1.7 Lignite Combustion

1.7.1 General[1-5]

Coal is a complex combination of organic matter and inorganic ash formed over eons from successive layers of fallen vegetation. Coals are classified by rank according to their progressive alteration in the natural metamorphosis from lignite to anthracite. Coal rank depends on the volatile matter, fixed carbon, inherent moisture, and oxygen, although no one parameter defines rank. Typically coal rank increases as the amount of fixed carbon increases and the amount of volatile matter decreases.

Lignite is a coal in the early stages of coalification, with properties intermediate to those of bituminous coal and peat. The two geographical areas of the U. S. with extensive lignite deposits are centered in the States of North Dakota and Texas. The lignite in both areas has a high moisture content (20 to 40 weight percent) and a low heating value (5,000 to 7,500 British thermal units per pound [Btu/lb], on a wet basis). Due to high moisture content and low Btu value, shipping the lignite would not be feasible; consequently, lignite is burned near where it is mined. A small amount is used in industrial and domestic situations, but lignite is mainly used for steam/electric production in power plants. Lignite combustion has advanced from small stokers to large pulverized coal (PC) and cyclone-fired units (greater than 500 megawatt).

The major advantages of firing lignite are that it is relatively abundant (in the North Dakota and Texas regions), relatively low in cost since it is surface mined, and low in sulfur content which can reduce the need for postcombustion sulfur emission control devices. The disadvantages are that more fuel and larger, more capital-intensive facilities are necessary to generate a unit of power with lignite than is the case with bituminous coal. The disadvantages arise because: (1) lignite's lower heating value means more fuel must be handled to produce a given amount of power; (2) the energy and maintenance costs of coal handling equipment are higher; (3) the high inherent moisture content of lignite decreases boiler efficiency; and (4) the ash characteristics of lignite require more attention to sootblowing and boiler operation to maintain high availability and reliability.

1.7.2 Firing Practices[3]

In a pulverized lignite-fired boiler, the fuel is fed from the stock pile into bunkers adjacent to the boiler. From there, the fuel is metered into several pulverizers which grind it to approximately 200-mesh particle size. A stream of hot air from the air preheater begins the fuel-drying process and conveys the fuel pneumatically to the burner nozzle where it is injected into the burner zone of the boiler. Firing configurations of boilers that fire pulverized lignite include tangential, horizontally opposed, front wall, cyclone, stoker, and fluidized bed combustor.

In the tangential firing method, the pulverized lignite is introduced from the corners of the boiler in vertical rows of burner nozzles. Such a firing mechanism produces a vortexing flame pattern which essentially uses the entire furnace enclosure as a burner. In front-wall firing and horizontally opposed firing boilers, the pulverized coal is introduced into the burner zone through a horizontal row of burners. This type of firing mechanism produces a more intense combustion pattern than the tangential design and has a slightly higher heat release rate in the burner zone itself.

In these methods of firing pulverized lignite, the ash is removed from the furnace both as fly ash and bottom ash. The bottom of the furnace is often characterized as either wet or dry, depending on whether the ash is removed as a liquid slag or as a solid. Pulverized coal units have been designed for both wet and dry bottoms, but the current practice is to design only dry bottom furnaces.

Another type of boiler firing lignite is the cyclone burner, which is a slag-lined high-temperature vortex burner. The coal is fed from the storage area to a crusher that reduces the lignite into particles of approximately 0.25 inch in diameter or less. Crushed lignite is partially dried in the crusher and is then fired in a tangential or vortex pattern into the cyclone burner. The temperature within the burner is hot enough to melt the ash to form a slag. Centrifugal force from the vortex flow forces the melted slag to the outside of the burner where it coats the burner walls with a thin layer of slag. As the solid lignite particles are fed into the burner, they are forced to the outside of the burner and are imbedded in the slag layer. The solid lignite particles are trapped there until complete burnout is attained. The ash from the burner is continuously removed through a slag tap which is flush with the furnace floor.

In a stoker furnace, the lignite is spread across a grate to form a bed which burns until the lignite is completely burned out. In such a mechanism, the lignite is broken up into approximately 2-inch pieces and is fed into the furnace by one of several feed mechanisms: underfeed, overfeed, or spreading. In most stoker units, the grate on which the lignite is burned gradually moves from one end of the furnace to the other. The lignite is spread on the grate in such a fashion that at the end of the grate only ash remains (i.e., all of the lignite has been burned to the final ash product). When the ash reaches the end of the grate, it falls into an ash collection hopper and is removed from the furnace. Stoker furnaces are dry-bottom furnaces and, as such, generally have lower heat release rates and lower temperature profiles than the corresponding pulverized or cyclone units.

There are two major categories of fluidized bed combustors (FBCs): (1) atmospheric FBCs, operating at or near ambient pressures, and (2) pressurized FBCs, operating between 4 and 30 atmospheres (60 to 450 pounds per square inch gauge). Pressurized FBC systems are not considered a demonstrated technology for lignite combustion. The two principal types of atmospheric FBCs are bubbling bed and circulating bed. The fundamental distinguishing feature between these types is the fluidization velocity. In the bubbling bed design, the fluidization velocity is relatively low, in order to minimize solids carryover or elutriation from the combustor. Circulating FBCs, however, employ high fluidization velocities to promote the carryover or circulation of the solids. High temperature cyclones are used in circulating bed FBCs and in some bubbling bed FBCs to capture the unburned solid fuel and bed material for return to the primary combustion chamber for more efficient fuel utilization.

