Appendix I – Commercial Evaluation of Circulating Fluidized Bed Combustion

Introduction

Circulating Fluidized Bed (CFB) is a power generation technology that combusts solid fuel while it is in a bed of material. This appendix presents a review of the business considerations that caused Mid-Michigan Energy to not select CFB technology for use at the Facility. This analysis provides and overview of the technology and discusses the performance considerations, cost and commercial availability of the technology.

Technology Overview

CFB combustion is a process for the combustion of solid fuel in which the fuel is held in suspension in a bed primarily consisting of fuel, fuel ash, limestone, and other inert materials. CFB boiler technology has been successfully applied to the process industries and the electric power industry, although its application is limited by the smaller steam generating capacity that can be produced by a single CFB boiler relative to a PC boiler. A CFB boiler can inherently produce less NO_x and SO_2 emissions than a PC boiler without add-on controls; however, to achieve the currently required emissions levels, both CFB boilers and PC boilers require add-on controls thus removing the emissions advantage of CFB boilers. The CFB boiler continues to hold an advantage over the PC boiler with respect to its ability to burn lower quality fuels.

Process Description

A CFB boiler combusts fuel while it is in a bed of material consisting of fuel, fuel ash, limestone, and other inert bed materials. The bed is supported within the furnace by air flowing into the bed from the bottom of the furnace. The air flow supports the bed and promotes mixing of the fuel and air to provide complete combustion. The bed temperature is typically below 2,000°F, which maintains the fuel ash below the softening point and also reduces the formation of thermal NO_x. The bed is sized to achieve low gas velocities that allow for long fuel residence time in the furnace which helps complete combustion and maximize heat transfer to the water-cooled furnace walls. Simultaneous with the fuel combustion, limestone reacts with SO_2 formed during combustion to lower overall SO_2 emissions from the boiler.

The intimate mixing of air and fuel, low combustion temperature, long residence time, and in-situ removal of SO_2 make CFB technology an ideal system for the combustion of fuels with low volatile matter content (such as anthracite coals and pet coke), high ash content (such as waste coal), and high sulfur content. Additionally, a CFB boiler has greater fuel flexibility relative to a PC boiler, which gives an owner the ability to minimize fuel expenses by burning lower quality, lower cost fuels.

History

Fluidized bed technology development was initiated in the 1920's as a process for the refining of petroleum and the production of chemical feedstocks from coal. Until the 1960's, fluidized bed technology was focused on the process industries. In the 1960's, governments (particularly in the U.S. and England) began looking at fluidized bed technology as a means to utilize coal while reducing emissions of SO_2 and NO_x. At that time, governments and boiler manufacturers began investing in the development of the technology and began building test modules and small scale commercial boilers. With the progression of time, a greater understanding of the CFB technology was gained which enabled boiler manufacturers to offer larger CFB boilers and expand the potential range of application from small industrial boilers to larger utility boilers.

The CFB combustion process is now a mature technology and CFB boilers have gained acceptance as a steam generator technology for power generation. Table I.1 summarizes some of the most recent domestic applications of CFB boilers for power generation.

Table I.1 –Domestic CFB Boiler Applications for Power Generation

Plant	Location	Operation	Capacity MW (gross)	Fuel
Tractebel Red Hills	Mississippi	2001	2 x 250 MW	Lignite
JEA Northside	Florida	2001	2 x 300 MW	Coal, pet coke
AES Puerto Rico	Puerto Rico	2002	2 x 250 MW	Coal
Reliant Seward	Pennsylvania	2004	2 x 292 MW	Waste coal
East Kentucky Power Coop	Kentucky	2004	1 x 268 MW	Coal

Performance

Efficiency

In terms of combustion performance, a CFB boiler has a marginally higher combustion efficiency relative to a PC boiler. This higher efficiency is gained from less unburned carbon due to the longer furnace residence time and the ability to lower the air heater exit temperature due to the lower concentration of SO_3 in the flue gas. However, the overall efficiency of a facility with a CFB boiler with advanced emission controls will be lower relative to a facility with a PC boiler with advanced emission controls due to the higher electric power consumption of the CFB boiler auxiliaries. The result of this lower efficiency is a higher fuel consumption rate for an equivalent electric generating capacity.

Fuel Source

The advantage of a CFB boiler is its ability to consume low cost "advantage" fuels not typically utilized in a PC boiler. These fuels are characterized by a high ash or moisture content, low heating value, and low volatile content and thus are lower cost on a $/MMBtu basis at the fuel source. However, transportation cost is a critical consideration in determining the fuel source and, in the case of using lower value fuels, transportation distances exceeding 50 to 100 miles often removes any economic benefit of burning the lower value fuel relative to high quality PRB coal. Long-term availability of these lower value fuels is also a consideration since a facility's economics will be severely impacted if the fuel source is no longer available in future years and higher cost fuels must be substituted. Therefore, most facilities equipped with a CFB boiler are located near one or more potential fuel sources to maximize the economic benefit of using the low value fuel and reduce the risk of fuel becoming unavailable.

