1.2 Anthracite Coal Combustion

1.2.1 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 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.

Anthracite coal is a high-ranking coal with more fixed carbon and less volatile matter than bituminous, subbituminous, or lignite varieties. Anthracite also has higher ignition and ash fusion temperatures. In the U.S., nearly all anthracite is mined in northeastern Pennsylvania and consumed in Pennsylvania and its surrounding states. The only significant amount of anthracite is used for steam/electric production. Anthracite currently accounts for only a small fraction of the total quantity of coal combusted in the U.S. The anthracite burned is primarily reclaim from old production as no new anthracite is mined.

Another form of anthracite coal burned in boilers is anthracite refuse, commonly known as culm. Culm was produced as breaker reject material from the mining/sizing of anthracite coal and was typically dumped by miners on the ground near operating mines. It is estimated that there are over 16 million tons of culm scattered in piles throughout northeastern Pennsylvania. The heating value of culm is typically in the 2,500 to 5,000 British thermal units/pound (Btu/lb) range, as compared to 12,000 to 14,000 Btu/lb for anthracite coal.

1.2.2 Firing Practices[6-8]

Due to its low volatile matter content and non-clinkering characteristics, anthracite coal is primarily used in medium-sized industrial and institutional stoker boilers equipped with stationary or traveling grates. Anthracite coal is not used in spreader stokers because of its low volatile matter content and relatively high ignition temperature. This fuel may also be burned in pulverized coal-fired (PC-fired) units, but, due to ignition difficulties, this practice is limited to only a few plants in eastern Pennsylvania. Anthracite coal has also been widely used in hand-fired furnaces. Culm has been combusted primarily in fluidized bed combustion (FBC) boilers because of its high ash content and low heating value.

Combustion of anthracite coal on a traveling grate is characterized by a coal bed 3 to 5 inches in depth and a high blast of underfire air at the rear or dumping end of the grate. This high blast of air lifts incandescent fuel particles and combustion gases from the grate and reflects the particles against a long rear arch over the grate towards the front of the fuel bed where fresh or "green" fuel enters. This special furnace arch design is required to assist in the ignition of the green fuel.

A second type of stoker boiler used to burn anthracite coal is the underfeed stoker. Various types of underfeed stokers are used in industrial boiler applications but the most common for anthracite coal firing is the single-retort side-dump stoker with stationary grates. In this unit, coal is fed intermittently to the fuel bed by a ram. In very small units the coal is fed continuously by a screw. Feed coal is pushed through the retort and upward towards the tuyere blocks. Air is supplied through the tuyere blocks on each side of the retort and through openings in the side grates. Overfire air (OFA) is commonly used with underfeed stokers to provide combustion air and turbulence in the flame zone directly above the active fuel bed.

In PC-fired boilers, the fuel is pulverized to the consistency of powder and pneumatically injected through burners into the furnace. Injected coal particles burn in suspension within the furnace region of the boiler. Hot flue gases rise from the furnace and provide heat exchange with boiler tubes in the walls and upper regions of the boiler. In general, PC-fired boilers operate either in a wet-bottom or dry-bottom mode; because of its high ash fusion temperature, anthracite coal is burned in dry-bottom furnaces.

For anthracite culm, combustion in conventional boiler systems is difficult due to the fuel's high ash content, high moisture content, and low heating value. However, the burning of culm in an FBC system was demonstrated at a steam generation plant in Pennsylvania. The FBC system consists of inert particles (e. g., rock and ash) through which air is blown so that the bed behaves as a fluid. Anthracite coal enters in the space above the bed and burns in the bed. Fluidized beds can handle fuels with moisture contents approaching 70 percent (total basis) because of the large thermal mass represented by the hot inert bed particles. Fluidized beds can also handle fuels with ash contents as high as 75 percent. Heat released by combustion is transferred to in-bed steam-generating tubes. Limestone may be added to the bed to capture sulfur dioxide SO_2 formed by combustion of fuel sulfur.

1.2.3 Emissions[2,6,8]

Emissions from coal combustion depend on coal type and composition, the design type and capacity of the boiler, the firing conditions, load, the type of control devices, and the level of equipment maintenance. Emissions from anthracite coal firing primarily include particulate matter (PM), sulfur oxides (SO_x), nitrogen oxides (NO_x), and carbon monoxide (CO); and trace amounts of organic compounds and trace elements.

