The Growing Experience of Fuel Flexible Circulating Fluidized Bed Technology in Large Scale Power Generation
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Abstract

The use of Circulating Fluidized Bed (CFB) combustion technology is growing strongly in large utility power plant applications. It has now reached sizes and efficiency levels never imagined by many executives of utility power companies.

This paper will explore the market drivers and technology advancements which allowed CFB boiler technology to grow from small-scale industrial applications to large ultra-supercritical power plants in less than 20 years.

The CFB’s fuel flexibility is the primary driver behind the decisions of many power company executives for selecting CFB boiler technology over conventional PC technology. This is due to a growing uncertainty in the global coal market and a trend of declining coal quality vs. attractive price discounts.

However, fuel flexibility means more than just being able to burn a wide range of coals and biomasses. It also means that plant reliability, maintenance, ease of operation, and stack emissions are not significantly impacted over the wider fuel range. Design features of SHI FW’s CFBs will be reviewed and compared to conventional PC boiler technology showing how they contribute to high reliability, low maintenance, and cost effective designs.

This paper will also provide an updated review of some of the largest and most advanced CFB plants around the world. Examples would be Tauron’s 460 MWe supercritical CFB Lagisza power plant in Bedzin, Poland successfully running since 2009 and the 2,200 MWe ultra-supercritical CFB plant in Samcheok, South Korea, currently in its commissioning phase.

Why is CFB Technology Growing So Strongly in the Utility Power Sector?

Circulating Fluidized Bed (CFB) combustion technology has been around for over 40 years; however, over the last 10 years its use in large utility power plants has grown strongly. It has now reached sizes and efficiency levels never imagined; drawing attention from utility power companies around the world.
Figure 1. Lagisza CFB Power Plant located in Bedzin, Poland

Figure 1 shows the most advanced CFB power plant operating in the world today, located at Tauron’s Lagisza power plant in Bedzin, Poland which has been successfully running since 2009. At the heart of the plant is a single 460 MWe supercritical SHI FW CFB featuring many unique first-of-a-kind design features and a very impressive net plant LHV efficiency of 43.3%. But, its most profound feature is that this plant meets its permitted stack emissions without SCR or FGD equipment, saving Tauron over $100 million in its construction cost.

An even more impressive example is the 2,200 MWe Green Power Plant currently under commissioning in Samcheok, South Korea, shown in figure 2. The Samcheok plant has four larger 550 MWe SHI FW CFBs utilizing ultra-supercritical steam conditions (257 barg, 603/603°C). The Samcheok plant will meet even tighter stack emissions without using FGD equipment, saving Korea’s Southern Power Company (KOSPO) over $250 million in construction cost. These CFBs are now the most advanced units in the world.
How did the CFB go from Small Industrial Units to a 2,200 MWe Ultra-Supercritical Power Plant?

The answer is just two words: Fuel Flexibility.

CFBs were originally developed as a solution for industrial facilities with a need for steam and power combined with sources of unwanted by-products, such as: waste bark, wood, plastic, cardboard, paper, and sludge's. Over the last 20 years, SHI FW has broadened the CFB’s fuels range and unit size so much that many power companies took notice and saw the CFB as a way to produce low cost power from low quality fuels such as brown coals, lignites, and waste coals, as well as, high-energy, hard-to-burn fuels like anthracite and petcoke.

Conventional PC boilers have trouble accepting these off-spec fuels due to their narrow fuel specs typically calling for heating values above 5500 kcal/kg, ash and moisture levels below 30%-35%, and volatility’s above 20%. However, this is not the case for CFB technology due to its capability of burning both the worst and best coals and lignites with heating values ranging from 1000 to 8500 kcal/kg, ash and moisture levels as high as 60%, and volatilities down to 5%, as shown in figure 3.

Meeting a Market Need

Large, utility scale CFB power plant references are growing just in time to meet the challenge of declining quality in internationally traded coals and to support the growing use of economical, low-quality and hard-to-burn domestic fuels in many countries.
Since 2005, Indonesian coal exports have grown faster than coal exports from all other countries combined, nearly quadrupling to over 400 million metric tons over the last few years (see figure 4) and projections show Indonesia maintaining its dominant position in the world’s global coal market over the long term.

