OVERVIEW OF
THE FLUIDIZED BED COMBUSTION PROCESS AND MATERIAL

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Abstract

The advent of fluidized bed combustion (FBC) technology has proven to be one of the most promising of the emerging Clean Coal Technologies. Low-grade fuels, that have a large ash and high sulfur content, can usually not be utilized in pulverized coal combustion (PCC) units. FBC units can not only efficiently burn low-grade fuels, but can also handle wide variations in fuel quality while still achieving strict air emission requirements.

With the commercial application of FBC units gaining widespread acceptance, there is a need to understand the similarities and differences in not only the FBC and PCC processes, but also in the characteristics of the solid byproducts that are generated. In the FBC process, limestone is added to the boiler to act as a sorbent for sulfur. The operating conditions for FBC units, in addition to the fuel and sorbent characteristics, directly contribute to the chemical characteristics of the residues. FBC bottom ash is a mixture of fuel ash, unburned carbon residues, and lime particles coated with sulfate layers. The ash properties are substantially different from typically PCC residues marketed as ASTM Class C or Class F fly ash. While PCC ash has found an application mainly in the cement industry, the utilization options for FBC ash is more diverse due to the influence of the sorbent on the ash chemistry.

Combustion Process and Conditions

Pulverized coal combustion (PCC) is the most commonly used method in coal-fired power plants. The technology is well developed, accounting for well over 90% of coal-fired capacity. The feed coal for a PCC unit is ground (pulverized) to a fine powder with about 75% of the coal particles below 75 µm in size. The pulverized coal is blown with part of the combustion air into the boiler through a series of burner nozzles. Combustion takes place at temperatures from 1300-1700°C, and the particle residence time in the boiler is typically 2-5 seconds.

In PCC, flue gas cleaning consists of particulate emissions control technology to capture the fly ash, such as ESP's (Electrostatic precipitators) and fabric filters, and NO_x and SO_x control. Primary measures for NO_x control (burner optimization, low-NO_x burners and overfire air) are now considered integral parts of a newly built power plant and existing units retrofit them whenever they are required to reduce their NO_x emissions. SCR (Selective catalytic reduction) is accepted throughout the world as the proven commercial option to achieve high NO_x removal. Sulfur is typically removed via Flue Gas Desulfurization (FGD) technology, where calcium-, sodium- and/or ammonium-based sorbents react with the SO_2 in the flue gas. Wet FGD scrubbers are the most widely used for SO_2 control throughout the world. Emissions from new PCC units with appropriate flue gas cleaning units can meet all current requirements, although the capital cost of these measures can represent about one third of the cost of the unit when meeting the most stringent current standards.

The advent of fluidized bed combustion (FBC) technology has proven to be one of the most promising of the emerging Clean Coal Technologies. Lower grade fuels, that have a large ash and high sulfur content, can usually not be utilized in pulverized coal combustion (PCC) units. FBC units can not only efficiently burn low-grade fuels, but can also handle wide variations in fuel quality while still achieving strict air emission requirements.

With the commercial application of FBC units gaining widespread acceptance, there is a need to understand the similarities and differences in not only the FBC and PCC processes, but also in the characteristics of the solid byproducts that are generated. Relatively coarse particles at around 1 mm to 3 mm in size are fed into the combustion chamber. Combustion takes place in a FBC unit at temperatures from 800-900°C, resulting in reduced NO_x formation compared with PCC. N_2O formation is, however, increased. In the FBC process, limestone is added to the boiler to act as an in-situ sorbent for sulfur. The direct injection of limestone into the bed offers the possibility of economic SO_2 removal without the need for expensive FGD equipment. Thermal decomposition of

$CaSO_4$ in normal fluidized bed combustion conditions is not probable because of low temperatures in the reactor. Circulating beds use a higher fluidizing velocity, so the particles are constantly held in the flue gases, and pass through the main combustion chamber and into a cyclone, from which the larger particles are extracted and returned to the combustion chamber. Because of recirculation of the bed material, particle residence times are relatively long compared with the gas residence time, and can be measured in tens of seconds. Commonly only particulate removal (via ESP) is required in order to meet emissions limits, but in some locations additional NO_x reduction is also required.

Comparison Between Pulverized Coal Combustion (PCC) and Fluidized Bed Combustion (FBC)

Parameters	PCC	FBC
CaO in Boiler	No	yes
Coal Particle Size	< 75 µm	1 - 3 mm
Coal Residence Time	seconds	minutes
Combustion Temperature	high 1300-1700 °C	low 800-900 °C
Ash Porosity	low	high
Ash pH	neutral - acidic	alkaline
Net Thermal Efficiency, %	33-35	36-40
* Emissions: SO_2	1.2	0.1
* Emissions: NO_x	0.6	0.15
NO_x origin	thermal, fuel	fuel
Cost of Electricity	100	90

* *Emission values in lbs/mmBTU*

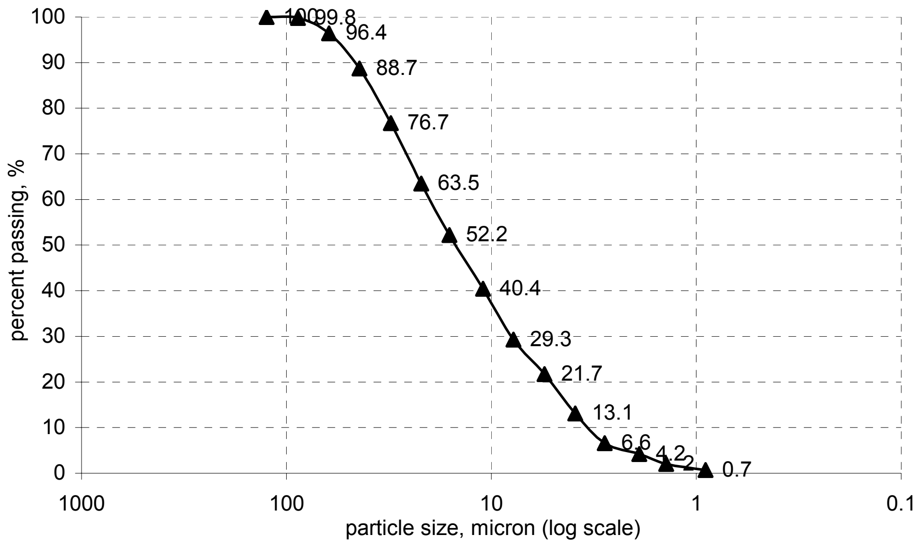
FBC By-Products

The operating conditions for FBC units, in addition to the fuel and sorbent characteristics, directly contribute to the chemical characteristics of the residues. FBC bottom ash is a mixture of fuel ash, unburned carbon residues, and lime particles coated with sulfate layers. The residues consist of the original mineral matter, most of which does not melt at the combustion temperatures used. Where sorbent is added for SO_2 removal, there will be additional CaO/MgO, $CaSO_4$ and $CaCO_3$ present. In general, the FBC fly ash composition distinctly differs from that of fly ash produced by conventional combustion, above all by the absence of glass, mullite and other high-temperature phases, showing on the other hand much higher calcium sulfate content and higher portion of unmetamorphosed or only slightly thermally influenced coal minerals (micas, feldspars, clay minerals). FBC ashes are composed principally of gypsum [$CaSO_4$], lime [CaO], quartz [SiO_2], and associated oxides of iron, magnesium, and dehydroxylated clays originating from the fuel ash components. Due to the high free lime content the leachates from FBC ash will be strongly alkaline. Carbon-in-ash levels are higher in FBC residues that in those from PCC.

Oxide Compositions (%) for Various Coal Combustion Ashes

Oxide Analysis	FBC bed material	FBC ash	C-ash	F-ash
Si	45	40	36	44
Al	6	14	15	17
Fe	3	8	7	18
Si+Al+Fe	54	62	57	79
Ca	26	15	22	5
SO_3	16	8	12	1
LOI (950 °C)	2	11	1	8

Particle Size Distribution Curve for FBC Fly Ash



The particle size distribution curve shows that about 96% of the FBC fly ash particles are smaller than 63 μm (-250 mesh) in size. The average particle size (D_{50}) is about 15 μm based on the plot. A uniformity coefficient greater than 4 shows that most of the grains are of the same size. More than 80% of the particles are within the range of 44 microns to 5 microns in size. The average specific gravity of the FBC fly ash was 2.66.

FBC Fly Ash Utilization

Diverse utilization options have been studied for FBC coal ashes. The potential applications include:

- Construction applications: cement substitute, concrete block production, brick production, soil stabilizer, roadbase/subbase materials, structural fill materials, and
- synthetic aggregates;
- agricultural applications: liming and soil amendment;
- waste stabilization: acidic waste stabilizer and sludge stabilizer.

Ash Use in Construction Applications: FBC fly ashes cannot be classified as Class F or C, because of low FAS (ferric oxide, alumina, and silica) and high SO_3 content. Even though the fly ash may not qualify as a Portland cement admixture, it may have the potential for use in concrete blocks. Bottom and fly ash can be used as an aggregate and pozzolan in concrete blocks. The bottom ash used as an aggregate has a lower unit weight than many naturally occurring aggregates, thus reducing the weight of the block. FBC fly ash with properties of Class C and F can be used as a partial replacement for Portland cement in some block plants. The free lime, carbon content and sulfate contents of FBC ashes can limit their utilization in concrete block production. Free lime in ash will form water-soluble calcium hydroxide, resulting in weakening of the block from contact with moisture. As with Portland cement concrete, etteringite can form in concrete blocks due to high sulfate levels resulting in mechanical weakening of the block. It is possible that FBC ash may replace some Class C or F fly ash or Portland cement in more moderate strength blocks. Such materials may not be preferred for heavy construction applications.

Soil/Mine Spoil Amendment: Ash streams from CFB boilers firing bituminous coals may be suitable for liming, depending upon how calcium is partitioned between the fly ash and bottom ash. FBC ash streams can also be used to stabilize waste streams from a variety of processing operations. This stabilization includes solidification and fixation of sludge materials for landfilling, neutralization of acidic wastes, and municipal sludge waste sludge. For each of these applications, the suitability of CFB ash is enhanced by its free lime content. Greenhouse studies demonstrated that FBC fly ash amended soils resulted in higher plant productivity than typical ag-lime-amended spoils. These results possibly are due to pH and nutritional issues, but root penetration was undoubtedly a factor.

Dr. Francois Botha joined the Illinois Clean Coal Institute (ICCI) in 2001 as Project Manager in the area of Coal Combustion Byproducts. As a project manager at the ICCI, he is involved in implementing and monitoring various

projects in the Illinois coal R&D program. He also acts as developer and webmaster for the ICCI website. A native from South Africa, Dr. Botha's career in coal science began with South Africa's Sasol petrochemicals company, famous for their manufacture of synthetic fuels from coal via the Fischer-Tropsch process. At Sasol he conducted research in gold adsorption onto activated carbon, coal cleaning and coal-derived fuels. He worked in the Chemistry Department at the University of Kentucky beginning in 1993 until his employment at the ICCI. He has a Ph.D in Materials Science from the University of Bath in England, and his research interest is in coal science and carbon materials.