Particulate Matter -

PM emissions from anthracite coal combustion are a function of furnace firing configuration, firing practices (boiler load, quantity and location of underfire air, soot blowing, fly ash reinjection, etc.), and the ash content of the coal. PC-fired boilers emit the highest quantity of PM per unit of fuel because they fire the anthracite in suspension, which results in a high percentage of ash carryover into exhaust gases. Traveling grate stokers and hand-fired units produce less PM per unit of fuel fired, and coarser particulates, because combustion takes place in a quiescent fuel bed without significant ash carryover into the exhaust gases. In general, PM emissions from traveling grate stokers will increase during soot blowing and fly ash reinjection and with higher fuel bed underfeed air flowrates. Smoke production during combustion is rarely a problem, because of anthracite's low volatile matter content.

Sulfur Oxides -

Limited data are available on the emission of gaseous pollutants from anthracite combustion. It is assumed, based on bituminous coal combustion data, that a large fraction of the fuel sulfur is emitted as SO_x. SO_x emissions are directly proportional to the sulfur content of fuel. Some minor differences will occur from unit to unit, however, due to (1) ash partitioning between fly ash and bottom ash and (2) the sodium content of the coal (which tends to react with and bind coal sulfur in the bottom ash as sodium sulfite or sodium sulfate). For FBC boilers, SO_x emissions are inversely proportional, in general, to the molar ratio of calcium (in the limestone) to sulfur (in the fuel) added to the bed.[8]

Nitrogen Oxides[8] -

NO_x emissions are lower in traveling grate and underfeed stokers compared to PC-fired boilers. Underfeed and traveling grate stokers have large furnace areas and consequently lower volumetric- and surface area-based heat release rates. Lower heat release rates reduce peak combustion temperatures and, hence, contribute to lower NO_x emissions. In addition, the partially staged combustion that naturally occurs in all stokers due to the use of underfire and overfire air contributes to reduced NO_x emissions relative to PC-fired units. The low operating temperatures which characterize FBC boilers firing culm also favor relatively low NO_x emissions. Reducing boiler load tends to decrease combustion intensity which, in turn, leads to decreased NO_x emissions for all boiler types.

Carbon Monoxide -

CO and total organic compound (TOC) emissions are dependent on combustion efficiency. Generally their emission rates, defined as mass of emissions per unit of heat input, decrease with increasing boiler size. Organic compound emissions are expected to be lower for PC-fired units and higher for underfeed and overfeed stokers due to relative combustion efficiency levels.

1.2.4 Controls[6,8]

Controls on anthracite-fired boilers have mainly have been applied to reduce PM emissions. The most efficient particulate controls—fabric filters, electrostatic precipitators (ESP), and scrubbers—have been installed on large pulverized anthracite-fired boilers. In fabric filters (baghouses), particulate-laden dust passes through a set of filters mounted inside the collector housing. Dust particles in the inlet gas are collected on the filters by inertial impaction, diffusion, direct interception, and sieving. The collection efficiencies of fabric filters or coal-fired boilers can exceed 99 percent.

Particulate collection in an ESP occurs in three steps: suspended particles are given an electrical charge; the charged particles migrate to a collecting electrode of opposite polarity while subjected to a diverging electric field; and the collected PM is dislodged from the collecting electrodes. Removal of the collected PM is accomplished mechanically by rapping or vibrating the collecting electrodes. When applied to anthracite coal-fired boilers, ESPs are only 90 to 97 percent efficient, because of the characteristic high resistivity of low sulfur anthracite fly ash. It is reported that higher efficiencies can be achieved using larger ESPs combined with flue gas conditioning.

The most widely used wet scrubbers for anthracite coal-fired boilers are venturi scrubbers. In a typical venturi scrubber, the particle-laden gas first contacts the liquor stream in the core and throat of the venturi section. The gas and liquid streams then pass through the annular orifice formed by the core and throat, atomizing the liquid into droplets which are impacted by particles in the gas stream. Impaction results mainly from the high differential velocity between the gas stream and the atomized droplets. The droplets are then removed from the gas stream by centrifugal action in a cyclone separator and (if present) a mist eliminator section.

