1.6 Wood Waste Combustion In Boilers

1.6.1 General[1-5]

The burning of wood waste in boilers is mostly confined to those industries where it is available as a byproduct. It is burned both to obtain heat energy and to alleviate possible solid waste disposal problems. In boilers, wood waste is normally burned in the form of hogged wood, bark, sawdust, shavings, chips, mill rejects, sanderdust, or wood trim. Heating values for this waste range from about 4,000 to 5,000 British thermal units/pound (Btu/lb) of fuel on a wet, as-fired basis. The moisture content of as-fired wood is typically near 50 weight percent, but may vary from 5 to 75 weight percent depending on the waste type and storage operations.

Generally, bark is the major type of waste burned in pulp mills; either a mixture of wood and bark waste or wood waste alone is burned most frequently in the lumber, furniture, and plywood industries. As of 1980, there were approximately 1,600 wood-fired boilers operating in the U. S., with a total capacity of over 1.0×10^{11} Btu/hour.

1.6.2 Firing Practices[5-7]

Various boiler firing configurations are used for burning wood waste. One common type of boiler used in smaller operations is the Dutch oven. This unit is widely used because it can burn fuels with very high moisture content. Fuel is fed into the oven through an opening in the top of a refractory-lined furnace. The fuel accumulates in a cone-shaped pile on a flat or sloping grate. Combustion is accomplished in two stages: (1) drying and gasification, and (2) combustion of gaseous products. The first stage takes place in the primary furnace, which is separated from the secondary furnace chamber by a bridge wall. Combustion is completed in the secondary chamber before gases enter the boiler section. The large mass of refractory helps to stabilize combustion rates but also causes a slow response to fluctuating steam demand.

In another boiler type, the fuel cell oven, fuel is dropped onto suspended fixed grates and is fired in a pile. Unlike the Dutch oven, the refractory-lined fuel cell also uses combustion air preheating and positioning of secondary and tertiary air injection ports to improve boiler efficiency. Because of their overall design and operating similarities, however, fuel cell and Dutch oven boilers have comparable emission characteristics.

The firing method most commonly employed for wood-fired boilers with a steam generation rate larger than 100,000 lb/hr is the spreader stoker. In this boiler type, wood enters the furnace through a fuel chute and is spread either pneumatically or mechanically across the furnace, where small pieces of the fuel burn while in suspension. Simultaneously, larger pieces of fuel are spread in a thin, even bed on a stationary or moving grate. The burning is accomplished in three stages in a single chamber: (1) moisture evaporation; (2) distillation and burning of volatile matter; and (3) burning of fixed carbon. This type of boiler has a fast response to load changes, has improved combustion control, and can be operated with multiple fuels. Natural gas, oil, and/or coal, are often fired in spreader stoker boilers as auxiliary fuels. The fossil fuels are fired to maintain constant steam when the wood waste moisture content or mass rate fluctuates and/or to provide more steam than can be generated from the waste supply alone. Although spreader stokers are the most common stokers among larger wood-fired boilers, overfeed and underfeed stokers are also utilized for smaller units.

Another boiler type sometimes used for wood combustion is the suspension-fired boiler. This boiler differs from a spreader stoker in that small-sized fuel (normally less than 2 mm) is blown into the boiler and combusted by supporting it in air rather than on fixed grates. Rapid changes in combustion rate and, therefore, steam generation rate are possible because the finely divided fuel particles burn very quickly.

A recent innovation in wood firing is the fluidized bed combustion (FBC) boiler. A fluidized bed consists of inert particles through which air is blown so that the bed behaves as a fluid. Wood waste enters in the space above the bed and burns both in suspension and in the bed. Because of the large thermal mass represented by the hot inert bed particles, fluidized beds can handle fuels with moisture contents up to near 70 percent (total basis). Fluidized beds can also handle dirty fuels (up to 30 percent inert material). Wood fuel is pyrolyzed faster in a fluidized bed than on a grate due to its immediate contact with hot bed material. As a result, combustion is rapid and results in nearly complete combustion of the organic matter, thereby minimizing the emissions of unburned organic compounds.