However, today about 50% of Indonesian coal exports consists of high-moisture, sub-bituminous coals with gross-as-received (GAR) higher heating values ranging between 3900-4200 kcal/kg. Further, the best quality Indonesian coal reserves are expected to produce coals with average heating values no greater than 5200 kcal/kg (with economical washing levels). These heating values are well below the 6000 kcal/kg benchmark used in the international coal market for the last 50 years.

The primary driver for the ballooning of Indonesian coal trading is simple economics. Even after accounting for the difference in heating value, on a comparative energy basis, Indonesian coals offer 15-40% discounts as compared to premium coals (see figure 5), which goes right to the bottom line of a power plant’s balance sheet. Since fuel makes up 75%-85% of the operating cost of a large power plant, the economic benefits of using low quality fuels are tough to ignore.
However, there is another trend that needs mentioning, which is, the steady decline in heating value of Indonesian export coals; a trend expected to continue well into the future, as shown in figure 6. Typically, as coal mines mature, mining operations move to lower quality coal seams. To save cost and reduce coal waste pile-up, mining companies will sell the higher ash and moisture fuels to the market at very attractive discounts, instead of increasing coal washing to maintain heating value.

![Average Gross Heating Value of Indonesian coal exports](image)

Figure 6. Average Gross Heating Value of Indonesian coal exports. Source: Marketing, Sales and Logistics Analyst, Banpu PCL

We also see the growing use of low quality fuels in several domestic markets as well, where low quality coals and lignites play a major role in power production. For example, 38% of Turkey's solid fuel power capacity utilizes low quality lignite, sub-bituminous and waste coals, while in Germany and the US this number grows to 45% and 49% respectively. Today, nearly all new-build coal projects in Turkey will solely utilize low quality Turkish lignite.

In addition to Turkey, use of low rank coals, lignites and petcoke for power production are growing in India, China, Indonesia, Philippines, Australia, and South Africa driven by better economics, lower fuel price volatility and higher fuel supply security. Further, the use of biomass for power production is growing in many countries to reduce net carbon emissions and meet future global warming targets.

This trend is not expected to change anytime soon. Instead it looks to be a permanent shift toward a more flexible solid fuel market, where buyers and sellers will trade fuel quality for price, very similar to many other commodity and finished good markets. These expanding low quality solid fuel markets across the globe have dramatically increased the value of fuel flexibility for large scale power plants and have been the primary driver behind the large CFB power plants coming on-line over the last 10 years.

Fuel flexibility can add up to huge operating cost savings over the life of a power plant. Figure 7 shows the savings in plant operating cost that can be realized for a 600 MWt coal plant by buying discounted lower quality fuels. Whereas, a power plant with a narrow fuel spec would be competitively disadvantage by a higher average fuel cost, limiting its dispatch and financial return.
Figure 7. Operating cost saving for 600 MWe supercritical coal plant with 90% annual capacity factor firing 70 $/tonne (5500 kcal/kg) coal as base fuel. NPV based on 30 year term and 5% discount rate.

In addition to fuel flexibility, the CFB also provides emission flexibility. It can achieve low air emissions without post combustion SCR NOx and FGD SOx control saving significant plant construction and operating cost over life of the power plant. This flexibility is important since emission regulations are continually tightening in nearly all countries.

To sum up the CFB’s value as compared PC, table 1 adds up both the capital and operating cost savings for each of the fuel and emission issues discussed above. The results show that the CFB can deliver over four times the value as compared to PC boiler technology.