Wet scrubbers have reported PM collection efficiencies of 90 percent or greater. Gaseous emissions such as SO_2, NO_x, CO, and organics may also be absorbed to a significant extent in a wet scrubber. Operational problems can occur with wet scrubbers due to clogged spray nozzles, sludge deposits, dirty recirculation water, improper water levels, and unusually low pressure drops. Mechanical collectors, or cyclones, use centrifugal separation to remove PM from flue gas streams. At the entrance of the cyclone, a spin is imparted to the particle-laden gas. This spin creates a centrifugal force which causes the PM to move away from the axis of rotation and toward the walls of the cyclone. Particles which contact the walls of the cyclone tube are directed to a dust collection hopper where they are deposited. Mechanical collectors typically have PM collection efficiencies up to 80 percent.

Emission factors and ratings for criteria pollutants from anthracite coal combustion are given in Tables 1.2-1, 1.2-2, and 1.2-3. Tables in this section present emission factors on a weight basis (lb/ton). To convert to an energy basis (lb/MMBtu), divide by a heating value of 24.6 MMBtu/ton. Cumulative particle size distribution data for uncontrolled and controlled boilers burning pulverized anthracite coal are given in Table 1.2-4. Figure 1.2-1 presents cumulative size-specific emission factors for stokers burning anthracite coal. Emission factors for speciated organic compounds are given in Table 1.2-5. Emission factors for TOCs and methane from burning anthracite are given in Table 1.2-6. Emission factors for speciated metals from stoker boilers firing anthracite coal are given in Table 1.2-7.

1.2.5 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.

Supplement A, February 1996

- An SCC (A2104001000) was provided for residential space heaters.

Supplement B, October 1996

- Text was enhanced concerning anthracite coal.
- Text was enhanced concerning emissions of SO_x, NO_x, and CO.
- Text was added concerning PM and SO_2 controls.
- Emission factor tables were rearranged so that criteria pollutants appear first.
- Mathematical errors were corrected for CO, TOC, and mercury.
- Emission factors were corrected for speciated organic compounds.

Table 1.2-1. EMISSION FACTORS FOR SO_x AND NO_x COMPOUNDS FROM UNCONTROLLED ANTHRACITE COAL COMBUSTORS[a]

Source Category	SO_x		NO_x	
	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING
Stoker-fired boilers[c] (SCC 1-01-001-02, 1-02-001-04, 1-03-001-02)	39S[b]	B	9.0	C
FBC boilers[d] (no SCC)	2.9	E	1.8	E
Pulverized coal boilers[e] (SCC 1-01-001-01, 1-02-001-01, 1-03-001-01)	39S[b]	B	18	B
Residential space heaters[e] (SCC A2104001000)	39S[b]	B	3	B

[a] Units are lb of pollutant/ton of coal burned. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code.
[b] S = weight percent sulfur. For example, if the sulfur content is 3.4%, then S = 3.4.
[c] References 9-10.
[d] Reference 11. FBC boilers burning culm fuel; all other sources burning anthracite coal.
[e] Reference 2.

Table 1.2-2. EMISSION FACTORS FOR CO AND CARBON DIOXIDE (CO_2) FROM UNCONTROLLED ANTHRACITE COAL COMBUSTORS[a]

Source Category	CO		CO_2	
	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING
Stoker-fired boilers[b] (SCC 1-01-001-02, 1-02-001-04, 1-03-001-02)	0.6	B	5,680	C
FBC boilers[c] (no SCC)	0.6	E	ND	NA

[a] Units are lb of pollutant/ton of coal burned. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data. NA = not applicable.
[b] References 2,9,12.
[c] Reference 11. FBC boilers burning culm fuel; all other sources burning anthracite coal.

Table 1.2-3. EMISSION FACTORS FOR PM AND LEAD (Pb) FROM UNCONTROLLED ANTHRACITE COAL COMBUSTORS[a]

Source Category	Filterable PM		Condensible PM		Pb	
	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING
Stoker-fired boilers[b] (SCC 1-01-001-02, 1-02-001-04, 1-03-001-02)	0.8A[c]	C	0.08A[c]	C	8.9 E-03	E
Hand-fired units[d] (SCC 1-02-002-07, 1-03-001-03)	10	B	ND	NA	ND	NA

[a] Units are lb of pollutant/ton of coal burned. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data.
NA = not applicable.
[b] References 9-10,13-14.
[c] A = ash content of fuel, weight %. For example, if the ash content is 5%, then A = 5.
[d] Reference 2.

Table 1.2-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR DRY BOTTOM BOILERS BURNING PULVERIZED ANTHRACITE COAL[a]

EMISSION FACTOR RATING: D

Particle Size[b] (µm)	Cumulative Mass % ≤ Stated Size			Cumulative Emission Factor As Fired[c] (lb/ton)		
	Uncontrolled	Controlled[d]		Uncontrolled	Controlled[d]	
		Multiple Cyclone	Baghouse		Multiple Cyclone	Baghouse
15	32	63	79	3.2A[e]	1.26A	0.016A
10	23	55	67	2.3A	1.10A	0.013A
6	17	46	51	1.7A	0.92A	0.010A
2.5	6	24	32	0.6A	0.48A	0.006A
1.25	2	13	21	0.2A	0.26A	0.004A
1.00	2	10	18	0.2A	0.20A	0.004A
0.625	1	7	—[f]	0.1A	0.14A	—[f]
TOTAL	100	100	100	10A	2A	0.02A

[a] Reference 15. Source Classification Codes are 1-01-001-01, 1-02-001-01, and 1-03-001-01.
[b] Expressed as aerodynamic equivalent diameter.
[c] Units are lb of pollutant/ton of coal burned. To convert from lb/ton to kg/Mg, multiply by 0.5.
[d] Estimated control efficiency for multiple cyclone is 80%; for baghouse, 99.8%.
[e] A = coal ash weight %, as fired. For example, if ash content is 5%, then A = 5.
[f] Insufficient data.

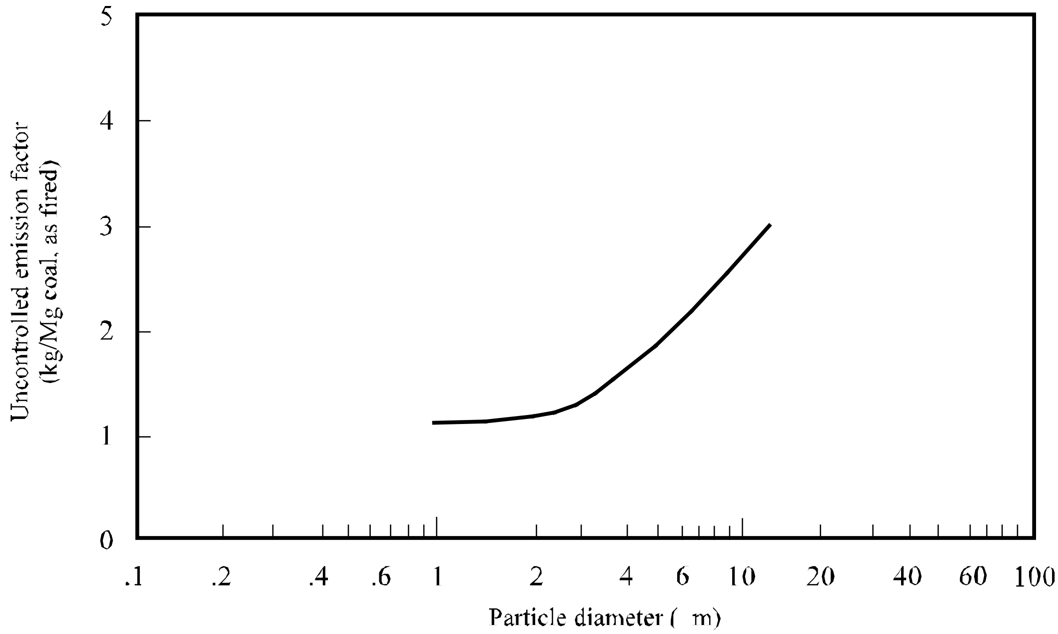

Figure 1.2-1. Cumulative size-specific emission factors for traveling grate stokers burning anthracite coal.