1.6.3 Emissions And Controls[6-11]

The major emission of concern from wood boilers is particulate matter (PM), although other pollutants, particularly carbon monoxide (CO), volatile organic compounds (VOC), and oxides of nitrogen (NO_x) may be emitted in significant quantities when certain types of wood waste are combusted or when operating conditions are poor. These emissions depend on a number of variables, including (1) the composition of the waste fuel burned, (2) furnace design and operating conditions, and (3) the degree of flyash reinjection employed.

1.6.3.1 Criteria Pollutants

The composition of wood waste and the characteristics of the resulting emissions depend largely on the industry from which the wood waste originates. Pulping operations, for example, produce great quantities of bark that may contain more than 70 weight percent moisture, sand, and other non-combustibles. As a result, bark boilers in pulp mills may emit considerable amounts of particulate matter to the atmosphere unless they are controlled. On the other hand, some operations, such as furniture manufacturing, generate a clean, dry wood waste (2 to 20 weight percent moisture) which produces relatively low particulate emission levels when properly burned. Still other operations, such as sawmills, burn a varying mixture of bark and wood waste that results in PM emissions somewhere between these two extremes. Additionally, NO_x emissions from bark boilers are typically low in comparison to NO_x emissions from sanderdust-fired boilers at urea formaldehyde process particleboard plants.

Furnace design and operating conditions are particularly important when firing wood waste. For example, because of the high moisture content that may be present in wood waste, a larger than usual area of refractory surface is often necessary to dry the fuel before combustion. In addition, sufficient secondary air must be supplied over the fuel bed to burn the volatiles that account for most of the combustible material in the waste. When proper drying conditions do not exist, or when secondary combustion is incomplete, the combustion temperature is lowered, and increased PM, CO, and organic compound emissions may result. Significant variations in fuel moisture content can cause short-term emissions to fluctuate.

Flyash reinjection, which is commonly used with larger boilers to improve fuel efficiency, has a considerable effect on PM emissions. Because a fraction of the collected flyash is reinjected into the boiler, the dust loading from the furnace and, consequently, from the collection device increase significantly per unit of wood waste burned. More recent boiler installations typically separate the collected particulate into large and small fractions in sand classifiers. The larger particles, which are mostly carbon, are reinjected into the furnace. The smaller particles, mostly inorganic ash and sand, are sent to ash disposal.

1.6.3.2 Greenhouse Gases[12-17]

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions are all produced during wood waste combustion. Nearly all of the fuel carbon (99 percent) in wood waste 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. CO_2 emitted from this source may not increase total atmospheric CO_2, however, because emissions may be offset by the offtake of CO_2 by regrowing biomass.

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°F) and excess air is kept to a minimum (less than 1 percent). N_2O emissions for wood waste combustion are not significant except for fluidized bed combustion (FBC), where localized areas of lower temperatures in the fuel bed produce N_2O emissions an order of magnitude greater than emissions from stokers.

Methane emissions are highest during periods of low-temperature combustion or incomplete combustion, such as the start-up or shut-down cycle for boilers. Typically, conditions that favor formation of N_2O also favor emissions of CH_4.

1.6.4 Controls

Currently, the four most common control devices used to reduce PM emissions from wood-fired boilers are mechanical collectors, wet scrubbers, electrostatic precipitators (ESPs), and fabric filters. The use of multitube cyclone (or multiclone) mechanical collectors provides particulate control for many fuel-fired boilers. Often, two multiclones are used in series, allowing the first collector to remove the bulk of the dust and the second to remove smaller particles. The efficiency of this arrangement varies from 65 to 95 percent. The most widely used wet scrubbers for wood-fired boilers are venturi scrubbers. With gas-side pressure drops exceeding 15 inches of water, particulate collection efficiencies of 90 percent or greater have been reported for venturi scrubbers operating on wood-fired boilers.

Fabric filters (i. e., baghouses) and ESPs are employed when collection efficiencies above 95 percent are required. When applied to wood-fired boilers, ESPs are often used downstream of mechanical collector precleaners which remove larger-sized particles. Collection efficiencies of 93 to 99.8 percent for PM have been observed for ESPs operating on wood-fired boilers.

