COAL COMBUSTION BYPRODUCTS

By Rustu Kalyoncu

Electricity accounts for about 35 % of the primary energy use in the United States and is produced by electric power generators designed to convert different fuel types into electricity. Electric power utilities are the largest coal consumers in the United States, as more than one-half the electricity in the United States is generated by burning coal, which translates into almost 90% of coal consumed. As a result, more than 100 million tons of solid residues known as coal combustion products (CCPs) are produced by electric utilities annually. This figure promises to rise considerably, owing mostly to the anticipated rise in the use of flue gas desulfurization (FGD) units in the control of Sulfur dioxide (SO_2) emissions.

The majority of electric power utilities, especially in the Eastern and Midwestern states, use high sulfur bituminous coal. Increased use of high-sulfur coal has contributed to an acid rain problem in North America. To effectively address this problem, the U.S. Congress passed the Clean Air Act Amendments of l990 (CAAA'90-Public Law 101-549) with stringent restriction on sulfur oxides emissions.

CCPs are the resultant solid residues produced upon coal burning in the production of electricity. The coal is crushed, pulverized, and blown into a combustion chamber, where it immediately ignites to heat the boiler tubes. Upon burning of the coal, the inorganic impurities, known as coal ash, either remain in the combustion chamber or are carried away via the flue gas stream. Coarse ash particles (bottom ash and boiler slags) fall to the bottom of the combustion chamber, while the fine portion (fly ash) remains suspended in the flue gas. Before leaving the stack, these fly ash particles are removed from the flue gas by electrostatic precipitators or other available scrubbing systems, such as mechanical dust collectors, often called cyclones or multicones. Added to the ash is the FGD material as the flue gas is "scrubbed" to remove the sulfur oxides. Among the nonfuel mineral sources, CCPs rank just behind crushed stone and sand and gravel in total tonnage in the United States, surpassing portland cement and iron ore.

The SO_2 reduction provision of CAAA'90, with its two phase implementation plan, has forced the electric utilities to find ways of reducing SO_2 emissions. Many utilities have switched to low-sulfur coal or fuel oil as partial and temporary solution to the problem. A significant number of powerplants still using medium- or high-sulfur coal installed flue gas desulfurization equipment from among a number of commercially available units. Wet lime FGD systems, later described, most commonly used in the United States, yield a byproduct known as FGD material.

FGD units solve the SO_2 problem, but add another in the form of large quantities of byproduct FGD material. Produced in inordinate quantities, FGD material adds to the accumulation of already high levels of CCPs. Of approximately 20 million metric tons of FGD material, produced in l993, less than 5% was utilized as a substitute for natural gypsum, mostly in agriculture and wallboard manufacturing. Synthetic gypsum use represented less than 4% of total gypsum consumed and approximately 5% of crude gypsum produced from 61 mines in the United States.

Among the industries directly or indirectly affected by the FGD gypsum issues are coal, limestone, lime, soda ash, and gypsum producers. Increased commercial use of FGD products represents an economic opportunity for the sorbent industry and the high-sulfur coal producers.

In addition to the FGD material, CCPs include fly ash, bottom ash, and boiler slag. Cumulative quantities of CCP's produced since l987 are more than 700 million metric tons. Boiler slags represent a minor component of CCPs. One hundred percent of boiler slags is profitably utilized, mostly in the manufacture of abrasives and roofing granules. Among the major CCP components, bottom ash has over the years represented the highest use rate at approximately 35% of the amount produced.

FGD Technology

Numerous processes and equipment to reduce SO_2 and Nitrogen oxides (NO_x) emissions have been developed, and many are commercially available. A significant number of electric powerplants, which continue to use medium- and high-sulfur coal as fuel, have installed FGD equipment. Close to 200 FGD systems, with small to significant variations have been described in the literature (Radian Corp., 1983). These systems are divided into two major types, wet and dry systems, which, in turn have been assigned to 16 categories, wet systems (calcium, sodium, ammonia, magnesium, potassium, organic, and others) and dry systems (reagent, carbon sorption, combustion, metal oxide sorption, catalytic oxidation, SO_2 reduction, etc.). Among the numerous systems mentioned, only a few have been developed to technically and economically feasible levels, and even fewer to commercial scale. Among these, the lime-limestone process is the most widely used system in the United States.

