Coal Combustion Product (CCP) Production, Use and Variability[1]

by

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Abstract. The four types of CCPs produced by electric utility boilers are fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) material. In 1997, 55% of electricity generated in the United States was produced by burning coal. Almost 90% of the coal used in the United States is burned to generate electricity; during 1997, electric utilities burned 898.5 million metric tons of coal and generated more than 95 million tons of CCPs, a figure that promises to increase owing mostly to the anticipated rise in FGD material generation. The quantities and types of CCPs produced at a given electric utility plant depend, for example, on the type of coal burned, the type of boiler, and the type of emission controls installed. Different types of CCPs possess distinct chemical and physical properties, making each suitable for particular applications.

Additional Key Words: fly ash, bottom ash, FGD material

Introduction

Coal Combustion Products (CCPs) have properties that are similar to those of virgin, processed, and manufactured materials. CCPs are produced when coal is burned in a boiler to generate electricity. The four types of CCPs produced by electric utility boilers are fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) material. In total output, CCPs rank behind only sand and gravel, and crushed stone and rank ahead of Portland cement and iron ore as produced mineral commodities.

In 1997, 55% of electricity generated in the United States was produced by burning coal. This number is projected to remain fairly constant until year 2015 (U.S. Department of Energy, 1997). Almost 90% of the coal used in the United States is burned to generate electricity; during 1997, electric utilities burned 898.5 million metric tons of coal and generated more than 95 million tons of CCPs, a figure that promises to increase owing mostly to the anticipated rise in FGD material generation.

The American Coal Ash Association, Inc. (ACAA), is a trade association representing the CCP industry. Members of the ACAA include producers and marketers of CCPs and supporting organizations. ACAA promotes the use of CCPs in numerous applications that are technically sound, commercially competitive, and environmentally safe.

The data presented in this paper has been taken from the annual survey of CCP production and use by the ACAA. The ACAA conducts an annual voluntary, confidential survey of U.S. coal-fired electric utilities to gather data about the production and use of CCPs. In 1997, the survey data collected account for approximately 80% of the coal burned by electric utilities.

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Information from previous ACAA surveys and U.S. Department of Energy (DOE) data were used to estimate CCP production and use for utility companies that did not respond to the survey (U.S. Department of Energy, 1996).

CCP Production

The quantities and types of CCPs produced at a given electric utility plant depend, for example, on the type of coal burned, the type of boiler, and the type of emission controls installed. Quantities of each type of CCPs produced are listed in Table 1. In 1997, production of CCPs totaled more than 95 million tons, an increase of 3% from that of 1996. This closely matched a 2.8% increase in coal burned by electric utilities (U.S. Department of Energy, 1997). Among types of CCPs, fly ash production increased by 1.5%; bottom ash production, by 5.3%; boiler slag production, 6.8%; and FGD material production, 5.5%. Fly ash accounted for 57%, and FGD material and bottom ash accounted for 24% and 16%, respectively, of the CCPs produced.

CCP production data, collected by the ACAA in surveys for calendar-years 1966 through 1997 are shown in Figure 1. The first year for which separate production figures for FGD material were made available was 1988. The data show that the expected rise in CCP production owing to the passage of the Clean Air Act Amendments of 1990 (CAAA '90)(Public Law 101-549) has not yet taken place. This is primarily because utilities, in order to avoid high initial capital expenditures for FGD installations, have opted for temporary solutions, such as fuel switching, power reduction, and purchase of emissions allowances. This trend is continuing, but increases in FGD production may accelerate owing to the implementation of Phase II of CAAA '90.

CCP Use

The data on CCP use between 1966 and 1997 are shown in Figure 2. The comparison of production and use data shows that although the quantities of CCP produced have steadily increased to 95.4 million tons from 22.9 million tons (Figure 1), the quantities of CCPs used during the same period increased at an even faster rate, increasing to 26.5 million tons from 2.8 million tons in 1996 (Figures 1 and 2). The overall percentage of CCPs used has increased to more than 33% from 12.3% in 1966.