A variation of the ESP is the electrostatic gravel bed filter. In this device, PM in flue gases is removed by impaction with gravel media inside a packed bed; collection is augmented by an electrically charged grid within the bed. Particulate collection efficiencies are typically near 95 percent.

Fabric filters have had limited applications to wood-fired boilers. The principal drawback to fabric filtration, as perceived by potential users, is a fire danger arising from the collection of combustible carbonaceous fly ash. Steps can be taken to reduce this hazard, including the installation of a mechanical collector upstream of the fabric filter to remove large burning particles of fly ash (i. e., "sparklers"). Despite complications, fabric filters are generally preferred for boilers firing salt-laden wood. This fuel produces fine particulates with a high salt content. Fabric filters are capable of high fine particle collection efficiencies; in addition, the salt content of the particles has a quenching effect, thereby reducing fire hazards. In two tests of fabric filters operating on salt-laden wood-fired boilers, particulate collection efficiencies were above 98 percent.

For stoker and FBC boilers, overfire air ports may be used to lower NO_x emissions by staging the combustion process. In those areas of the U. S. where NO_x emissions must be reduced to their lowest levels, the application of selective noncatalytic reduction (SNCR) to waste wood-fired boilers has been accomplished; the application of selective catalytic reduction (SCR) is being contemplated. Both systems are postcombustion NO_x reduction techniques in which ammonia (or urea) is injected into the flue gas to selectively reduce NO_x to nitrogen and water. In one application of SNCR to an industrial wood-fired boiler, NO_x reduction efficiencies varied between 35 and 75 percent as the ammonia-to-NO_x ratio increased from 0.4 to 3.2.

Emission factors and emission factor ratings for wood waste boilers are summarized in Tables 1.6-1, 1.6-2, 1.6-3, 1.6-4, and 1.6-5.[18-19] 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 9.0 MMBtu/ton. Emission factors are for uncontrolled combustors unless otherwise indicated. Cumulative particle size distribution data and associated emission factors are presented in Tables 1.6-6 and 1.6-7. Uncontrolled and controlled size-specific emission factors are plotted in Figure 1.6-1 and Figure 1.6-2. All emission factors presented are based on the feed rate of wet, as-fired wood with average properties of 50 weight percent moisture and 4500 Btu/lb higher heating values.

1.6.5 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. 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

- Significant figures were added to some PM and PM-10 emission factors.

- In the table with NO_x and CO emission factors, text was added in the footnotes to clarify meaning.

Supplement B, October 1996

- SO_x, CH_4, N_2O, CO_2, speciated organics, and trace elements emission factors were corrected.

- Several HAP emission factors were updated.

Supplement D, February 1998

- Table 1.6-1, the PM-10 and one PM emission factors were revised to present two significant figures and the PM-10 emission factor for wood-fired boilers with mechanical collectors without flyash reinjection was revised to 2.6 lb/ton to reflect that these values are based on wood with 50% moisture. A typographical error in the wet scrubber emission factor for PM-10 was corrected.

- Table 1.6-2, the SO_x emission factors for all boiler categories were revised to 0.075 lb/ton to reflect that these factors are based on wood with 50% moisture.

- Tables 1.6-4 and 1.6-5 were re-titled to reflect that the speciated organic and trace element analysis presented in these tables are compiled from wood-fired boilers equipped with a variety of PM control technologies.

Supplement D, August 1998

- Table 1.6-4, the emission factor for trichlorotrifluoroethane was removed. The phenol emission factor was corrected to 1.47E-04; the phenanthrene factor was corrected to 5.02E-05; the chrysene factor was corrected to 4.52E-07; and, the polychlorinated dibenzo-p-furans factor was corrected to 2.9E-08.

Supplement E, February 1999

- In the footnotes of tables 1.6-1, 2, 3, 4, 5, 6, 7, some text was removed that described how to adjust the factors when burning wood with moisture and thermal content significantly different from 50% or 4500 Btu/lb, respectively. The EPA is revising Section 1.6 and, in the interim, consistent with EPA's recommendations regarding proper use of AP-42, the EPA encourages users of the wood combustion emission factors to account for the specific assumptions included in the factors and to convert the factors to a thermal content basis (i.e., lb/MMBtu) to estimate emissions when burning wood that differs significantly from 4500 Btu/lb or 50% moisture.

