due to reduced differential temperature between gas and water side
- Insensitive to sudden changes in fuel quality
- Long residence time for good carbon burn out



Source: FW internal modelling

Figure 3—CFB vs. PC heat flux comparison

requirements (e.g. SO_X limits above 2000 mg/Nm³ and NO_X limits above 750 mg/Nm³). In other words, no selective catalytic redcution system (SCR) or flue gas desulphurization (FGD) system would be required on the back end of the PC unit in this example. In this example, there may be at first a slight cost advantage in selecting the PC over the CFB. However, if required to ratchet down emissions at some future date, there are substantial retrofit capital costs that would have to be accounted for in the analysis of lifecycle costs of the plant. With scrubber costs in the range of US$125–$270 per kilowatt for new units, it could cost as much as US$500 per kilowatt to retrofit units.

CFB - low emission requirements/lower fuel quality available

On the other hand, if the emission requirements were much lower, e.g. below 200 mg/Nm³, and there is reasonable access to lower quality fuel with a higher sulphur content and lower heating value or higher ash, this could easily favour the CFB because of its ability to burn lower quality fuels while maintaining low emissions without the addition of the SCR or FGD systems that would be necessary for a PC. For a clearer understanding of the differences in fuel burning capability of each technology, refer to Figure 4, which it compares the fuel burning range in heating value versus the burning difficulty of most of today's fuels. Note the fuel range of the PC in the black circle, as compared to the range of the red rectangle for the CFB. This clearly shows the fuel flexibility of the CFB. When this flexibility is coupled with with the ability to burn or blend lower-cost fuels, the economics clearly favour the CFB.

Economic analysis

A recent Foster Wheeler study was completed comparing the economics of PC and CFB technolgies. The results of this study are summarized in Table IV. This analysis compares the two steam generator technologies for a plant configured for an output of 660 MW_e. The base technology is a PC compared with a CFB for three different fuels, all using supercritical steam cycles.

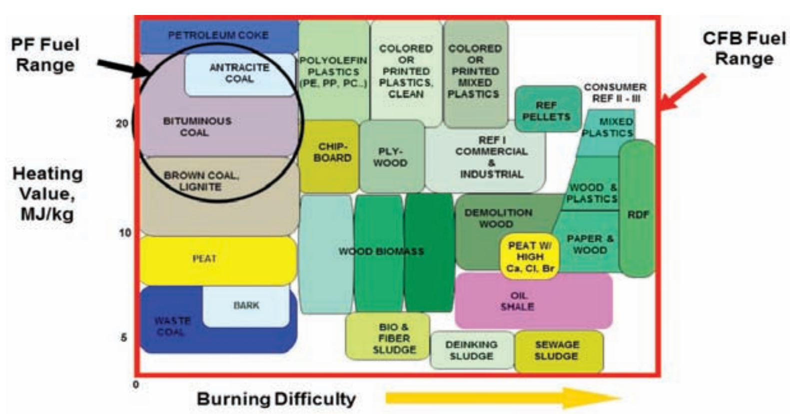


Figure 4—Fuel heating value. burning difficulty

Table IV

Power plant case assumptions

Case	Units	1"	2"	3"	4"
Plant type		PC	CFB	CFB	CFB
Steam cycle technology		Supercritical OTU	Supercritical OTU	Supercritical OTU	Supercritical OTU
Additional economical fuels plant can utilize			All coals, petcoke, biomass	All coals, petcoke, biomass	All coals, petcoke, biomass
Additional pollution control requried		Dry FGD + SCR			Dry FGD
Plant gross power capacity	MW_e	660	660	660	660
Plant net power capacity	MW_e	595	594	594	591
Plant utilization factor	%	90	90	90	90
Plant net efficiency	% HHV	40	40	40	40
Fuel		6000 kcal coal	6000 kcal coal	4900 kcal coal	Petcoke
Fuel sulfur content	%	0.8	0.8	0.2	6.0
Fuel cost	$/Mbtu	4.2	4.2	3.9	2.0
Fuel cost	$/tonne	100	100	75	60
Electricity production cost	$/MWh	101	96	92	81
Savings in electricity production cost	$/MWh	Base	5	9	20
Annual savings in electricity production cost[1]	M$/year	Base	23.45	42.15	93.19
Plant EPC capital cost	$/KWe	2150	2000	2000	2100
Additional plant EPC cost savings	B$	Base	-0.09	-0.09	-0.03

Note 1 - Assumes 595 MW_e continuous output for 90% of the time

Source: Foster wheeler internal study

The coal used in the example for the PC is a typical 6000 kcal/kg steam coal. The supercritical CFB comparison in column 2 is based upon utilizing the same coal as the supercritical PC. Note there is a few per cent decrease in electricity production costs, but an almost US$150 per kilowatt reduction in capital cost for the CFB because of the FGD system required for the PC. The economics of burning a lower heating value coal in a CFB is shown column 3, and a typical petroleum coke in column 4. The data clearly shows that the CFB option can offer increased value for power production as compared to the PC, especially when burning a lower grade fuel or petroleum coke. The CFB petcoke-fired unit's production cost is US$20 per megawatt-hour less than that of the PC unit firing the 6000 kcal coal.

When the advantage of fuel arbitrage for the CFB is added, as shown in Table V for the 600 MW example, not only is the capital cost reduced due to less equipment being required (no FGD + Denox), but there is potential for a US$14.6 million per year fuel saving with a 10 year NPV of US$95 million. This saving can be even greater when burning even lower grade fuels or blends of waste fuels and biomass, for example.

Conclusions

Historical pricing and future global coal price projections continue to put pressure on solid fuel plant economics. However, the trends also suggest that in the long term, pricing will drop from the current peak of around US$110 per ton FOB and settle in at around $80 per ton FOB in about 5 years. After that, global pricing is predicted to be stable for the next 15 years or so. Since fuel is the largest contributor to a plant's operating costs, fuel supply agreements will always play a significant role in the financial success of a given project. A key selection driver to make the case for either technology will be the fuel security issue. Fuel uncertainty tends to favor CFB technology.

The case for pulverized coal

The PC (PF) boiler has been the standard for large coal-fired utility plant applications for the past several decades. The units have proven reliability, and when coupled with the right air-quality control systems (AQCS) can achieve the lower standards of emissions required in many of the global utility markets today. Additionally, with the increasing demand for better efficiency, PF units are readily avaialbe with supercritical steam parameters. The success of the Longview 760 MW_e supercritical PF project has proven the BENSON VRT technology is a viable solution for today's supercritical PC application. In most developed countries the emissions requirements dictate the inclusion of a selective cataytic reduction (SCR) system as well as either a dry flue-gas desulphurization system (FGD) or wet FGD in additon to back-end particulate collection systems, all of which form the full AQCS. It is likely that the PC will continue to be strongly considered when looking at today's plant requirements, and will continue to be favoured when steam-quality coal is readily available in long-term contracts within the defined limits of heating values, ash content, moisture content, sulphur content, and especially ash fusion temperatures. However, if the orginal design fuel is not consistently available then there are extreme challenges in PF firing when fuel switching is driven by economic factors. In other words, the PC becomes limited as to which fuels can be fired without making expensive modifications to the boiler to accommodate the new fuels.

The case for CFB

The CFB, on the other hand, is not severely limited by the quality of fuel which can be fired, based on the original design. In other words, the favourable economics of the CFB come into play when an owner can purchase different quality fuel than originally designed for, as discussed earlier in this paper. The CFB boiler has long been viewed and accepted in the industry as viable technolgy in the 20–350 MW_e sub-critical class units. As shown in Figure 5, the Foster Wheeler CFB has steadily grown to larger sizes with supercritical and ultra-supercritical steam values. It should also be noted that while incrementally increasing steam output, the Foster Wheeler CFB has never had an issue related to scale-up in its development history.

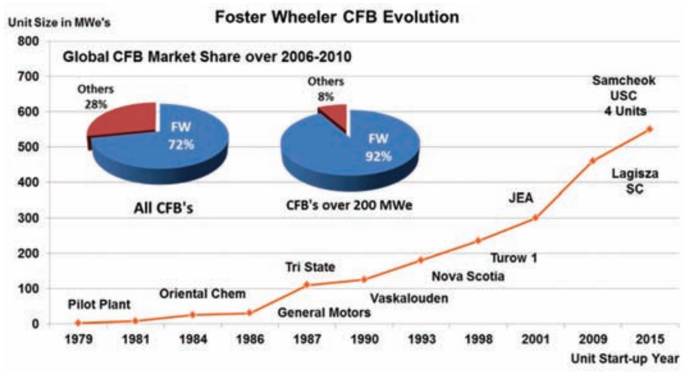
The Łagisza CFB unit in Poland has successfully demonstrated once-through supercritical (OTCS) technology and validated the Foster Wheeler design plaform for the larger 550, 660, and 800 MW_e units. While the Łagisza CFB unit competed directly with a PC unit in the intial international bid tender and won, it is also significant to note that the Kospo Samcheok project OTSC CFBs were selected as the preferred technology over the PC due to the multiple fuel capability and favorable emission flexibility, as well as reduced variable O&M costs.

Table V

600 MW_e net CFB supercritical plant operating at 90% capacity factor

Plant parameter	Units	6000 kcal South African coal	4900 kcal Indonesian sub-bituminous coal	Annual fuel arbitrage ($/year)	10 year NPV fuel arbitrage ($)
Plant net power	MW_e	600	600		
Fuel cost	$/metric ton	100	75		
Fuel heating value	kcal/kg	6000	4900		
Fuel heating value	MJ/Kg	25.1	20.5		
Plant capacity factor	%	90%	90%		
Fuel consumption	Metric ton/year	1 689 152	2 057 166		
Fuel cost	$/year	168 915 200	154 287 450		
Difference in fuel price				$14 627 750	$95 008 129

Source: Foster wheeler model



Source: Foster Wheeler sales database for Foster Wheeler-served markets

Figure 5 –Evolution of the Foster Wheeler CFB

- 4 × 550 MW_e CFBs powering 2 × 1000 MW_e steam turbines
- Advanced ultra supercritical vertical tube steam technology
- 603/603°C steam temperatures
- Firing a wide range of import and domestic coals
- Commercial operation expected
- Units 1 and 2: mid-2015
- Units 3 and 4: end of 2015.

Proven advances in supercritical/ultra-supercritical CFB technology now clearly provide competition for large-scale utility PC offerings in the 500 MW to 1000 MW size ranges. The competitive pricing and fuel flexibility offered by the OTSC CFB can bring certainty to the invesment decision by utility plant owners, especially given the uncertainty in predicting future global fuel costs and availability. The OTSC CFB can capitilize on fuel arbitrage and opportunity fuels while providing highly competitive value and reduced emissions for many years into the future. ◆

Figure 6—The Kospo Samcheok Project – 4 × 550 MWe SC CFBs