FGD Methods

Passage of the CAAA'90 by the 101st Congress brought about FGD requirements for coal-fired powerplants. This generated a beehive of activity in the research and development of FGD processes for the control of SO_2 emissions in the flue gas. Close to 200 FGD processes and 24 subsystems of processes have been reported. Description of all the processes, even in a summary fashion, is beyond the scope of this publication. A list of categories and the number of processes within the categories are shown in table 1.

The major process division is between wet and dry systems. Wet systems completely saturate the flue gas with moisture while dry systems do not. With wet FGD systems , the fly ash is usually removed from the flue gas stream prior to the flue gas entering the FGD system. A large majority of the processes are systems that have been proposed but never carried beyond the laboratory due to poor performance or unfavorable economics. A summary of the development status of FGD Systems are shown in table 2.

Lime-Limestone-Based Systems

The great majority of FGD systems—about 90%—being installed in the United States utilize limestone or lime as a sorbent. Currently, more than 10,000 megawatts (MW) of electric power generating capacity use FGD systems. An additional 23,000 MW are either in the construction or the planning stages for retrofit with FGD units (Mc Ilvane Co.).

Lime is more reactive than limestone; consequently, higher efficiencies can be obtained with lime as the sorbent, and thus lesser amounts are needed. This, in turn, results in reduced quantities of byproducts. In FGD systems using the quick lime (CaO) process, quicklime is slaked on site to form a calcium hydroxide slurry. This slurry is added to the reaction tank or scrubber basin, where it is mixed with recycled slurry from the scrubber. In the wet systems, the flue gas stream is sprayed with the lime slurry. The lime reacts with sulfur gases to form calcium sulfite and calcium sulfate. Sulfites formed need to be converted to sulfate. This is accomplished by increasing the oxygen content in the system, thus effecting the oxidation of sulfite to sulfate. The oxidation of sulfite to sulfate is dependent upon many process variables such as equipment design, pH, O_2:SO_2 ratio etc., and has caused serious operating problems due to scale formation in some systems.

Briefly, in a typical system, illustrated in figure 1, the flue gas comes in contact with a slurry of lime or limestone, ground to approximately 90% 200 mesh, and the reagent. The gas may or may not contain fly ash, depending on the absorber design. A larger amount of slurry (relative to the gas volume) is sprayed or dispersed in the contactor, saturating the flue gas and removing the SO_2. The scrubbed gas is then passed through mist eliminators and is often reheated to restore buoyancy prior to discharge.

The SO_2 -rich liquor typically drains into large tanks where neutralization and precipitation reactions occur. Alkaline reagents may be added to the system to control the acidity.

Production

Table 3 depicts the history of CCP production data, collected by American Coal Ash Association (ACAA) through survey of its member utility companies, for the years 1992 through 1996. The data show that the expected rise in the production did not take place after the passage of the CAAA '90. Even though only 10% of the utilities were affected by the first-phase implementation of the law, it was still expected to make a noticeable difference in the CCP quantities produced, due to the increase in the FGD sludge production. This did not take place largely owing to the fact that many utilities, to avoid high initial capital expenditures for FGD installations, opted for temporary solutions, such as fuel switching, power reduction, and purchase of emissions allowances. This trend has continued to date. The commencement of the implementation of the second phase of the law, which encompasses the remaining 90% of the utilities affected, will render the first-phase options, especially emissions allowances, insufficient for minimum compliance. Even if such options were still available, they would probably be equal to the cost of retrofitting utilities with FGD technology. The utilities, therefore, will be compelled to find a permanent solution to the emission problems. They likely will find it in the installation of FGD units. It is, therefore, anticipated that in the coming years the number of FGD units will increase, hence a commensurate rise in the FGD material will substantially add to the total of CCPs produced. This, however, remains to be seen.

Consumption

Table 3 illustrates the history of CCP usage between l992 and l996. For the year 1996, boiler slags have led the way with a use rate of 92.3%, followed by bottom ash with 30.45% use. The FGD material, though with the smallest use percentage, has recorded the largest increase in use percentages among the CCPs, jumping from 1.8% in 1992 to 7% in 1996, representing a 3.5-fold increase. The comparison of the production and use data shows that while the quantities of CCPs produced have steadily increased from 80.6 million metric tons in 1992 to 92.4 million metric tons in 1996 (a 14.5% increase in 5 years), the quantities of CCPs used during the same period increased at even a faster rate during the same period, going from 18.5 million tons in 1992 to 23 million tons in 1996, which is almost a 25% increase over the past 5 years.

Table 4 summarizes the 1996 production and use data for individual CCP categories method of handling and specific use areas. The cement and concrete industry uses the greatest quantities of CCPs, accounting for approximately one-third of total CCPs used, followed by structural fills (2.7%) and blasting grit and roofing granules (2.1%), which account for all the boiler slags used. Tables 5 and 6 present the 1996 production and use data—illustrated in table 4, for dried and ponded categories, respectively. Comparison of the two tables points to the fact that greater portion of the dried product is more suitable for beneficial uses, as illustrated by the total use percentages for the two categories.

Figures 5 and 6 are graphic representations of the production and use data summarized in table 3. The production and use data for CCPs are summarized on regional basis and various use categories in figures 4 through 8. Figures 4 and 5 depict total CCPs produced and used in 1996. Figure 5 presents separate data for six regions of the country. (See figure 13 for the States in each geographic region.) Figure 6 summarizes the production data by geographic region and by the CCP type, whereas figures 7 and 8 show individual share of each CCP produced and used, respectively. As figures 4 and 5 illustrate, in spite of significant gains in recent years, with the exception of boiler slags, almost 100% of which is used, only a small fraction of total CCPs is profitably utilized.

Components of CCPs have different uses as they exhibit distinct chemical and physical properties making each one suitable for a particular application. Current uses of CCPs include in cement, concrete, mine backfill, agriculture, blasting grit and roofing applications.

Other current uses include, to a lesser extent, waste stabilization, road base-subbase, and wallboard production (FGD gypsum). Recently, the use of FGD gypsum in wallboard production has significantly increased. In the past year, three wallboard companies have announced plans to build wallboard plants that will use FGD gypsum as their raw materials. Potential uses also include applications in subsidence control, acid mine drainage control, and as fillers and extenders. Figures 9 through 12 summarize the leading applications for the four CCPs, namely fly ash, bottom ash, FGD product, and boiler slags.

Fly ash is used in the largest quantities accounting for 60% of the total CCPs used. As depicted in figure 9, use in cement and concrete production tops the list of leading fly ash applications with more than 50%, followed by structural fills and waste stabilization. Figure 10 lists the leading bottom ash applications. Approximately one-half of bottom ash was used in road base-subbase, cement and concrete, structural fill, waste stabilization, and snow and ice control. Miscellaneous other applications, such as mineral fillers and extenders, flowable fill, etc., make up the other half of the use categories. Mining applications (about one-half of the total used), agriculture (about one-third), and blasting/roofing granules account for the bulk of FGD product uses, amounting to more than 90% of its total use, as illustrated in figure 11. Boiler slag uses are summarized in figure 12. Virtually 100% of the boiler slags produced are utilized. Owing to its considerable abrasivity, boiler slag is used almost exclusively in the manufacture of blasting grit and roofing granules.

Current Research and Technology

Research and development (R& D) activities have been in two distinct directions, namely developing FGD methods and finding new application areas for the CCPs, especially the FGD product. Owing to the proprietary nature of FGD technology developments, open literature is void of any significant information on the subject. Promotional efforts at various technical conferences by a number of manufacturers, however, indicate a beehive of activity in the new FGD technologies area, spearheaded by Japanese and European researchers. Higher R & D activity levels in these countries is no surprise as, due to the space requirements, the utility industries in these countries have no room for the disposal of the coproducts from the current FGD processes that produce large quantities of process byproducts. They are, therefore, forced to find better solutions to flue gas emission problems. Research efforts emphasize the development of technology that require less space for installation and yield smaller quantities of coproducts than the current well-established methods using lime or limestone as sorbents.

R&D efforts in FGD technologies have largely been directed toward either decreasing the quantities of the reaction coproducts or increasing their economic value to upgrade them as resource rather than waste products. The ultimate goal, of course, would be to eliminate altogether any coproducts in FGD processes.

Outlook

CCP's will be proportional to the increase in coal use for electric power production. This may be limited to 5% to 7% per year. Increases in the FGD product, however, is another matter. As afore-mentioned phase one of the CAAA'90 affected only 10% of the coal burning electric utilities. With phase two, the remaining 90% of the utilities will be subject to the emissions restrictions set by the law. The majority of the utilities affected by phase one got by restrictions on short-term remedies, such as fuel switching, emission allowance purchases, and reduction of power production where feasible. Such temporary measures, however, shall not be available to all. Simple arithmetic dictates that annual (1996) FGD production may increase an order of magnitude to almost 200 million tons, exceeding the total quantities of the other CCPs. A sufficient number of wet lime based FGD units are already under construction to triple the amount of FGD material produced. The planned capacity may bring it up to fivefold to sixfold of the current amounts. This will present a challenge to several industries, such as construction, agriculture, and certain manufacturing sectors, to find additional uses for these materials.

References Cited

Radian Corporation, The Evaluation and Status of Flue Gas Desulfurization Systems, Research Project 982-28, Final Report January 1984.

McIlvane Company, FGD and DeNOx Manual, V. 2.

TABLE 1
FGD PROCESS CATEGORIES

Categories	Number of processes
Calcium-Base Wet Systems	24
Sodium-Base Wet Systems	24
Ammonia-Base Wet Systems	12
Magnesium-Base Wet Systems	9
Potassium-Base Wet Systems	5
Organic-Based Wet Systems	22
Other Wet Systems	34
Wet Reagent Dry Systems	5
Dry Reagent Dry Systems	4
Carbon-Based Sorption Systems	10
Metal Oxide Sorption Systems	9
Other Solid Sorption Systems	5
Catalytic Oxidation Systems	11
SO2 Reduction Systems	8
Combustion Systems	2
Other Dry Systems	5
FGD Subsystems	24

Source: Radian Corporation.

TABLE 2
STATUS OF FGD SYSTEMS

Status	Number of processes
Commercial - 100 MW or greater FGD capacity use	10
Commercially available - domestic or foreign	14
Commercially used in other industries	10
Prototype - integrated process operation at utility site	19
Experimental - laboratory and pilot scale	74
Conceptual - not tested beyond fundamental chemistry	37
Unknown - insufficient information	26

Source: Radian Corporation.

TABLE 3
HISTORICAL COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE

(Thousand metric tons, unless otherwise specified)

	1992	1993	1994	1995	1996
Fly ash:					
Production	43,600	43,400	49,800	49,200	53,900
Use	11,900	9,540	11,700	12,300	14,800
Percent use	27.30	22.00	23.60	25.00	27.50
Bottom ash:					
Production	12,600	12,900	13,500	13,800	14,600
Use	3,510	3,840	4,610	4,600	4,430
Percent use	27.80	29.80	34.30	33.30	30.40
Boiler slag:					
Production	3,730	5,660	3,440	2,550	2,360
Use	2,810	3,110	2,830	2,440	2,180
Percent use	75.20	55.10	82.30	95.70	92.30
FGD material:					
Production	14,400	18,500	14,100	18,100	21,700
Use	260	1,050	850	1,340	1,510
Percent use	1.83	5.70	6.05	7.41	6.96
Total CCP:					
Production	74,400	80,400	80,800	83,700	92,400
Use	18,500	17,500	20,000	20,700	23,000
Percent use	24.80	21.80	24.80	24.90	24.90

Source: American Coal Ash Association (ACAA).

TABLE 4
TOTAL 1/ COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE

(Thousand metric tons, unless otherwise specified)

	Fly ash	Bottom ash	Boiler slag	FGD material	Total all CCPs
Production:					
Disposed	37,100	9,210	220	15,800	62,300
Produced	53,900	14,600	2,360	21,700	92,400
Removed from disposal	1,200	150	130	70	1,550
Stored on-site	3,290	1,100	70	4,440	8,890
Use:					
Agriculture	10	10	--	--	20
Blasting grit/roofing granules	--	150	1,970	--	2,130
Cement/concrete/grout	7,280	690	--	60	8,040
Flowable fill	280	40	--	10	330
Mineral filler	150	30	50	--	220
Mining applications	690	60	--	30	770
Roadbase/subbase	680	660	--	110	1,440
Snow and ice control	--	610	100	--	710
Structural fills	1,970	610	40	50	2,670
Wallboard	10	--	--	790	810
Waste stabilization/solidification	1,750	230	--	50	2,040
Other	1,910	1,340	10	400	3,660
Total use	14,700	4,430	2,170	1,500	22,800
Individual use percentage	27.50	30.40	92.30	6.96	NA
Cumulative use percentage	27.40	28.00	30.10	24.90	24.90

NA Not available.
1/ Total CCPs include Categories I and II; Dry and Ponded respectively.

Source: American Coal Ash Association (ACAA).

TABLE 5
DRY COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE

(Thousand metric tons, unless otherwise specified)

	Fly ash	Bottom ash	Boiler slag	FGD material	Total all CCPs
Production:					
Disposed	25,400	5,500	150	9,370	40,400
Produced	39,000	8,610	880	11,100	59,600
Removed from disposal	170	30	10	0	210
Stored on-site	2,020	360	10	410	2,810
Use:					
Agriculture	10	10	--	--	20
Blasting grit/roofing granules	--	10	650	--	660
Cement/concrete/grout	6,960	490	--	60	7,510
Flowable fill	250	40	--	10	300
Mineral filler	150	10	10	--	170
Mining applications	420	40	--	--	460
Roadbase/subbase	670	480	--	110	1,250
Snow and ice control	--	360	20	--	380
Structural fills	1,140	240	40	50	1,470
Wallboard	10	--	--	740	750
Waste stabilization/solidification	1,010	230	--	50	1,300
Other	1,110	890	--	320	2,320
Total use	11,700	2,800	720	1,340	16,600
Individual use percentage	30.10	32.40	82.60	12.10	NA
Cumulative use percentage	30.10	30.50	31.50	27.80	27.80

NA Not available.

Source: American Coal Ash Association (ACAA).

TABLE 6
PONDED COAL COMBUSTION PRODUCT (CCP) PRODUCTION AND USE

(Thousand metric tons, unless otherwise specified)

	Fly ash	Bottom ash	Boiler slag	FGD material	Total all CCPs
Production:					
Disposed	11,700	3,710	70	6,410	21,900
Produced	14,900	5,970	1,450	10,500	32,900
Removed from disposal	1,030	120	120	70	1,340
Stored on-site	1,260	740	50	4,030	6,080
Use:					
Agriculture	--	--	--	--	--
Blasting grit/roofing granules	--	150	1,320	--	1,470
Cement/concrete/grout	330	200	--	--	530
Flowable fill	40	--	--	--	40
Mineral filler	--	20	40	--	60
Mining applications	270	20	--	20	310
Roadbase/subbase	10	180	--	--	190
Snow and ice control	--	240	80	--	320
Structural fills	830	370	--	--	1,200
Wallboard	--	--	--	50	50
Waste stabilization/solidification	740	--	--	--	740
Other	800	450	10	80	1,330
Total use	3,020	1,630	1,450	150	6,240
Individual use percentage	20.20	27.30	99.80	1.50	NA
Cumulative use percentage	20.20	22.20	27.20	19.00	19.00

NA Not available.

Source: American Coal Ash Association (ACAA).