Table 1.6-1. EMISSION FACTORS FOR PARTICULATE MATTER (PM), PARTICULATE MATTER LESS THAN 10 MICRONS (PM-10), AND LEAD (Pb) FROM WOOD WASTE COMBUSTION[a]

Source Category (SCC)	PM[b]		PM-10[c]		Pb[d]	
	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING
Bark-fired boilers (1-01-009-01, 1-02-009-01, 1-02-009-04, 1-03-009-01)						
Uncontrolled	47	B	17	D	2.9 E-03	D
Mechanical collector with flyash reinjection	14	B	11	D	ND	NA
without flyash reinjection	9.0	B	3.2	D	ND	NA
Wet scrubber	2.9	D	2.5	D	ND	NA
Wood/bark-fired boilers (1-01-009-02, 1-02-009-02, 1-02-009-05, 1-03-009-02)						
Uncontrolled	7.2	C	6.5	E	ND	NA
Mechanical collector with flyash reinjection	6.0	C	5.5	E	3.2 E-04[e]	D
without flyash reinjection	5.4	C	1.7	E	3.2 E-04[e]	
Wet scrubber	0.48	D	0.47	E	3.5 E-04	D
Electrostatic precipitator	0.04	D	ND	NA	1.6 E-05	D
Wood-fired boilers (1-01-009-03, 1-02-009-03, 1-02-009-06, 1-03-009-03)						
Uncontrolled	8.8	C	ND	NA	ND	NA
Mechanical collector without flyash reinjection	4.2	C	2.6[f]	D	3.1 E-04	D
Electrostatic precipitator	0.17	D	ND	NA	1.1 E-03	D

[a] Units are lb of pollutant/ton of wood waste burned. To convert from lb/ton to kg/Mg, multiply by 0.5. To convert from lb/ton to lb/MMBtu, multiply by 0.11. Emission factors are based on wet, as-fired wood waste with average properties of 50 weight % moisture and 4500 Btu/lb higher heating value. PM-10 = particulate matter less than 10 micrometers. SCC = Source Classification Code. ND = no data. NA = not applicable.
[b] References 11,20-24.
[c] References 1,21,25.
[d] References 11,21-23,26.
[e] Due to lead's relative volatility, it is assumed that flyash reinjection does not have a significant effect on lead emissions following mechanical collectors.
[f] Based on one test in which 61% of emitted PM was less than 10 micrometer in size.

Table 1.6-2. EMISSION FACTORS FOR NITROGEN OXIDES (NO_x), SULFUR OXIDES (SO_x), AND CARBON MONOXIDE (CO) FROM WOOD WASTE COMBUSTION[a]

Source Category (SCC)	NO_x[b]		SO_x[c]		CO[d]	
	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING
Fuel cell/Dutch oven boiler (no SCC)	0.38 (0.0033 - 1.5)	C	0.075 (0.01 - 0.2)	B	6.6 (0.65 - 21)	C
Stoker boilers (no SCC)	1.5 (0.66 - 3.6)	C	0.075 (0.01- 0.2)	B	13.6 (1.9 - 80)	C
FBC boilers (no SCC)	2.0	D	0.075 (0.01 - 0.2)	B	1.4 (0.47 - 2.4)	D

[a] Units are lb of pollutant/ton of wood waste burned. To convert from lb/ton to kg/Mg, multiply by 0.5. To convert from lb/ton to lb/MMBtu, multiply by 0.11. Emission factors are based on wet, as-fired wood waste with average properties of 50 weight % moisture and 4500 Btu/lb higher heating value. SCC = Source Classification Code. FBC = fluidized bed combustion.

[b] References 20-22,27-28. NO_x formation is primarily a function of wood nitrogen content. Values in parenthesis represent the range of emission factors.

[c] Reference 29. Lower limit of the range (in parentheses) should be used for wood and higher values for bark.