Operational Flexibility

CFB boilers have a more restrictive ramp rate than PC boilers because of the considerable mass of material in the bed that needs to be moved and kept within temperature ranges. CFB boilers can operate at baseload and in a load-following mode. The load-following capability is limited in comparison to PC boilers. Minimum load for a CFB boiler is in range of 40%, without supplemental fuel, minimum load for a PC boiler is in the range of 25%. CFB technology is not well suited for on-off cycling. The bed material is susceptible to hardening if the bed temperature falls below its recommended operating range.[1]

Emissions

The main advantage of a CFB boiler is the lower emission of NO_x and SO_2 relative to a PC boiler not equipped with selective catalytic reduction (SCR) or flue gas desulfurization (FGD). The lower combustion temperature of a CFB boiler will generate less thermal NO_x while SO_2 emissions are reduced by the reaction with limestone in the bed.

Recent facilities equipped with CFB boilers have used post-combustion controls to further reduce emissions of NO_x and SO_2 to meet the increasingly stringent emissions requirements. The controls typically applied are selective noncatalytic reduction systems (SNCR) to reduce NO_x emissions and dry FGD systems to reduce SO_2 emissions. An SNCR reduces NO_x by injecting urea or ammonia into the furnace which reacts with NO_x to form N_2, O_2, and H_2O. A dry FGD system may use bed material collected in a baghouse as the reagent or fresh lime feed similar to a dry FGD system installed with a PC boiler. The utilization of bed material or lime as the reagent in the dry FGD system is an economic decision based on the amount of additional SO_2 reduction required and the relative costs of limestone and lime.

Similar to recent CFB boiler installations, a new PC boiler will be required to install post-combustion controls to reduce emissions of NO_x and SO_2. The systems typically installed are SCR for control of NO_x emissions and FGD for control of SO_2 emissions. The addition of these systems enables a PC boiler facility to have emissions equal to the emissions from a facility equipped with a CFB boiler, SNCR, and dry FGD system. However, a facility equipped with a CFB boiler will have a lower overall efficiency than a comparably sized facility equipped with a PC boiler due to greater auxiliary power requirements of the CFB boiler facility. Therefore, more fuel will have to be burned to produce the same amount of electricity, likely leading to greater total annual emissions at a CFB facility than a PC plant.

The amount of combustion products generated by a facility equipped with a CFB boiler and a dry flue gas desulfurization (FGD) system will be higher than a facility equipped with a PC boiler and a dry FGD system as a result of the overall lower efficiency of the CFB boiler based facility and the higher limestone consumption of a CFB boiler relative to the lime consumption of a PC boiler equipped with a dry FGD system. Table I.2 below shows a comparison of the fuel and reagents consumed by each technology and by-products generated for a 600 MW facility firing PRB coals. (A 600 MW plant is used since that would maximize the efficiency for CFB boilers.)

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[1] Sargent & Lundy, LLC, "New Coal Generation Technology Assessment Study." November 2005

Table I.2 – Comparison of Fuel Consumption and Combustion Product Generation for a 600 MW plant

	CFB Boilers	PC Boiler
Fuel consumption (tpy)	3,222,749	3,154,383
Incremental fuel consumption (tpy)	68,366	--
Fuel ash (tpy)	165,971	159,699
Sulfur absorption products (tpy)	117,849	64,375
Incremental disposal volume (tpy)	59,746	--

Cost

MME has a proposed generating capacity of 750 MW, utilizing one PC unit. The 300 MW CFB boilers at JEA Northside are currently the largest operating CFB boilers in the United States. Unlike PC boilers, CFB boilers have not been scaled up to the 750 MW capacity proposed for the Facility. Thus, steam generation capacities greater than 300 MW require the use of multiple CFB boilers to generate the steam flows required. The use of multiple boilers to achieve a given steam flow is more costly relative to utilizing a single boiler to generate the same steam flow due to the increased physical size of the facility, the incremental ancillary equipment to support three boilers, and the incremental staff to operate and maintain the additional boilers.

A recent report prepared by Black & Veatch for Florida Power & Light estimated the EPC capital costs for a CFB facility to be ~ 21% higher than an ultra-supercritical PC facility and ~ 6% higher than a subcritical PC facility. Black & Veatch also estimated the busbar cost, assuming degraded performance and taking into account emission allowances, for a CFB facility to be ~ 22% higher than an ultra-supercritical PC facility and ~ 10% higher than a subcritical PC facility. [2]

Commercial Availability

CFB boiler technology is a mature technology that is commercially available from multiple suppliers. Application of a CFB boiler is principally driven by the fuel to be consumed. A single CFB boiler is limited in capacity to approximately 300 MW; greater capacities would require multiple boilers. In contrast, a single PC boiler can be furnished with a capacity up to approximately 1,000 MW. Emissions from a facility equipped with a CFB boiler with advanced emission controls will be comparable to a facility equipped with a PC boiler with advanced emission controls when measured on a heat input basis. The true advantage of a CFB boiler is that it can utilize low cost fuels not typically suited for combustion in a PC boiler.

A CFB boiler has not been selected for the Facility due to the increased cost of installing three CFB boilers per PC boiler to meet the required capacity of the Facility, the lack of any low cost "advantage" fuels of sufficient volume and within reasonable distance from the facility to provide any economic advantage, and the efficiency penalty for using a CFB boiler.

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[2] Black & Veatch, Clean Coal Technology Selection Study. Final Report. January 2007.