1.7.3 Emissions [2-4,6-13]

The emissions generated from firing lignite, as with any coal, include the criteria pollutants particulate matter (PM), PM less than, or equal to, 10 micrometers in diameter (PM-10), sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and total organic compounds (TOC). The other pollutants generated include greenhouse gases, organics, trace elements, and acid gases.

Particulate Matter Emissions -

Emission levels for PM from lignite combustion are directly related to the ash content of the lignite and the firing configuration of the boiler. Pulverized coal-fired units fire much or all of the lignite in suspension. Cyclone furnaces collect much of the ash as molten slag in the furnace itself. Stokers (other than spreader) retain a large fraction of the ash in the fuel bed and bottom ash. Spreader stokers fire about 15 percent of the coal in suspension and the remainder in a bed.

Sulfur Oxides Emissions -

The SO_x emissions from lignite combustion are a function of the sulfur content of the lignite and the lignite composition (i.e., sulfur content, heating value, and alkali concentration). The conversion of lignite sulfur to SO_x is generally inversely proportional to the concentration of alkali constituents in the lignite. The alkali content is known to have a great effect on sulfur conversion and acts as a built-in sorbent for SO_x removal.

Nitrogen Oxides Emissions -

The NO_x emissions from lignite combustion are mainly a function of the boiler design, firing configuration, and excess air level. Tangential units, stoker boilers, and FBCs typically produce lower NO_x levels than wall-fired units and cyclones. The boilers constructed since implementation of the 1971 and 1979 New Source Performance Standards (40 Code of Federal Regulations, Part 60, Subparts D and Da, respectively) have NO_x controls integrated into the boiler design and have NO_x emission levels that are comparable to emission levels from small stokers. In most boilers, regardless of firing configuration, lower excess combustion air results in lower NO_x emissions. However, lowering the amount of excess air in a lignite-fired boiler can also affect the potential for ash fouling.

Carbon Monoxide Emissions[14] -

The CO emission rate from combustion sources depends on the oxidation efficiency of the fuel. By controlling the combustion process carefully, CO emissions can be minimized. Thus, if a unit is operated improperly or not maintained, the resulting concentrations of CO (as well as organic compounds) may increase by several orders of magnitude.

Greenhouse Gases [15-20] -

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions are all produced during lignite combustion. Nearly all of the fuel carbon (99 percent) in lignite is converted to CO_2 during the combustion process. This conversion is relatively independent of firing configuration. Although the formation of CO acts to reduce CO_2 emissions, the amount of CO produced is insignificant compared to the amount of CO_2 produced. The majority of the fuel carbon not converted to CO_2 is due to incomplete combustion and is entrained in the bottom ash.

Formation of N_2O during the combustion process is governed by a complex series of reactions and its formation is dependent upon many factors. Formation of N_2O is minimized when combustion temperatures are kept high (above 1475^oF) and excess air is kept to a minimum (less than 1 percent). N_2O emissions for lignite combustion are not significant except for fluidized bed combustion, where localized areas of lower temperatures in the fuel bed produce N_2O emissions significantly higher than emissions from stokers.

Methane emissions vary with the type of coal being fired and firing configuration, but are highest during periods of incomplete combustion, such as the start-up or shut-down cycle for coal-fired boilers. Typically, conditions that favor formation of N_2O also favor emissions of CH_4.

Organic Compounds -

Trace amounts of organic compounds are emitted during lignite combustion. As with CO emissions, the rate at which organic compounds are emitted depends on the combustion efficiency of the boiler. Therefore, combustion modifications that change combustion residence time, temperature, or turbulence may increase concentrations of organic compounds in the flue gas.

Organic emissions include volatile, semivolatile, and condensable organic compounds either present in the lignite or formed as a product of incomplete combustion (PIC). Organic emissions are primarily characterized by the criteria pollutant class of unburned vapor-phase hydrocarbons. These emissions include alkanes, alkenes, aldehydes, alcohols, and substituted benzenes (e.g., benzene, toluene, xylene, and ethyl benzene).

Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/PCDF) are formed during the combustion of lignite. Of primary interest environmentally are tetrachloro- through octachloro- dioxins and furans. Dioxin and furan emissions are influenced by the extent of destruction of organics during combustion and through reactions in the air pollution control equipment. The formation of PCDD/PCDF in air pollution control equipment is primarily dependent on flue gas temperature, with maximum potential for formation occurring at flue gas temperatures of 450 degrees to 650 degrees Fahrenheit.

The remaining organic emissions are composed largely of compounds emitted from combustion sources in a condensed phase. These compounds can almost exclusively be classed into a group known as polycyclic organic matter (POM), and a subset of compounds called polynuclear aromatic hydrocarbons (PNA or PAH).

Trace Metals-

Trace metals are also emitted during lignite combustion. The quantity of any given metal emitted, in general, depends on:

- the physical and chemical properties of the metal itself;
- the concentration of the metal in the lignite;
- the combustion conditions; and
- the type of particulate control device used, and its collection efficiency as a function of particle size.

Acid Gases-

In addition to SO_x and NO_x emissions, combustion of lignite also results in emissions of chlorine and fluorine, primarily in the form of hydrogen chloride (HCl) and hydrogen fluoride (HF). Lesser amounts of chlorine gas and fluorine gas are also emitted. A portion of the chlorine and fluorine in the fuel may be absorbed onto fly ash or bottom ash. Both HCl and HF are water soluble and are readily controlled by acid gas scrubbing systems.