[d] References 11,20-22,27,30-32. Values in parenthesis represent the range of emission factors.

Table 1.6-3. EMISSION FACTORS FOR TOTAL ORGANIC COMPOUNDS (TOC), METHANE (CH_4), NITROUS OXIDE (N_2O), AND CARBON DIOXIDE (CO_2) FROM WOOD WASTE COMBUSTION[a]

Source Category (SCC)	TOC[b]		CH_4[c]		N_2O[d]		CO_2[e]	
	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING	Emission Factor (lb/ton)	EMISSION FACTOR RATING
Fuel cell/Dutch oven boilers (no SCC)	0.18	C	ND	NA	ND	NA	1900	B
Stoker boilers (no SCC)	0.22	C	0.1	E	0.04	D	2000	B
FBC boilers (no SCC)	ND	NA	ND	NA	0.2	E	1800	B

[a] Units are lb of pollutant/ton of wood waste burned. To convert from lb/ton to kg/Mg, multiply by 0.5. To convert from lb/ton to lb/MMBtu, multiply by 0.11. Emission factors are based on wet, as-fired wood waste with average properties of 50 weight % moisture and 4500 Btu/lb higher heating value. SCC = Source Classification Code. FBC = fluidized bed combustion. ND = no data. NA = not applicable.
[b] References 11,22-23,27. Emissions measured as total hydrocarbons.
[c] Reference 17.
[d] References 14-15.
[e] References 1,11,20-23,27,30-32.

Table 1.6-4. EMISSION FACTORS FOR SPECIATED ORGANIC COMPOUNDS FROM WOOD WASTE COMBUSTION WITH PM CONTROLS[a]

Organic Compound[b]	Average Emission Factor (lb/ton)	EMISSION FACTOR RATING
Phenols[cc]	1.47 E-04[c]	C
Acenaphthene[dd]	4.10 E-06[d]	C
Fluorene[dd]	8.22 E-06[e]	C
Phenanthrene[dd]	5.02 E-05[c]	B
Anthracene	3.3 E-06[f]	C
Fluoranthene[dd]	1.83 E-05[g]	B
Benzo(a)anthracene[dd]	3.27 E-06[h]	C
Benzo(k)fluoranthene[dd]	7.65 E-07[j]	E
Benzo(b+k)fluoranthene[dd]	2.9 E-05[k]	C
Benzofluoranthenes[dd]	1.08 E-06[m,n]	E
Benzo(a)pyrene[dd]	6.75 E-08[m,n]	E
Benzo(g,h,i)perylene[dd]	1.41 E-06[p]	D
Chrysene[dd]	4.52 E-07[q]	C
Indeno(1,2,3,c,d)pyrene[dd]	3.6 E-07[r]	D
Polychlorinated dibenzo-p-dioxins	1.2 E-08[k,s,t]	C
Polychlorinated dibenzo-p-furans	2.9E-08[k,s,u]	C
Acenaphthylene[dd]	4.76 E-05[v]	B
Methyl anthracene[dd]	1.4 E-04[m]	D
Acrolein[dd]	4.0 E-06[m]	D
Solicyladehyde	2.3 E-05[m]	D
Benzaldehyde	1.2 E-05[m]	D
Formaldehyde[dd]	8.2 E-03[w]	B
Acetaldehyde[dd]	1.92 E-03[w]	B
Benzene[dd]	9.95 E-03[x]	B
Naphthalene[dd]	3.39 E-03[y]	C
2,3,7,8-Tetrachlorodibenzo-p-dioxin[dd]	3.6 E-11[k]	D
2-Chlorophenol[dd]	5.13 E-07[m,n]	E
2,4-Dinitrophenol[dd]	4.23 E-06[m,n]	E
Methane	1.12 E-02[z]	D
4-Nitrophenol[dd]	2.97 E-06[m]	E
Pyrene	1.67 E-05[bb]	B

[a] Units are lb of pollutant/ton of wood waste burned. To convert from lb/ton to kg/Mg, multiply by 0.5. To convert from lb/ton to lb/MMBtu, multiply by 0.11. Emission factors are based on wet, as-fired wood waste with average properties of 50 weight % moisture and 4500 Btu/lb higher heating value. Source Classification Codes are 1-01-009-01/02/03, 1-02-009-01/02/03/04/05/06/07, and 1-03-009-01/02/03.