Table 1.2-5. EMISSION FACTORS FOR SPECIATED ORGANIC COMPOUNDS FROM ANTHRACITE COAL COMBUSTORS[a]

EMISSION FACTOR RATING: E

	Stoker-Fired Boilers[b] (SCC 1-01-001-02, 1-02-001-04, 1-03-001-02)	Residential Space Heaters[c] (SCC A2-10-400-1000)	
Pollutant	Emission Factor (lb/ton)	Emission Factor Range (lb/ton)	Average Emission Factor (lb/ton)
Acenaphthene	ND	1.1 E-05 - 2.9 E-05	2.2 E-05
Acenaphthylene	ND	1.1 E-05 - 2.2 E-04	8.6 E-05
Anthanthrene	ND	1.5 E-07 - 8.8 E-07	5.7 E-07
Anthracene	ND	7.0 E-06 - 3.7 E-05	2.5 E-05
Benzo(a)anthracene	ND	1.1 E-05 - 1.6 E-04	7.1 E-05
Benzo(a)pyrene	ND	3.1 E-06 - 7.0 E-06	5.3 E-06
Benzo(e)pyrene	ND	3.5 E-06 - 1.0 E-05	6.2 E-06
Benzo(g,h,i,) perylene	ND	3.1 E-06 - 9.5 E-06	5.5 E-06
Benzo(k)fluoranthrene	ND	1.1 E-05 - 4.5 E-05	2.5 E-05
Biphenyl	2.5 E-02	ND	ND
Chrysene	ND	1.8 E-05 - 1.8 E-04	8.3 E-05
Coronene	ND	8.8 E-07 - 6.4 E-06	3.9 E-06
Fluoranthrene	ND	7.5 E-05 - 2.7 E-04	1.7 E-04
Fluorene	ND	7.0 E-06 - 4.1 E-05	2.5 E-05
Indeno(123-cd) perylene	ND	3.5 E-06 - 1.1 E-05	6.9 E-06
Naphthalene	1.3 E-01	7.0 E-06 - 4.8 E-04	2.2 E-04
Perylene	ND	6.1 E-07 - 1.8 E-06	1.2 E-06
Phenanthrene	6.8 E-03	7.1 E-05 - 3.4 E-04	2.4 E-04
Pyrene	ND	4.2 E-05 - 1.9 E-04	1.2 E-04

[a] Units are lb of pollutant/ton of anthracite coal burned. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data.
[b] Reference 13.
[c] Reference 16.

Table 1.2-6. EMISSION FACTORS FOR TOC AND METHANE (CH_4) FROM ANTHRACITE COAL COMBUSTORS[a]

EMISSION FACTOR RATING: E

Source Category	TOC Emission Factor (lb/ton)	CH_4 Emission Factor (lb/ton)
Stoker fired boilers[b] (SCC 1-01-001-02, 1-02-001-04, 1-03-001-02)	0.30	ND
Residential space heaters[c] (A2-10-400-1000)	ND	8

[a] Units are lb of pollutant/ton of coal burned. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data.
[b] Reference 13.
[c] Reference 16.

Table 1.2-7. EMISSION FACTORS FOR SPECIATED METALS FROM ANTHRACITE COAL COMBUSTION IN STOKER FIRED BOILERS[a]

EMISSION FACTOR RATING: E

Pollutant	Emission Factor Range (lb/ton)	Average Emission Factor (lb/ton)
Arsenic	BDL - 2.4 E-04	1.9 E-04
Antimony	BDL	BDL
Beryllium	3.0 E-05 - 5.4 E-04	3.1 E-04
Cadmium	4.5 E-05 - 1.1 E-04	7.1 E-05
Chromium	5.9 E-03 - 4.9 E-02	2.8 E-02
Manganese	9.8 E-04 - 5.3 E-03	3.6 E-03
Mercury	8.7 E-05 - 1.7 E-04	1.3 E-04
Nickel	7.8 E-03 - 3.5 E-02	2.6 E-02
Selenium	4.7 E-04 - 2.1 E-03	1.3 E-03

[a] Reference 13. Units are lb of pollutant/ton of coal burned. To convert from lb/ton to kg/Mg, multiply by 0.5. Source Classification Codes are 1-01-001-02, 1-02-001-04, and 1-03-001-02. BDL = below detection limit.

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