1.7.4 Controls[2-4,6-13]

Particulate Matter -

The primary PM control systems for lignite-fired utility boilers are electrostatic precipitators (ESPs) and fabric filters (baghouses) with collection efficiencies as high as 99.5 percent. Older and smaller ESPs can have lower collection efficiencies of approximately 95 percent for total PM.

Multiple cyclone collectors and scrubbers are typically used alone, or in series, with an ESP or baghouse on small industrial stoker boilers and normally achieve 60 to 80 percent collection efficiency for total PM.

Sulfur Oxides[14] -

Flue gas desulfurization (FGD) systems are in current operation on several lignite-fired utility boilers. Flue gases can be treated through wet, semi-dry, or dry desulfurization processes of either the throwaway type (in which all waste streams are discarded) or the recovery (regenerable) type (in which the SO_x absorbent is regenerated and reused). To date, wet systems are the most commonly applied. Wet systems generally use alkali slurries as the SO_x absorbent medium and can be designed to remove in excess of 90 percent of the incoming SO_x. Lime/limestone scrubbers, sodium scrubbers, spray drying, and dual alkali scrubbing are among the commercially proven FGD techniques.

Spray drying is a dry scrubbing approach in which a solution or slurry of alkaline material is sprayed into a reaction vessel as a fine mist and mixes with the flue gas. The SO_2 reacts with the alkali solution or slurry to form liquid-phase salts. The slurry is dried by the latent heat of the flue gas to about 1 percent free moisture. The dried alkali continues to react with SO_2 in the flue gas to form sulfite and sulfate salts. The spray dryer solids are entrained in the flue gas and carried out of the dryer to a particulate control device such as an ESP or baghouse.

Limestone may also be injected into the furnace, typically in an FBC, to react with sulfur dioxide (SO_2) and form calcium sulfate. An FBC is composed of a bed of inert material that is suspended or "fluidized" by a stream of air. Lignite is injected into this bed and burned. Limestone is also injected into this bed where it is calcined to lime and reacts with SO_2 to form calcium sulfate. Particulate matter emitted from the boiler is generally captured in a cyclone and recirculated or sent to disposal. Additional PM control equipment, such as an ESP or baghouse, is used after the cyclone to further reduce particulate emissions.

Nitrogen Oxides[21] -

The most common NO_x control technique for lignite-fired boilers is overfire air (OFA) which involves diverting a portion of the total combustion air (5 to 20 percent) from the burners and injecting it through dedicated air ports above the top level of burners. OFA can be applied to tangential-fired, wall-fired, and stoker boilers; however, it cannot be used on cyclone boilers or other slag-tapping furnaces because it can alter the heat release profile of the boiler which can change the slagging characteristics of the boiler. Depending on the design of the existing furnace, OFA can be a retrofit technology that may achieve 20 to 30 percent NO_x reduction from uncontrolled levels. It is a typical NO_x control technique used in new Subpart D and Subpart Da boilers.

Another NO_x control technique used on lignite-fired boilers is low NO_x burners (LNB) which limit NO_x formation by controlling both the stoichiometric and temperature profiles of the combustion process. LNBs can be retrofit in existing tangential- and wall-fired boilers or installed in new boilers; however, they are not applicable to cyclone boilers since the fuel is fired in cylindrical chambers in the cyclone boiler rather than with conventional burners. Depending on boiler design and the desired NO_x level, OFA and LNB can be applied separately, or in combination, to achieve as much as 50-60 percent reduction from uncontrolled levels.

1.7.5 Emission Factors

Uncontrolled emission factors for SO_x, NO_x, CO, and CO_2 are presented in Table 1.7-1. Controlled emission factors for SO_x are presented in Table 1.7-2 and for NO_x and CO in Table 1.7-3.

Table 1.7-4 presents uncontrolled emission factors for PM and N_2O, and controlled emission factors for PM are shown in Table 1.7-5. Cumulative particle size distributions and particle size-specific emission factors are provided in Tables 1.7-6 and 1.7-7. In addition, particle size-specific emission factors are presented graphically in Figures 1.7-1 and 1.7-2.

Tables 1.7-8 through 1.7-10 present emission factors for polynuclear organic matter (POM), polynuclear aromatic hydrocarbons (PAH), and various organic compounds, respectively.
Table 1.7-14 presents emission factors for hydrogen chloride and hydrogen fluoride.

Table 1.7-11 presents emission factor equations that may be used to estimate controlled and uncontrolled emissions of nine trace metals. Table 1.7-12 presents uncontrolled emission factors for trace metals, and Table 1.7-13 presents controlled emission factors. The emission factor equations are based on statistical correlations among measured trace element concentrations in coal, measured fractions of ash in coal, and measured particulate emissions. Because these are the major parameters affecting trace metals emissions, it is recommended that the emission factor equations be used to estimate uncontrolled and controlled emissions when the inputs to the equations are available. If the inputs to the emission factor equations are not available for a pollutant and there is an emission factor in Table 1.7-12 or Table 1.7-13, then the emission factor(s) could be used to estimate emissions.

Tables in this section present emission factors on both a weight basis (lb/ton) and an energy basis ($lb/10^{12}Btu$). Emission factors in units of lb/ton can be converted to units of lb/MMBtu by multiplying the emission factor by 0.077, assuming a heating value for lignite of 6500 Btu/lb.

1.7.6 Updates Since the Fifth Edition

The Fifth Edition was released in January 1995. Revisions to this section since that date are summarized below. For further detail, consult the memoranda describing each supplement or the background report for this section. These and other documents can be found on the CHIEF electronic bulletin board (919-541-5742), or on the new EFIG home page (http://www.epa.gov/oar/oaqps/efig/).

Supplement A, February 1996

- In the table for SO_x emission factors, the footnote "f" was moved into the header of the SO_x column, and “other stoker” was clarified as a traveling grate (overfeed) stoke. Text was added to the same table to clarify that “S” is a weight percent and not a fraction.

- In the tables for PM factors, text was added to the footnotes to clarify that “A” is a weight percent and not a fraction.

Supplement B, October 1996

- Text was enhanced concerning lignite coal characteristics.

- Text was updated and enhanced concerning firing practices, emissions, and controls.

- The SO_x emission factor was updated and a CO_2 emission factor was added for all categories.

- The table containing NO_x and CO factors from controlled sources was revised to present data by appropriate categories.

- New factors for controlled SO_x were added.
- All POM factors were revised.
- New tables were added with new HAP emission factors.
- References were editorially corrected.

Table 1.7-1. EMISSION FACTORS FOR SO_x, NO_x, CO, AND CO_2 FROM UNCONTROLLED LIGNITE COMBUSTION[a]

EMISSION FACTOR RATING: C (except as noted)

Firing Configuration	SO_x Emission Factor[b] (lb/ton)	NO_x Emission Factor[c] (lb/ton)	CO Emission Factor[d] (lb/ton)	CO_2 Emission Factor[e] (lb/ton)
Pulverized coal, dry bottom, tangential (SCC 1-01-003-02)	30S	7.3	ND	72.6C
Pulverized coal, dry bottom, wall-fired (SCC 1-01-003-01)	30S	11.1	0.25	72.6C
Cyclone (SCC 1-01-003-03)	30S	12.5	ND	72.6C
Spreader stoker (SCC 1-01-003-06)	30S	5.8	ND	72.6C
Traveling Grate Overfeed stoker (SCC 1-01-003-04)	30S	ND	ND	72.6C
Atmospheric fluidized bed (SCC 1-01-003-17/18)	10S[f]	3.6	0.15[g]	72.6C

[a] To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data.

[b] Reference 2. S = Weight % sulfur content of lignite, wet basis. For example, if the sulfur content equals 3.4%, then S = 3.4. For high sodium ash ($Na_2O > 8\%$), use 22S. For low sodium ash ($Na_2O < 2\%$), use 34S. If ash sodium content is unknown, use 30S.

[c] References 2-3, 8-9, 22-23.

[d] References 8, 23.

[e] EMISSION FACTOR RATING: B. C = Weight % carbon of lignite, as-fired basis. For example, if carbon content equals 63%, then C = 63. If the %C value is not known, a default CO_2 emission value of 4600 lb/ton may be used.

[f] EMISSION FACTOR RATING: D

[g] Emission factor is for circulating fluidized bed only SCC = 1-01-003-18.

Table 1.7-2. EMISSION FACTORS FOR SO_x FROM CONTROLLED LIGNITE COMBUSTION[a]

EMISSIONS FACTOR RATING: D (except as noted)

Firing Configuration	Control Device	Emission Factor (lb/ton)
Subpart D boilers:[b]		
Pulverized coal (SCC 1-01-003-01/-02)	Spray dryer	7.3S
Pulverized coal (SCC 1-01-003-01/-02)	Wet scrubber	16.8S[c]
Subpart Da boilers:[b]		
Pulverized coal (SCC 1-01-003-01/-02)	Spray dryer	7.9S
Pulverized coal (SCC 1-01-003-01/-02)	Wet scrubber	3.7S[c]

[a] References 22-23. S = weight % sulfur content of lignite, wet basis. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code.

[b] Subpart D boilers are boilers constructed after August 17, 1971 and with a heat input rate greater than 250 million Btu per hour (MMBtu/hr). Subpart Da boilers are boilers constructed after September 18, 1978 and with a heat input rate greater than 250 MMBtu/hr.

[c] EMISSION FACTOR RATING: C

Table 1.7-3. EMISSION FACTORS FOR NO_x AND CO FROM CONTROLLED LIGNITE COMBUSTION[a]

Firing Configuration	Control Device	NO_x[b] Emission Factor (lb/ton)	NO_x[b] EMISSION FACTOR RATING	CO[c] Emission Factor (lb/ton)	CO[c] EMISSION FACTOR RATING
Subpart D boilers:[d]					
Pulverized coal, tangential-fired (SCC 1-01-003-02)	Overfire Air	6.8	C	ND	NA
Pulverized coal, wall-fired (SCC 1-01-003-01)	Overfire air and low NO_x burners	4.6	C	0.48	D
Subpart Da boilers:[d]					
Pulverized coal, tangential-fired (SCC 1-01-003-02)	Overfire Air	6.0	C	0.1	D

[a] To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data. NA = not applicable.

[b] References 22-23.

[c] Reference 22.

[d] Subpart D boilers are boilers constructed after August 17, 1971 and with a heat input rate greater than 250 million Btu per hour (MMBtu/hr). Subpart Da boilers are boilers constructed after September 18, 1978 and with a heat input rate greater than 250 MMBtu/hr.

Table 1.7-4. EMISSION FACTORS FOR PM AND N_2O FROM UNCONTROLLED LIGNITE COMBUSTION[a]

EMISSION FACTOR RATING: E (except as noted)

Firing Configuration	PM Emission Factor[b] (lb/ton)	N_2O Emission Factor[c] (lb/ton)
Pulverized coal, dry bottom, tangential (SCC 1-01-003-02)	6.5A	ND
Pulverized coal, dry bottom, wall fired (SCC 1-01-003-01)	5.1A	ND
Cyclone (SCC 1-01-003-03)	6.7A[d]	ND
Spreader stoker (SCC 1-01-003-06)	8.0A	ND
Other stoker (SCC 1-01-003-04)	3.4A	ND
FBC, Circulating bed (SCC 1-01-003-18)	ND	2.5

[a] To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data.

[b] References 6-7, 24-25. A = weight % ash content of lignite, wet basis. For example, if the ash content is 5%, then A = 5.

[c] Reference 26.

[d] EMISSION FACTOR RATING: C

Table 1.7-5. EMISSION FACTORS FOR PM EMISSIONS FROM CONTROLLED LIGNITE COMBUSTION[a]

EMISSION FACTOR RATING: C (except as noted)

Firing Configuration	Control Device	PM Emission Factor (lb/ton)
Subpart D Boilers[b] (SCC 1-01-003-01/-02)	Baghouse Wet scrubber	0.08A 0.05A
Subpart Da Boilers[b] (SCC 1-01-003-01/-02)	Wet scrubber	0.01A
FBC, Circulating bed and bubbling bed (SCC 1-01-003-17/18)[b,c]	Limestone addition	0.07A

[a] References 22-23. A = weight % ash content of lignite, wet basis. For example, if lignite is 2.3% ash, then A = 2.3. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code.

[b] Subpart D boilers are boilers constructed before August 17, 1971, and with a heat input rate greater than 250 million Btu per hour (MMBtu/hr). Subpart Da boilers are boilers constructed after September 18, 1978, and with a heat input rate greater than 250 MMBtu/hr.

[c] EMISSION FACTOR RATING: D.

Table 1.7-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR BOILERS FIRING PULVERIZED LIGNITE[a]

EMISSION FACTOR RATING: E

Particle Size[b] (µm)	Cumulative Mass % ≤ Stated Size		Cumulative Emission Factor[c] (lb/ton)	
	Uncontrolled	Multiple Cyclone Controlled	Uncontrolled	Multiple Cyclone Controlled[d]
15	51	77	3.4A	1.0A
10	35	67	2.3A	0.88A
6	26	57	1.7A	0.75A
2.5	10	27	0.66A	0.36A
1.25	7	16	0.47A	0.21A
1.00	6	14	0.40A	0.19A
0.625	3	8	0.19A	0.11A
TOTAL			6.6A	1.3A

[a] Reference 27. Based on tangential-fired units (Source Classification Code 1-01-003-02). For wall-fired units (Source Classification Code 1-01-003-01), multiply emission factors in the table by 0.79.

[b] Expressed as aerodynamic equivalent diameter.

[c] A = weight % ash content of lignite, wet basis. For example, if lignite is 3.4% ash, then A = 3.4. To convert from lb/ton to kg/Mg, multiply by 0.5.

[d] Estimated control efficiency for multiple cyclone is 80%, averaged over all particle sizes.

Table 1.7-7. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR LIGNITE-FIRED SPREADER STOKERS[a]

EMISSION FACTOR RATING: E

Particle Size[b] (µm)	Cumulative Mass % ≤ Stated Size		Cumulative Emission Factor[c] (lb/ton)	
	Uncontrolled	Multiple Cyclone Controlled	Uncontrolled	Multiple Cyclone Controlled[d]
15	28	55	2.2A	0.88A
10	20	41	1.6A	0.66A
6	14	31	1.1A	0.50A
2.5	7	26	0.56A	0.42A
1.25	5	23	0.40A	0.37A
1.00	5	22	0.40A	0.35A
0.625	4	—[e]	0.33A	—[e]
TOTAL			8.0A	1.6A

[a] Reference 27. Source Classification Code 1-01-003-06.

[b] Expressed as aerodynamic equivalent diameter.

[c] A = weight % ash content of lignite, wet basis. For example, if the lignite is 5% ash, then A = 5. To convert from lb/ton to kg/Mg, multiply by 0.5.

[d] Estimated control efficiency for multiple cyclone is 80%.

[e] Insufficient data.

Table 1.7-8. EMISSION FACTORS FOR POM FROM CONTROLLED LIGNITE COMBUSTION[a]

EMISSION FACTOR RATING: E

Firing Configuration	Control Device	Emission Factor (lb/10^{12} Btu)
		POM
Pulverized coal (SCC 1-01-003-01)	High efficiency cold-side ESP	2.3
Pulverized dry bottom (no SCC)	Multi-cyclones	1.8 - 18[b]
	ESP	2.6[b]
Cyclone furnace (SCC 1-01-003-03)	ESP	0.11[c] - 1.6[b]
Spreader stoker (SCC 1-01-003-06)	Multi-cyclones	15[c]

[a] References 28-29. To convert from lb/10^{12} Btu to pg/J, multiply by 0.43. SCC = Source Classification Code. ND = no data.

[b] Primarily trimethyl propenyl naphthalene.

[c] Primarily biphenyl.

Table 1.7-9 EMISSION FACTORS FOR POLYNUCLEAR AROMATIC HYDROCARBONS (PAH) FROM CONTROLLED COAL COMBUSTION[a]

Pollutant	Emission Factor[b] (lb/ton)	EMISSION FACTOR RATING
Biphenyl	1.7E-06	D
Acenaphthene	5.1E-07	B
Acenaphthylene	2.5E-07	B
Anthracene	2.1E-07	B
Benzo(a)anthracene	8.0E-08	B
Benzo(a)pyrene	3.8E-08	D
Benzo(b,j,k)fluoranthene	1.1E-07	B
Benzo(g,h,i)perylene	2.7E-08	D
Chrysene	1.0E-07	C
Fluoranthene	7.1E-07	B
Fluorene	9.1E-07	B
Indeno(1,2,3-cd)pyrene	6.1E-08	C
Naphthalene	1.3E-05	C
Phenanthrene	2.7E-06	B
Pyrene	3.3E-07	B
5-Methyl chrysene	2.2E-08	D

[a] References 30-40. Factors were developed from emissions data from six sites firing bituminous coal, four sites firing subbituminous coal, and from one site firing lignite. Factors apply to boilers utilizing both wet limestone scrubbers or spray dryers with an electrostatic precipitator (ESP) or fabric filter (FF). The factors also apply to boilers utilizing only an ESP or FF. SCCs = pulverized coal-fired boilers, 1-01-003-01, 1-02-003-01, 1-03-003-05; pulverized coal tangentially-fired boilers, 1-01-003-02, 1-02-003-02, 1-03-003-06; and cyclone boilers, 1-01-003-03, and 1-02-003-03.

[b] Emission factor should be applied to coal feed, as fired. To convert from lb/ton to kg/Mg, multiply by 0.5. Emissions are lb of pollutant per ton of coal combusted.

Table 1.7-10 EMISSION FACTORS FOR VARIOUS ORGANIC COMPOUNDS FROM CONTROLLED COAL COMBUSTION[a]

Pollutant[b]	Emission Factor[c] (lb/ton)	EMISSION FACTOR RATING
Acetaldehyde	5.7E-04	C
Acetophenone	1.5E-05	D
Acrolein	2.9E-04	D
Benzene	1.3E-03	A
Benzyl chloride	7.0E-04	D
Bis(2-ethylhexyl)phthalate (DEHP)	7.3E-05	D
Bromoform	3.9E-05	E
Carbon disulfide	1.3E-04	D
2-Chloroacetophenone	7.0E-06	E
Chlorobenzene	2.2E-05	D
Chloroform	5.9E-05	D
Cumene	5.3E-06	E
Cyanide	2.5E-03	D
2,4-Dinitrotoluene	2.8E-07	D
Dimethyl sulfate	4.8E-05	E
Ethyl benzene	9.4E-05	D
Ethyl chloride	4.2E-05	D
Ethylene dichloride	4.0E-05	E
Ethylene dibromide	1.2E-06	E
Formaldehyde	2.4E-04	A
Hexane	6.7E-05	D
Isophorone	5.8E-04	D
Methyl bromide	1.6E-04	D
Methyl chloride	5.3E-04	D
Methyl ethyl ketone	3.9E-04	D
Methyl hydrazine	1.7E-04	E
Methyl methacrylate	2.0E-05	E
Methyl tert butyl ether	3.5E-05	E
Methylene chloride	2.9E-04	D

Table 1.7-10 (continued)

Pollutant[b]	Emission Factor[c] (lb/ton)	EMISSION FACTOR RATING
Phenol	1.6E-05	D
Propionaldehyde	3.8E-04	D
Tetrachloroethylene	4.3E-05	D
Toluene	2.4E-04	A
1,1,1-Trichloroethane	2.0E-05	E
Styrene	2.5E-05	D
Xylenes	3.7E-05	C
Vinyl acetate	7.6E-06	E

[a] References 30-48. Factors were developed from emissions data from ten sites firing bituminous coal, eight sites firing subbituminous coal, and from one site firing lignite. The emission factors are applicable to boilers using both wet limestone scrubbers or spray dryers and an electrostatic precipitator (ESP) or fabric filter (FF). In addition, the factors apply to boilers utilizing only an ESP or FF. SCCs = pulverized coal-fired boilers, 1-01-003-01, 1-02-003-01, 1-03-003-05; pulverized coal tangentially-fired boilers, 1-01-003-02, 1-02-003-02, 1-03-003-06; cyclone boilers, 1-01-003-03, 1-02-003-03; and atmospheric fluidized bed combustor, circulating bed, 1-01-003-18. This table is similar to Table 1.1-13 and is reproduced here for the convenience of the reader.

[b] Pollutants sampled for but not detected in any sampling run include: Carbon tetrachloride- 2 sites; 1,3-Dichloropropylene- 2 sites; N-nitrosodimethylamine- 2 sites; Ethylidene dichloride- 2 sites; Hexachlorobutadiene- 1 site; Hexachloroethane- 1 site; Propylene dichloride- 2 sites; 1,1,2,2-Tetrachloroethane- 2 sites; 1,1,2-Trichloroethane- 2 sites; Vinyl chloride- 2 sites; and, Hexachlorobenzene- 2 sites.

[c] Emission factor should be applied to coal feed, as fired. To convert from lb/ton to kg/Mg, multiply by 0.5.

Table 1.7-11. TRACE METAL EMISSION FACTOR EQUATIONS FOR FROM COAL COMBUSTION[a]

EMISSION FACTOR EQUATION RATING: A[b]

Pollutant	Emission Factor Equation ($lb/10^{12}$ Btu)[c]
Antimony	$0.92 * (C/A * PM)^{0.63}$
Arsenic	$3.1 * (C/A * PM)^{0.85}$
Beryllium	$1.2 * (C/A * PM)^{1.1}$
Cadmium	$3.3 * (C/A * PM)^{0.5}$
Chromium	$3.7 * (C/A * PM)^{0.58}$
Cobalt	$1.7 * (C/A * PM)^{0.69}$
Lead	$3.4 * (C/A * PM)^{0.80}$
Manganese	$3.8 * (C/A * PM)^{0.60}$
Nickel	$4.4 * (C/A * PM)^{0.48}$

[a] Reference 49. The equations were developed from emissions data from bituminous coal combustion, subbituminous coal combustion, and from lignite combustion. The equations should be used to generate factors for controlled boilers when the necessary input information is available. The emission factor equations are applicable to all typical firing configurations and PM controls for electric generation (utility), industrial, and commercial/industrial boilers firing bituminous coal, subbituminous coal, or lignite. Thus, all SCCs for these boilers are assigned to the equations.

[b] AP-42 criteria for rating emission factors were used to rate the equations.

[c] The factors produced by the equations should be applied to heat input. To convert from $lb/10^{12}$ Btu to kg/joules multiply by 4.31×10^{-16}.
C = concentration of metal in the coal, parts per million by weight (ppmwt).
A = weight fraction of ash in the coal. For example, 10% ash is 0.1 ash fraction.
PM = Site-specific emission factor for total particulate matter, $lb/10^6$ Btu.

Table 1.7-12. EMISSION FACTORS FOR TRACE ELEMENTS FROM UNCONTROLLED LIGNITE COMBUSTION[a]

EMISSION FACTOR RATING: E

Firing Configuration	Emission Factor (lb/10^{12}Btu)						
	As	Be	Cd	Cr	Mn	Hg	Ni
Pulverized, wet bottom (no SCC)	2730	131	49 - 77	1220 - 1880	4410 - 16,250	21	154 - 1160
Pulverized, dry bottom (no SCC)	1390	131	49	1500 - 1880	16,200	21	928 - 1160
Cyclone furnace (SCC 1-01-003-03)	235 - 632	131	31	253 - 1880	3,760	21	157 - 1160
Stoker configuration unknown (no SCC)	ND	118	ND	ND	11,800	21	ND
Spreader stoker (SCC 1-01-003-06)	538 - 1100	ND	23 - 47	1130 - 1880	ND	ND	696 - 1160
Traveling grate (overfed) stoker (SCC 1-01-003-04)	1100 - 2100	ND	47 - 90	ND	ND	ND	ND

[a] References 28-29. To convert from lb/10^{12} Btu to pg/J, multiply by 0.43. SCC = Source Classification Code. ND = no data.

Table 1.7-13 EMISSION FACTORS FOR TRACE METALS FROM CONTROLLED COAL COMBUSTION[a]

Pollutant	Emission Factor (lb/ton)[b]	EMISSION FACTOR RATING
Antimony	1.8E-05	A
Arsenic	4.1E-04	A
Beryllium	2.1E-05	A
Cadmium	5.1E-05	A
Chromium	2.6E-04	A
Chromium (VI)	7.9E-05	D
Cobalt	1.0E-04	A
Lead	4.2E-04	A
Magnesium	1.1E-02	A
Manganese	4.9E-04	A
Mercury	8.3E-05	A
Nickel	2.8E-04	A
Selenium	1.3E-03	A

[a] References 30-48, 50-58. The emission factors were developed from emissions data at eleven facilities firing bituminous coal, fifteen facilities firing subbituminous coal, and from two facilities firing lignite. The factors apply to boilers utilizing either venturi scrubbers, spray dryer absorbers, or wet limestone scrubbers with an electrostatic precipitator (ESP) or Fabric Filter (FF). In addition, the factors apply to boilers using only an ESP, FF, or venturi scrubber. SCCs = pulverized coal-fired boilers, 1-01-003-01, 1-02-003-01, 1-03-003-05; pulverized coal tangentially-fired boilers, 1-01-003-02, 1-02-003-02, 1-03-003-06; cyclone boilers, 1-01-003-03, 1-02-003-03; and atmospheric fluidized bed combustor, circulating bed, 1-01-003-18.

[b] Emission factor should be applied to coal feed, as fired. To convert from lb/ton to kg/Mg, multiply by 0.5.

Table 1.7-14. EMISSION FACTORS FOR HYDROGEN CHLORIDE (HCI) AND HYDROGEN FLUORIDE (HF) FROM COAL COMBUSTION[a]

EMISSION FACTOR RATING: B

Firing Configuration	SCC	HCl Emission Factor (lb/ton)	HF Emission Factor (lb/ton)
PC-fired	1-01-003-01 1-02-003-01 1-03-003-05	1.2	0.15
PC-fired, tangential	1-01-003-02 1-02-003-02 1-03-003-06	1.2	0.15
Cyclone Furnace	1-01-003-03 1-02-003-03	1.2	0.15
Traveling Grate (overfeed stoker)	1-01-003-04 1-02-003-04 1-03-003-07	1.2	0.15
Spreader Stoker	1-01-003-06 1-02-003-06 1-03-003-09	1.2	0.15
FBC, Circulating Bed	1-01-003-18	1.2	0.15

[a] Reference 59. The emission factors were developed from bituminous coal, subbituminous coal, and lignite emissions data. To convert from lb/ton to kg/Mg, multiply by 0.5. The factors apply to both controlled and uncontrolled sources.