The data in the ACAA's 1997 survey reports increases in most use categories. Some of the increases may be more the result of changes in data analysis than actual increases. A good example of this is the use of fly ash in concrete, cement, and grouting applications. Use in these applications reportedly increased by 1.3 million tons (an 18% increase compared with 1996); the actual increase, however, is likely to be closer to 0.3 million tons (a 4% increase). Use of fly ash in waste stabilization and solidification applications and in road base and subbase applications increased by more than 20% compared with 1996. Overall, fly ash use increased by 19%, bottom ash use, 4.7%; boiler slag use, 7.6%; and FGD use, 32%. The large increase in fly ash use in 1997 is likely the result of cement shortages in some regions of the United States. The large increase in FGD use represents greater gypsum use by wallboard plants.

The method of handling CCPs will also influence their use. Currently, about 68% of the fly ash, 60% of the bottom ash, and 54% of the FGD material produced are handled in a dry or moisture-conditioned state (Table 2) and have higher use percentages than those handled by ponding. Boiler slag is produced in wet-bottom boilers and primarily is handled by ponding (62%). CCPs handled in a dry or moisture-

Table 1. Coal combustion product production and use data for 1997.

Total CCPs - Dry & Ponded	Fly Ash	Bottom Ash	Boiler Slag	FGD Material	Total All CCPS
CCP Production			----- million metric tons-----		
Total CCP Production	54.71	15.35	2.49	22.84	95.39
Total CCP Disposed	35.55	9.88	0.39	15.88	61.70
Total CCP Removed from Disposal	1.20	0.44	0.27	0.07	1.97
Total CCP Stored On-Site	3.17	1.43	0.07	5.03	9.69
CCP Use					
Cement/Concrete/Grout	8.55	0.55	0.01	0.18	9.30
Flowable Fill	0.35	0.01	0.00	0.00	0.36
Structural Fills	2.61	1.26	0.08	0.00	3.95
Road Base/Subbase	1.29	1.17	0.00	0.02	2.47
Mineral Filler	0.26	0.12	0.10	0.00	0.48
Snow and Ice Control	0.00	0.66	0.05	0.00	0.71
Blasting Grit/Roofing Granules	0.00	0.15	2.08	0.00	2.22
Mining Applications	1.28	0.15	0.00	0.10	1.53
Wallboard	0.00	0.00	0.00	1.46	1.46
Waste Stabilization/Solidification	2.83	0.19	0.00	0.01	3.03
Agriculture	0.03	0.01	0.00	0.05	0.09
Miscellaneous/Other	0.33	0.38	0.03	0.17	0.90
Total Use	17.54	4.63	2.34	1.98	26.49
Individual Use Percentage	32.1%	30.2%	94.1%	8.7%	27.8%

Table 2. Coal combustion product production and use data (material handled dry) for 1997.

Dry and Moisture Conditioned CCP	Fly Ash	Bottom Ash	Boiler Slag	FGD Material	Total All CCPs
CCP Production	-----million metric tons-----				
Total CCP Production	37.57	9.30	0.82	12.34	60.03
Total CCP Disposed	22.63	6.12	0.14	9.86	38.75
Total CCP Removed from Disposal	0.63	0.20	0.03	0.00	0.85
Total CCP Stored On-Site	1.43	0.50	0.01	0.99	2.93
CCP Use					
Cement/Concrete/Grout	8.01	0.41	0.00	0.16	8.59
Flowable Fill	0.30	0.01	0.00	0.00	0.32
Structural Fills	1.34	0.35	0.04	0.00	1.73
Road Base/Subbase	1.21	0.90	0.00	0.00	2.11
Mineral Filler	0.26	0.12	0.01	0.00	0.39
Snow and Ice Control	0.00	0.40	0.01	0.00	0.41
Blasting Grit/Roofing Granules	0.00	0.08	0.64	0.00	0.72
Mining Applications	0.78	0.11	0.00	0.00	0.89
Wallboard	0.00	0.00	0.00	1.22	1.22
Waste Stabilization/Solidification	1.90	0.16	0.00	0.01	2.08
Agriculture	0.03	0.01	0.00	0.05	0.09
Miscellaneous/Other	0.23	0.31	0.00	0.04	0.58
Total Use	14.06	2.88	0.70	1.49	19.13
Individual Use Percentage	37.4%	31.0%	84.9%	12.0%	31.9%