<table>
<thead>
<tr>
<th>Technology Value Points (M$)</th>
<th>PC</th>
<th>CFB</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler cost savings</td>
<td>60</td>
<td></td>
<td>Installed boiler cost saving of PC without SCR compared to CFB boiler, with both firing the same 4500 kcal/kg sub-bituminous Indonesian coal. Savings based on average 100 $/KWe discount for PC seen in market pricing over 2015-2016 period.</td>
</tr>
<tr>
<td>Fuel flexibility</td>
<td>156</td>
<td></td>
<td>NPV of fuel cost savings for CFB assuming average 10 $/tonne fuel cost discount over 30 year plant life due to CFB’s ability to fire lower quality fuels. Based on 50/40 $/tonne (4500/4000 kcal/kg) coals.</td>
</tr>
<tr>
<td>SCR cost savings</td>
<td>36</td>
<td></td>
<td>NPV cost saving for avoiding SCR in CFB to achieve 200 mg/Nm3 stack NOx emission. Based on a 40 $/KWe installed SCR cost for PC plus 30 year NPV of SCR operating expenses.</td>
</tr>
<tr>
<td>Post boiler FGD savings</td>
<td>39</td>
<td></td>
<td>NPV cost savings for avoiding post boiler FGD for CFB plant to achieve 400 mg/Nm3 stack SO2 emission. Based on 60 $/KWe installed seawater scrubber cost for PC plus 30 year NPV of FGD operating expenses.</td>
</tr>
<tr>
<td>Biomass co-firing</td>
<td>35</td>
<td></td>
<td>NPV of future CO2 credits. Based on 10% biomass co-firing in CFB and average 10 $/tonne for future CO2 credit value over 30 year plant life.</td>
</tr>
<tr>
<td>Total Value (M$)</td>
<td>60</td>
<td>266</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Value comparison of 600 MWe CFB vs. PC plant. NPV based on 30 year term and 5% DR.
**Fuel Flexibility is No Good without Plant Reliability**

Plants with SHI FW CFBs have demonstrated plant availabilities well above conventional PC boilers over a wider fuel range. Figure 8 shows the results from a study comparing PC plant availabilities to plants utilizing SHI FW CFBs.

![Average Annual Plant Availability](image)

Figure 8. Results from Reliability study of PC vs. CFB Power Plants. *Availability means total time plant is available to run accounting for both planned and unplanned downtime. The SHI FW CFB availability values were based on data reported by plants in Europe over 2000-2008, whereas, the PC values were reported over 2002-2012 in VGB’s PowerTech 2012 Report, TW103Ve. PC plants co-firing anthracite, brown coals, lignite, etc. do not exist and therefore not shown in the chart.

As shown by figure 8, the plants with SHI FW CFBs had about a 5% higher availability than the PC plants. This higher availability difference was maintained for even brown coals and lignites which can translate to over a $250 million NPV gain in net income over the life of a 600 MWe power plant, as shown in figure 9.

![Loss in Plant Income for 600 MWe Coal Plant (M$)](image)

Figure 9. Impact of plant utilization factor on annual plant net income of 600 MWe supercritical coal plant firing 50 $/tonne (4500 kcal/kg) Indonesian coal, selling power at 100 $/MWh at a base 90% capacity factor. Plant Capacity Factor = Actual electricity produced by plant/ possible maximum (600 MWe x 8760 hrs). NPV based on 30 year term and 5% discount rate.
**CFB’s Fuel Flexibility comes from its Unique Combustion Process**

The CFB’s fuel flexibility is rooted in its unique flameless, low-temperature combustion process. As shown in figure 10, unlike conventional pulverized coal (PC) or oil/gas boilers, instead of an open flame, circulating solids are used to achieve high combustion and heat transfer efficiency to burn a wide range of fuels. The fuel’s ash does not melt or soften which allows the CFB to avoid the fouling and corrosion problems encountered in conventional boilers.

From an environmental aspect, the low temperature CFB combustion process minimizes NOx formation and allows limestone to be fed directly into the furnace to capture SOx as the fuel burns. In most cases, a SCR and FGD are not needed for NOx and SOx control, dramatically reducing the plant’s construction, operating cost and water consumption while improving plant reliability and efficiency.