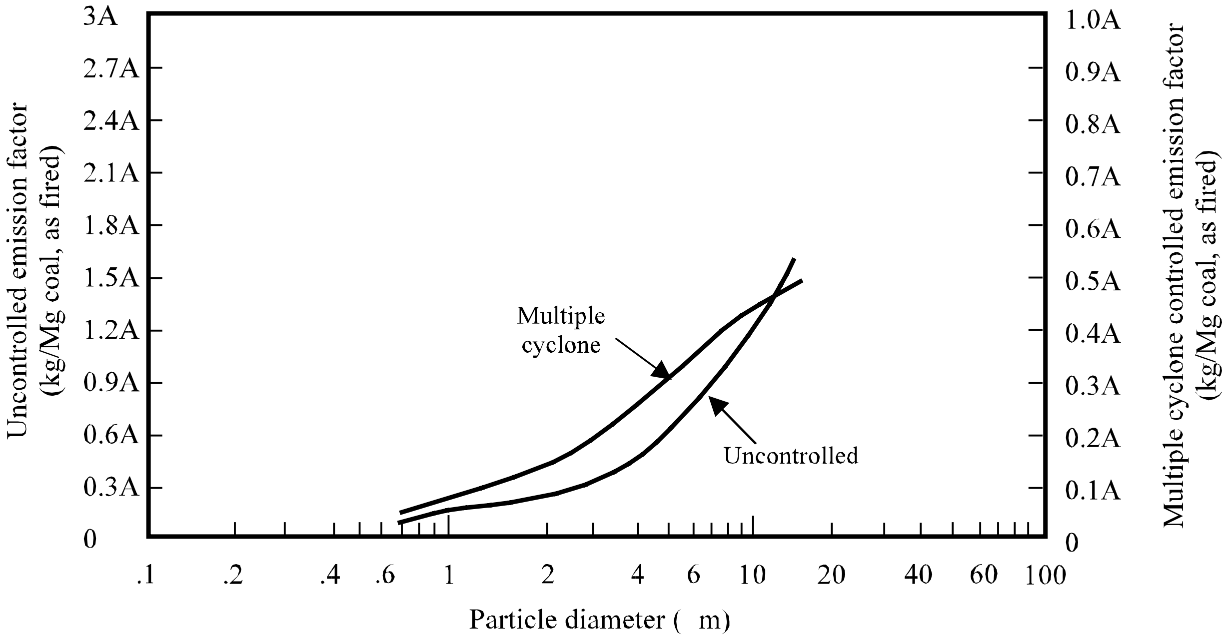

Figure 1.7-1. Cumulative size-specific emission factors for boilers firing pulverized lignite.

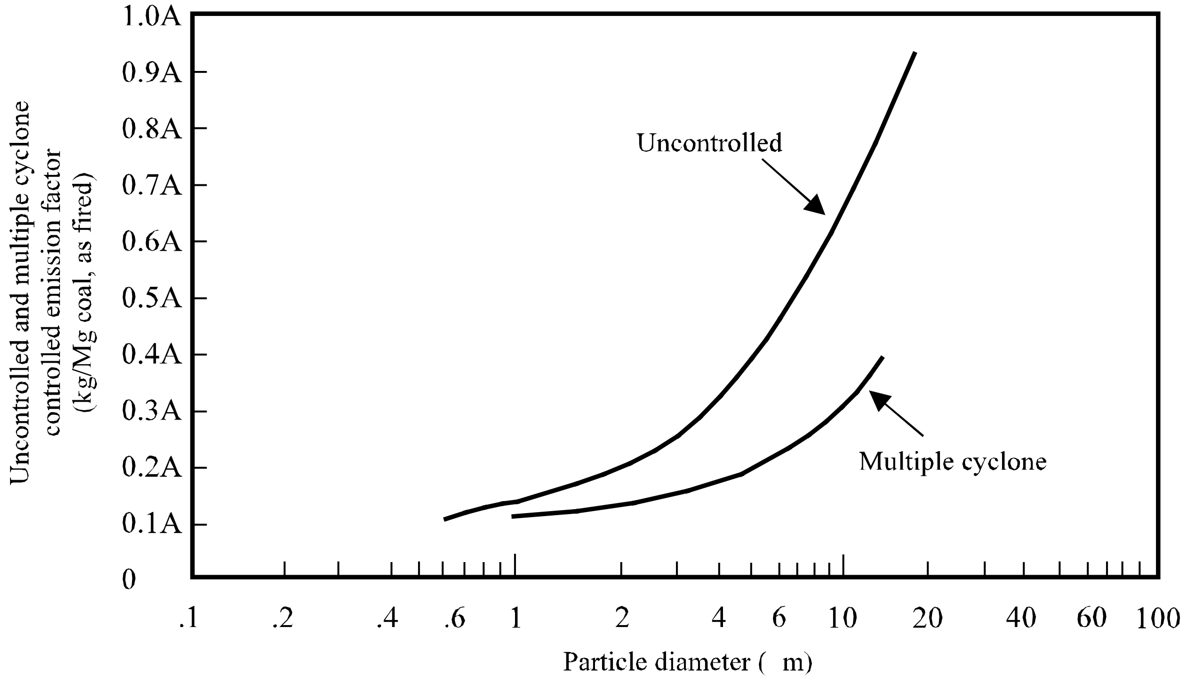

Figure 1.7-2. Cumulative size-specific emission factors for lignite-fired spreader stokers.

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