[b] Pollutants in this table represent organic species measured for wood waste combustors equipped with PM controls (i.e., fabric filters, multi-cyclones, ESP, and wet scrubbers). Other organic species may also have been emitted but either were not measured or were present at concentrations below analytical limits.

[c] References 32-35.

[d] References 34-39.

[e] References 34-41.

[f] References 34-39,41.

[g] References 32-41.

[h] References 34,37,39,40.

Table 1.6-4 (cont.).

[j] References 34,36.
[k] References 11,19-23,26,31,42.
[m] Based on data from one source test.
[n] Reference 35.
[p] References 35-36,39.
[q] References 34-35,39-40.
[r] References 35,39.
[s] Emission factors are for total dioxins and furans, not toxic equivalents.
[t] Excludes data from combustion of salt-laden wood. For salt-laden wood, emission factor is 1.3 E-06 lb/ton with a D rating.
[u] Excludes data from combustion of salt-laden wood. For salt-laden wood, emission factor is 5.5 E-07 lb/ton with a D rating.
[v] References 32,34-40.
[w] References 32-41,43.
[x] References 32-40,43.
[y] References 32-34,37,40-41.
[z] Reference 44.
[aa] References 34,36-38.
[bb] References 32,34-36,37-41.
[cc] Emission factor value includes phenol, which is a hazardous air pollutant (HAP), plus substituted phenols which are not HAPs
[dd] Hazardous air pollutant.

Table 1.6-5. EMISSION FACTORS FOR TRACE ELEMENTS FROM WOOD WASTE COMBUSTION WITH PM CONTROLS[a]

Trace Element[b]	Average Emission Factor (lb/ton)	EMISSION FACTOR RATING
Chromium (VI)	4.6 E-05[c]	D
Copper	3.73 E-04[d]	B
Zinc	2.51 E-03[d]	B
Barium	4.4 E-03[e]	D
Potassium	7.8 E-01[e]	D
Sodium	1.8 E-02[e]	D
Iron	4.4 E-02[c]	D
Lithium	7.0 E-05[e]	D
Boron	8.0 E-04[e]	D
Chlorine	7.8 E-03[e]	D
Vanadium	1.2 E-04[e]	D
Cobalt	1.3 E-04[e]	D
Thorium	1.7 E-05[e]	D
Tungsten	1.1 E-05[e]	D
Dysprosium	1.3 E-05[e]	D
Samarium	2.0 E-05[e]	D
Neodymium	2.6 E-05[e]	D
Praseodymium	3.0 E-05[e]	D
Iodine	1.8 E-05[e]	D
Tin	3.1 E-05[e]	D
Molybdenum	1.9 E-04[e]	D
Niobium	3.5 E-05[e]	D
Zirconium	3.5 E-04[e]	D
Yttrium	5.6 E-05[e]	D
Rubidium	1.2 E-03[e]	D
Bromine	3.9 E-04[e]	D
Germanium	2.5 E-06[e]	D
Arsenic	8.53 E-05[f]	B
Cadmium	2.12 E-05[f]	B
Chromium (Total)	1.56 E-04[g]	B
Lead	4.45 E-04[d]	B
Manganese	1.26 E-02[f]	B
Mercury	5.15 E-06[h]	C
Nickel	6.90 E-05[j]	B
Selenium	4.59 E-05[e,k]	E

[a] Units are lb of pollutant/ton of wood waste burned. To convert from lb/ton to kg/Mg, multiply by 0.5. To convert from lb/ton to lb/MMBtu, multiply by 0.11. Emission factors are based on wet, as-fired wood waste with average properties of 50 weight % moisture and 4500 Btu/lb higher heating value. Source Classification Codes are 1-010-09-01/02/03, 1-02-009-01/02/03/04/05/06/07, and 1-03-009-01/02/03.
[b] