FUEL QUALITY FOR FLUIDIZED BED COMBUSTORS

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Introduction

When the fluidized bed combustor (FBC) was introduced to America, it was hailed as the savior of the high-sulfur, high-ash coal market. The design of fluidized bed combustors allows the use of very low grade fuels; and it can provide good sulfur control. In addition, FBC's generally require lower capital than equivalent-sized pulverized or stoker-fired boilers equipped with scrubbers. This is especially true for medium-sized boilers designed to serve the industrial and cogeneration markets. This lower capital cost makes the FBC the most popular boiler sold today. As more FBC's are operated, more experience with different fuels is gained. The industry is learning that fuel quality can significantly impact the cost of operating FBC's. It is being determined that if ash disposal costs are high and/or the units are located far from coal producing fields, then higher quality, lower sulfur coals can be the most economical FBC fuels.

Coal Quality Impacts

As with conventional combustion systems, the quality of the coal burned in an FBC can have a significant effect on boiler equipment and operation costs. There are many different types of FBC's, for example, bubbling-bed or circulating. Generally, circulating FBC's have greater fuel flexibility than the bubbling-bed type. Several U.S. manufacturers are listed in the references.[1–6] A general introduction to FBC's is given in Thomas and others.[7]

Several important fuel impact areas are listed in Table 1. In general, coals with lower moisture, ash, and sulfur perform better, require less material handling, and cause less wear and tear on the equipment. When these parameters are taken into account, the delivered cost of coals can be evaluated to represent a true cost of utilization. The evaluated cost of a coal can be approximated using simple spreadsheet calculations.

Availability and Maintenance

In areas such as unit availability and maintenance, costs are presently hard to predict due to the limited operational experience of FBC's. There have been several studies conducted on pulverized and cyclone-fired units that have correlated higher sulfur and ash to lower unit availability and higher maintenance cost.[8,9] A similar relationship should exist for fluidized bed combustors. Typically, the relationships are exponential in nature once a critical point is reached. Examples of these critical points include: an ash removal system that cannot keep up with ash production, tube leaks due to ash erosion or high stack opacity due to overloading of particulate collection devices.

Example Cost

An analysis of two different quality coals is shown in Table 2. Coal A represents a typical Illinois Basin raw coal and Coal B is a raw strip fuel from Central Appalachia. These coals will be used in an example coal evaluation. The power plant under consideration is located in a non-coal producing state approximately 500 miles from the two coal sources. The facility will produce 100 megawatts using a circulating fluidized bed combustor. Table 3 lists the estimated assumptions used for economic and technical considerations.

Fuel Costs

The cost of coals today can vary widely due to quality differences, and more importantly, market conditions. The market is still in an over-supply situation which results in depressed prices on all coals. The present premium for low sulfur coal is small, and in some markets doesn't exist. The fuel costs shown in Table 3 have been altered slightly to widen the low/high sulfur differential. This situation would exist for longer term contracts in anticipation of some form of "acid rain" legislation. The transportation cost was based on equivalent mileage. In reality, there could be a difference in the transportation due to market conditions. The delivered cost of the high sulfur coal is $7.00 per ton less, or to remove the Btu differential, $0.09 per million Btu less than the low sulfur coal. This represents an annual savings of about $750,000 when utilizing Coal A over Coal B. However, this savings does not take into account the differences in qualities such as ash and sulfur. A simple look at these may show that Coal B is actually the lowest cost fuel.

Material Handling—Coal

The unit will require approximately 8.4 trillion Btu's per year. The following annual tonnages of each coal would be required:

Coal A: 382,000 tons/yr
Coal B: 336,000 tons/yr

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Table 1. FBC equipment and operational areas affected by coal quality

Coal lime and refuse handling equipment and storage facilities
Refuse disposal
Boiler size and design
Boiler efficiency/Heat rate
Fans
Particulate removal equipment
Availability
Maintenance costs
SO_x emissions
Heat exchanger material

Due to Coal A's lower heating value, an additional 46,000 tons of coal would have to be purchased to equate Btu's.

Coal handling charges cover the cost of unloading, stockpiling, reclaiming, and bunkering the coal. They typically fall into the $1–3.00/ton range depending on the amount of coal and the type of equipment. If smaller and/or less heavy equipment is required, or a car shaker versus a rotary dumper can be utilized, substantial capital savings can be realized. In addition, less man-hours are required to move the coal. An example cost of $2.00/ton results in an annual savings of $92,000 due to the higher heating value of Coal B.

Material Handling—Limestone

The limestone requirements for Coal B are lower due to the lower sulfur, even though it may require a higher calcium-to-sulfur ratio (Ca/S) to maintain 90% sulfur capture. Using 90% $CaCO_3$ limestone, a 2.5 Ca/S for Coal A, and a 3.5 Ca/S for Coal B, the following annual limestone requirements are calculated:

Coal A: 116,000 tons/yr
Coal B: 37,000 tons/yr

The differential limestone requirements are substantial. At the $2.00/ton charge used for coal, Coal B represents a limestone handling savings of $158,000. The material costs are even more significant. At $10.00/ton for limestone, Coal B has an annual savings of $790,000, over the higher sulfur coal.

Material Handling and Disposal—Ash and Refuse

The annual ash and refuse quantities are estimated below for the two coals:

	Ash Tons/Yr	Refuse Tons/Yr	Total
Coal A	50,000	101,000	151,000
Coal B	27,000	30,000	57,000

As shown above, Coal A generates almost three times the amount of refuse material as Coal B. Again, there would be considerable down sizing of the handling and storage equipment for Coal B. Typical cost for ash disposal in a close proximity land fill would be around $3–7.00/ton, including transportation. If the material must be taken some distance or returned to the mine site, these costs can soar to $20.00+/ton. In some cases, a usable by-product can be generated in which the disposal costs can be avoided or the material sold. Unfortunately, even if the material is sold the capital equipment costs and the wear and tear on the equipment can outweigh using a higher sulfur/ash fuel. For our example in this paper, the disposal cost was set at $5.00/ton, or a differential savings of $470,000 annually.

Table 2. Coal analysis of example coals

	Coal A	Coal B
Moisture	13.0	7.0
Ash	13.0	8.0
Sulfur	3.5	0.9
Btu/lb.	11,000	12,500
Carbon	59.0	71.0
Hydrogen	4.4	4.5
Nitrogen	1.3	1.4
Chlorine	0.15	0.06
Oxygen	5.7	7.1
Fusion—S.T. Red.	2000°F	2700+°F

Boiler Efficiency

Coal quality can affect the boiler efficiency in several ways. The most significant in our example is the moisture in the flue gas produced from the moisture in the coal, and from the combustion of hydrogen in the coal. Another is from the carbon loss in the ash or incomplete combustion. For this example the carbon in the ash was set at 5%. Carbon in ash can be approximated by the loss on ignition (L.O.I.) test. Because the two coals have different amounts of ash, with the same carbon content there is less carbon loss with Coal B, the lower ash coal. Using an abbreviated form of the heat loss method for calculating boiler efficiency, from ASME Power Test Code 4.1,[10] the following boiler efficiencies are calculated under similar conditions for the two coals:

Coal A: 88.26%
Coal B: 89.68%

The differential of 1.43% represents an additional 4800 tons of Coal B that would not have to be purchased. The delivered cost of Coal B is $42.00/ton which represents about $202,000 per year less spent on coal.

Corrosion and Erosion

The industry is still learning about the corrosion and erosion potential of different coals. Several components, especially the in-bed heat exchangers, have had serious problems with erosion and corrosion. Erosion is due primarily to the presence of a large amount of solids moving at relatively high velocities. Coals with high and/or hard

Table 3. Economic and technical assumptions

	Coal A (high sulfur)	Coal B (low sulfur)
Coal price $/ton	17.00	24.00
Transportation $/ton	18.00	18.00
Delivered $/ton	35.00	42.00
$/MBtu	1.59	1.68
Ca/S for 90% removal	2.5	3.5
Coal handling charge at plant	$2.00/ton	
Ash disposal charge	$5.00/ton	
Limestone costs	$10.00/tn	
Heat input	8.4×10^{12} Btu/Yr	

Table 4. **Differential annual costs between Coal A and Coal B**

	Coal A − Coal B
Fuel costs	($750,000)
Material handling—costs	$92,000
Material handling—limestone	$158,000
Material—limestone	$790,000
Material handling ash & refuse	$470,000
Boiler efficiency	$202,000
Total	$962,000

mineral constituents can increase the erosion rate as can other solids such as limestone. As noted before, higher sulfur coals require more limestone which also increases the solids loading. The boiler manufacturers continue to improve the design or materials used to reduce the erosion to acceptable levels. Successfully used solutions include altering air/gas distribution and flows, avoiding highly erosive bed materials, and covering troublesome areas with refractory shields and fins or studs on the tubes. Corrosion problems can be harder to predict and fix. The corrosion of the metal bed components is primarily caused by sulfides formed through reactions with SO_2 and the tube metals.[11] There is some concern that the chloride level in coals may also contribute to the corrosion rate of in-bed boiler components.[12]

Conclusion

A summary of the annual cost differentials for the two coals is shown in Table 4. As can be seen, even though Coal A had the lower purchase cost, the quality impact differential between the two coals was substantial. In the example made here the quality impacts of Coal B are over $1.7 million annually. This does not include any of the savings due to lower capital costs in boiler and auxiliary equipment, or the potentially lower corrosion and erosion potential that Coal B may have due to lower solids and chlorine contents.

This short example covers only a few of the major effects that a company must take into consideration when building a fluidized bed combustor and is hypothetical in nature. It does, however, serve to show that the coal quality impacts on an FBC may drastically alter fuel choices and costs.

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Viewpoint: Coal Export

U.S. EXPORT COAL—1988

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One of the interesting questions for the U.S. export market in 1988 is how much the channel-deepening projects in Hampton Roads and Baltimore will benefit U.S. East Coast exports when those projects are completed. Both channels will be deepened to accommodate vessels with 50-foot (15.2-meters) outbound draft. The debate