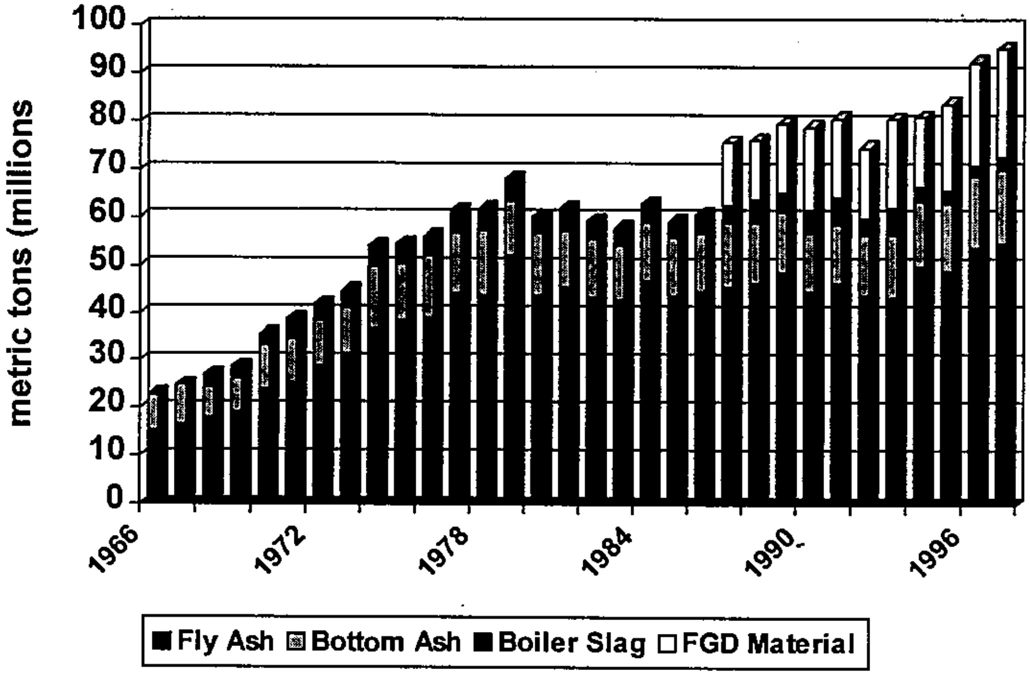

Figure 1. CCP production data for 1966-1997.

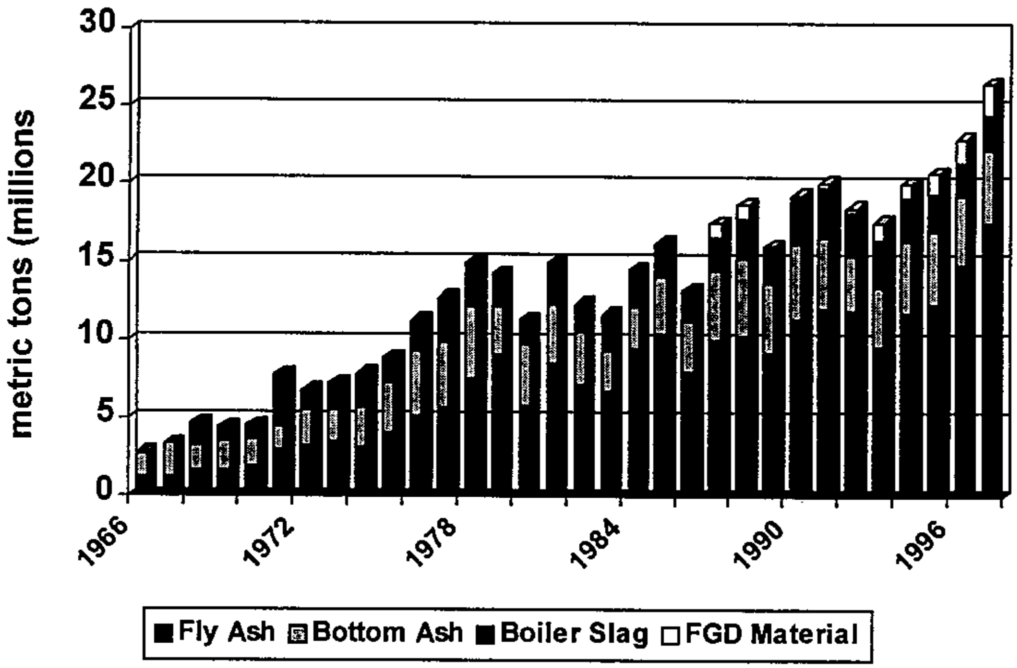

Figure 2. CCP use data 1966 - 1997.

conditioned state have a 32% usage rate compared with ponded CCPs, which have a 21% usage rate (Table 3). This usage gap is the largest for fly ash, 37% of which is represented by dry fly ash compared with 20% for wet fly ash.

Different types of CCPs possess distinct chemical and physical properties, making each suitable for particular applications. Fly ash has a siltlike texture and is pozzolanic in character. The largest volume use of any one CCP is the use of fly ash in cement, concrete, and grout. To be used in concrete and grout, fly ash usually needs to meet ASTM Standard C618 (American Society for Testing and Materials, 1996). The standards define two classes of fly ash-Class F ash has a low calcium content and is usually produced by burning bituminous coals, and Class C ash has a higher calcium content and is usually produced by the burning of sub bituminous coals. The standard also sets limits for carbon, sulfate, and alkali contents in the ash. When the appropriate standards are met, the fly ash can be used as a replacement for portland cement in concrete. Fly ash can also be used as kiln feed in the manufacture of cement, use as a material for structural fill, as a bulking and dewatering agent in waste stabilization, in mine reclamation, and as road base and subbase material.

The use of fly ash in concrete applications has increased during the past 15 years (Figure 3). The use of fly ash as a structural fill material has fluctuated between 1 and 2 million metric tons per year for the past decade. Use of ash in structural fill is expected to increase owing to the recently adopted ASTM Standard E1861 (American Society for Testing and Materials, 1997). The lack of standards for CCP use has been identified as a barrier to greater CCP use in the past. The use of fly ash in road base applications has remained steady at near 1 million tons per year. Use of fly ash in waste stabilization and flowable fill are two of the more-recent applications and show promise for increased use of fly ash. Flowable fill usage should increase owing to recent action by the U.S. Environmental Protection Agency to list flowable fills containing coal fly ash in Recovered Materials Advisory Notice III (U.S. Environmental Protection Agency, 1998). The notice provides guidance for procuring agencies in the purchase of certain items containing recovered materials, including flowable fill containing coal fly ash.

Bottom ash is the coarser of the two ash compounds and has a sandlike texture. Leading bottom ash uses include concrete, as either lightweight aggregate or kiln feed. Bottom ash is also used as a traction aid in snow and ice control, as structural fill, and for pipe-bedding material because of its lower density and good drainage characteristics.

More than 90% of the boiler slag produced is used as roofing granules and blasting grit. The material that is too fine to be used as roofing granules is primarily used as blasting grit. Some boiler slag is also used for snow and ice control. Because the number of boilers that produce boiler slag is decreasing, the amount of boiler slag is expected to decline in the coming years.

The SO_x-reduction provisions of CAAA '90, with its two-phase implementation plan, have forced electric utilities to find ways of reducing SO_x emissions. Many utilities have switched to low sulfur coal or fuel oil as a partial and (or) temporary solution to the problem. A significant number of those powerplants still using medium- or high-sulfur coal have installed flue gas desulfurization equipment. Wet lime FGD systems are most commonly used in the United States and yield FGD material in a wet form.

Table 3. Coal combustion product production and use data (material handled wet) for 1997

Wet (Ponded) CCPs	Fly Ash	Bottom Ash	Boiler Slag	FGD Material	Total All CCPs
CCP Production	-----million metric tons-----				
Total CCP Production	17.14	6.05	1.67	10.50	35.35
Total CCP Disposed	12.93	3.76	0.24	6.02	22.95
Total CCP Removed from Disposal	0.57	0.24	0.24	0.07	1.12
Total CCP Stored On-Site	1.74	0.93	0.05	4.03	6.76
CCP Use					
Cement/Concrete/Grout	0.54	0.13	0.01	0.02	0.71
Flowable Fill	0.05	0.00	0.00	0.00	0.05
Structural Fills	1.27	0.90	0.04	0.00	2.22
Road Base/Subbase	0.07	0.27	0.00	0.02	0.36
Mineral Filler	0.00	0.00	0.09	0.00	0.09
Snow and Ice Control	0.00	0.25	0.04	0.00	0.29
Blasting Grit/Roofing Granules	0.00	0.06	1.44	0.00	1.50
Mining Applications	0.50	0.03	0.00	0.09	0.63
Wallboard	0.00	0.00	0.00	0.23	0.23
Waste Stabilization/Solidification	0.93	0.02	0.00	0.00	0.95
Agriculture	0.00	0.00	0.00	0.00	0.00
Miscellaneous/Other	0.10	0.06	0.03	0.13	0.32
Total Use	3.47	1.75	1.64	0.50	7.36
Individual Use Percentage	20.3%	28.9%	98.6%	4.7%	20.8%

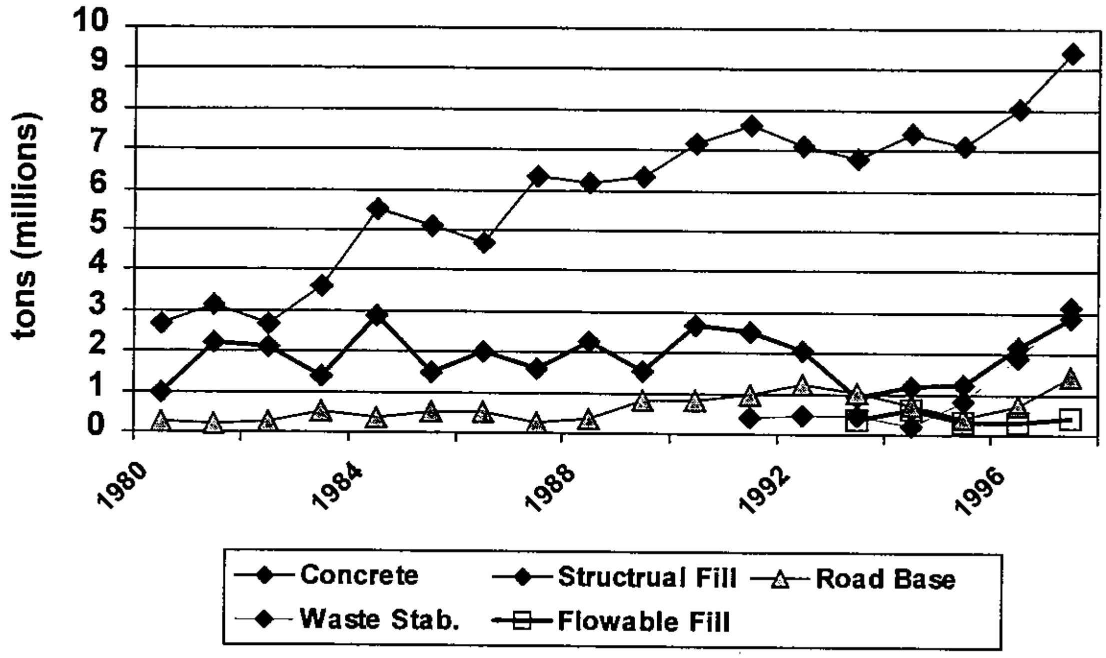

Figure 3. Fly ash use in selected applications, 1980 - 1997. Data is in short tons.

Although FGD units solve the SO_x problem, they also produce additional CCP in the process. Of the approximately 23 million tons of FGD material produced in 1997, slightly less than 9% was used (Table 1). Most of this use came as a substitute for mined gypsum in wallboard manufacture.

CCP Variability

The amount and types of CCPs produced at a given plant will be controlled by many factors including, coal source, boiler type, CCP collection and handling methods, and emission control technology used at the plant. The following is a brief summary of how these factors will affect the variability of CCPs.

Coal source

The coal source can have a great impact on the properties, and quantities of the types of the CCPs produced, mostly due to the chemical content of the coal. In general plants which burn high sulfur coal will be equipped with scrubbers and will produce substaintial amounts of FGD material in addition to fly ash, bottom ash or boiler slag. Plants burning low-sulfur (< 1.2 lbs S $Mbtu^{-1}$) may or may not be equipped with scrubbers and will produce lesser amounts of FGD material compared to an equal amount of high sulfur coal. A study of two power plants in Kentucky (Affolter, et. al., 1997) found that different coal sources affect the shape, fineness, particle-size distribution, and density of the fly ash produced.

The coal source will also determine the calcium content of the ash which is important in classification of the fly ash according to ASTM C618 *Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete.* This standard establishes two classes of coal fly ash for use in concrete based largely upon the amount of Al, Ca, Fe, and Si in the ash. The amount of Al, Fe, and Si varies inversely with the amount of Ca in the ash and Ca content varies with coal source (Table 4). Class F fly ashes are pozzolans, and contain low (<10%) amounts of CaO. Class C fly ashes are also pozzolans, and are also self cementing due to their higher CaO content. Although it is commonly believed that coal rank will determine the class of fly ash produced this is not always the case. Bituminous coals produce Class F fly ashes, but sub-bituminous coals and lignite coals produce Class F or Class C ash depending upon the chemical content of the coal.

The Clean Air Act and its Amendments have spurred the electric utilities to seek ways to reduce their SO_x emission. One way of doing this burning lower sulfur coal. In the 1970's large amounts of low sulfur sub-bituminous coal from the western U.S. (mainly from the Powder River basin in Wyoming and Montana) began to be mined and shipped eastward. Some utilities began buring this low-sulfur coal to meet air emission standards without the use of expensive scrubbers. This trend is evident in Table 5 which documents what types of coal are being burned in different regions of the U.S. The trend is clear; coal from the Powder River Basin is being shipped into eastern markets. Thus Class C fly ash available in many areas of the U.S.

The terms Class F and Class C fly ash imply that the ash meets the criteria for these classes in ASTM C618. Many fly ashes do not meet the criteria of this standard and should not be used in concrete applications. These ashes may be used in a number of other applications, however. The terms Class C and Class F are sometimes applied as generic terms for high calcium and low calcium ashes, respectively even though the ash may meet the standard criteria.

Table 4. Calcium content and classification of fly ash classification produced by combustion of coals from various sources (Tishmack and Olek, 1999).

Source Coal	**% CaO in Ash**	**Classification (ASTM C618)**
Appalachian Region "Eastern" (bituminous)	1-6	Class F
Powder River Basin "Wyoming" (subbituminous)	22-32	Class C
Illinois Basin (bituminous)	1-6	Class F
Gulf Coast "Texas" (lignite)	7-15	Class F
Fort Union "North Dakota" (lignite)	18-25	Class C

Table 5. Distribution of U.S. Coal Sales (Tishmack and Olek, 1999)

Where Coal is Used	Where Coal is Produced*					
Region and State	Total Coal Used (mst)	% Appal. Basin	% Illinois Basin	% Powder River Basin	% Gulf Coast	% Fort Union
New England						
Massachusetts	2.5	100				
New Hampshire	1.0	100				
Connecticut	1.6	100				
Mid Atlantic						
New Jersey	2.9	100				
New York	11.5	100				
Pennsylvania	59.1	100				
South Atlantic						
Delaware	1.8	100				
Florida	26.3	62	35	2		
Georgia	29.1	72	4	23		
Maryland	10.8	100				
North Carolina	27.4	100				
South Carolina	13.4	100				
Virginia	16.2	100				
West Virginia	36.0	100				
East North Central						
Illinois	44.5	9	40	45		
Indiana	62.7	17	53	30		
Michigan	33.2	44	1	55		
Ohio	61.7	100				
Wisconsin	26.3	9	6	79		
East South Central						
Alabama	33.1	17	16	11		
Kentucky	34.4	44	55			
Mississippi	5.7	19	33	39		
Tennessee	32.5	45	41	1		

Table 5. (cont)

Where Coal is Used	Where Coal is Produced*					
Region and State	Total Coal Used (mst)	% Appal. Basin	% Illinois Basin	% Powder River Basin	% Gulf Coast	% Fort Union
West North Central						
Iowa	21.0	3	6	87		
Kansas	14.0			85		
Minnesota	18.7	1	1	98		
Missouri	40.1	1		98		
Nebraska	10.7			100		
North Dakota	30.4			1		99
South Dakota	1.7			100		
West South Central						
Arkansas	14.9		1	98		
Louisiana	13.5	12			88	
Oklahoma	21.9			92		
Texas	95.4			45	55	
Mountain						
Arizona	15.8					
Colorado	16.9			36		
Idaho	3.3			80		
Montana	8.4			100		
Nevada	0.7			3		
New Mexico	1.5					
Utah	11.2	5				
Wyoming	26.8			99		
Pacific						
California	2.2					
Oregon	1.0	2		88		
Washington	4.8	1				

* Some coal producing regions such as the Warrior basin in Alabama, the Black Mesa Basin in Arizona, and the Centralia basin in Washington are not represented in these data.

Boiler type

The type of coal-fired boiler will determine the types and ratios of CCPs produced. Pulverized coal boilers make up the majority of the coal-fired boilers used by electric utilities. In preparation for combustion in these boilers, coal is pulverized to a fine powder (70% < 75 μm) and then is injected into the boiler with preheated air. In a pulverized dry-bottom furnace the ash particles are formed in an air suspension. Approximately 80% of the particles remain suspended and exit the furnace in the flue gas (fly ash) and 20% falls out of suspension and is removed from the bottom of the furnace (bottom ash). In a pulverized wet-bottom, or slag tap furnace, up to 50% of the ash forms on the walls of the boiler. The molten ash falls into a tank of water at the bottom of the boiler where it is quenched to form boiler slag. The other 50% of the ash exists the flue of the furnace as fly ash.

The cyclone boiler is capable for burning a wide variety of solid fuels. Coals burned in cyclone boilers are crushed but not pulverized. This results in more ash with a larger particle size. Between 70% to 80% of the ash produced by a cyclone boiler is bottom ash. The remaining 20% is fly ash.

Stoker-fired boilers were one of the earliest types of boilers used for the combustion of coal for steam production. These boilers use lump like coal (about 5 cm in diameter) and smaller, which is fed into the boiler using a chain grate conveyor. These boilers are generally inefficient in combustion and can have loss on ignition (LOI) (a measure of unburned carbon) of around 10% and ranging up to 60%. About 80% of the ash produced by a stoker boiler is fly ash and the remaining 20% is bottom ash.

Fluidized bed combustion (FBC) boilers are being used in greater numbers due to their ability to control SO_x emissions from high-sulfur coals without the need for flue gas treatment. In an FBC boiler the coal is crushed to 2.5 cm or less and injected into the boiler with limestone, lime or some other alkaline sorbent. The calcium (or other alkaline element) in the sorbent reacts with the SOx produced from the coal to form (assuming calcium was used) calcium sulfate, calcium sulfite, calcium oxide, and calcium hydroxide and coal ash. The finer particles, FBC fly ash, are collected using baghouses or electrostatic precipitators the coarser particles are collected from as FBC bed ash.

Recently a number of coal-fired boilers have been retro-fitted with "low NO_x" burners to further reduce air emissions. These installations usually affect the LOI of the fly ash. A general rule of thumb is that the LOI of a boiler may double when low NO_x burners are installed. Some operators have been able to lower the LOI by careful monitoring of combustion conditions.

Emission controls

The installed emission control devices are another determining factor on the CCPs produced and collected at a coal-fired utility. CCPs are removed from the flue gas stream using one or a combination of the the following: mechanical collectors, electrostatic precipitators (ESPs), baghouses, and FGD systems.

Mechanical collectors (often called cyclones) are used to collected larger fly ash particles from the flue gas stream. Mechanical collectors are most effective in collecting particles 10 μm or larger. Collection efficiency drops sharply for smaller particles, thus mechanical collectors are no longer used as primary collection systems. Fine fly ash collected downstream from a mechanical collector will be devoid of larger particles.

Baghouses and ESPs both have collection efficiencies of 99.8% or greater. These devices are often arranged in banks, typically the coarser ash is collected in the first bank and finer ash is collected in subsequent banks. This particle size gradient may effect the element distribution of elements (especially trace elements) within the ash (Affolter et. al., 1997).

FGD systems may be added to pulverized, cyclone and stoker boilers. FGD systems remove sulfur gases from the flue gases typically using a high-calcium sorbent such as limestone or lime. The three primary types of FGD systems are wet scrubbers, dry scubbers, and sorbent injection. Each of these systems produces a different suite of materials in its FGD material.

Wet scrubbers usually received flue gas after the fly ash has been removed. The flue gas is then spayed with a fine mist of a sorbent (usually lime or limestone) slurried with water. The sorbent reacts with the SO_2 to produce calcium sulfite and calcium sulfate. Some utilities use forced oxidation to produce an FGD that is a high purity gypsum which can be used in the manufacture of wall board, or applicaitons where gypsum is used. Without forced oxidation the material is mainly calcium sulfite. Wet FGD systems produce a product which contains a large amount of water and usually resembles toothpaste or oatmeal in consistency. Often these materials are mixed with a dry material (such as fly ash) to stabilize and dry them for easier handling.

In a dry scrubber lime is added to water to produce a slurry. This slurry is then sprayed into the flue gas stream which still contains fly ash. The fine slurry spray reacts with the SO_2 producing calcium sulfite and calcium sulfate, the heat of the flue gas evaporates some of the water, and the dry FGD material and the fly ash are collected dry without separation.

In direct sorbent injection, the sorbent (usually pulverized limestone or lime) is injected directly into the boiler for SO_2 control. The FGD material is collected dry along with the fly ash.

In many FGD systems the FGD material is mixed with fly ash and also contains un-reacted sorbent materials. These other materials must be taken into account when the FGD material is used.

Outlook

Increases in the production of fly ash and bottom ash will be proportional to the increase in coal used for electric power production and the level of environmental controls applied. DOE projects that U.S. coal production will increase 1% per year, to 1,268 million tons in the year 2015, from 1,033 million tons in 1996 (U.S. Department of Energy, 1997). Most of this increase will be used for domestic consumption. An increase in coal burn will lead to an increase in the production of CCPs. The largest growth in CCP production is expected to be in the form of increasing amounts and types of FGD materials.

Since its founding, the ACAA's goal has been to gain recognition and acceptance of CCP as engineering materials on a par with competing virgin, processed, and manufactured materials. It is clear from the survey data gathered by the ACAA during the past several years that the annual use of some 26 million tons of CCPs reflects a continuing marketing effort by the principals, including producers and marketers of CCPs and supporting organizations. It is equally clear, however, that significant quantities of CCPs are not used. It is essential for the ACAA to continue to promote the use of CCPs in applications that are technically sound, commercially competitive, and environmentally safe.

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