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**Figure 10. Comparison of PC vs. CFB combustion process**

**Furnace Size vs. Fuel Quality**

Since the fuel's ash doesn’t soften or melt in a CFB, the size of the furnace doesn’t grow as much as PC boilers when firing lower quality fuels. As can be seen in figure 11, in order to control fouling, slagging and corrosion, PC furnace height increases by 45% and its footprint increases by over 60% when firing low quality fuels like high sodium lignite, whereas, the CFB boiler height increases by only 8% and its footprint increases by only 20%. This results in a smaller and lower cost CFB boiler as compared to the PC boiler for lower quality fuels.

Further, unlike a PC, a CFB doesn’t need soot blowers to control the build-up of deposits and slag in the furnace since the circulating solids keep the furnace walls, panels and steam coils clean for the most efficient heat transfer.
**Superheater and Reheater Design Considerations**

Another very important feature of the CFB involves the final superheat and reheat steam coils. These coils operate at the highest metal temperatures in the boiler making them the most vulnerable to corrosion and fouling attack. This vulnerability increases significantly for supercritical boilers with high steam temperatures.

![Figure 11. PC vs. CFB - Impact on furnace size as fuel quality degrades](image1)

![Figure 12. PC vs. CFB boiler design feature comparison](image2)
In a PC or oil/gas boiler, these coils are hung from the furnace ceiling and are directly exposed to the slagging ash and corrosive gases (sodium and potassium chlorides) in the hot furnace flue gas. To cope with this undesirable situation, boiler designers use costly high grade alloys and recommend a high level of cleaning and maintenance for these coils.

As shown in figure 12, this design weakness is avoided in SHI FW’s CFBs by submerging these coils in hot solids, fluidized by clean air in heat exchanger compartments called INTREXs, protecting them from the corrosive flue gas. The bubbling hot solids efficiently conduct their heat to the steam contained in the coils and since the solids never melt or soften, fouling and corrosion of these coils are minimal. Further, due to the high heat transfer rate of the solids (via conduction heat transfer), the final superheat and reheat coil sizes are many times smaller than the pendent and convective coils in PCs saving more capital and operating cost.

**Fuel Delivery System**

One last important design feature is the fuel delivery system to the boiler. A PC boiler requires coal pulverizers to grind the coal to a powder which is then pneumatically transported and distributed in coal pipes to many burners. For low quality, high ash fuels, like brown coals and lignites, the initial cost, maintenance and power consumption of the fuel pulverizers increase dramatically while the reliability of the entire fuel delivery system declines.

For a CFB, these issues are avoided since pulverizers are not needed. The fuel is only coarsely crushed by primary crushers in the fuel yard, once in the boiler island fuel silos, the fuel is fed to the CFB via a simple gravity feed system. Figure 13 shows a typical fuel feed system for an SHI FW CFB.
**Important Points to Remember**

The traditional fixed 6000 kcal/kg global steam coal market has moved to a more flexible “price vs. quality” market dramatically increasing the value of fuel flexibility for large scale power plants and has been the primary driver behind the large Circulating Fluidized Bed (CFB) power plants coming on-line over the last 10 years.

Pulverized coal (PC) power plants with tight coal specifications will have a limited ability to capitalize on the growing supply of discounted coals, domestic lignites, waste coals and petroleum cokes. These plants will have a choice to stay within the premium steam coal market or venture into the broader market and trade fuel price discounts for lower plant output, reduced reliability and higher plant maintenance cost.

This is not to say that new PC boiler power plants can’t be designed to burn these low rank fuels, because they can. The point for consideration is that once a PC is designed for a specific low rank or hard-to-burn fuel, it is difficult to burn other fuels without negatively impacting plant performance, reliability and maintenance.

However, power plants utilizing CFB boiler technology allows power generators to fully capitalize on fuel cost savings by accessing the full range of discount coals, lignites, and other low rank solid fuels (even for ultra-supercritical designs); buying fuels for maximum economic benefit with little impact to their plant’s performance, maintenance and reliability.

For countries with domestic low rank coals, lignites, waste coals or hard-to-burn fuels, like anthracite and petcoke, the CFB opens the door to affordable and secure power over the long term while lessening the risk of future carbon regulation due to the CFB’s ability to utilize biomass and other carbon neutral fuels.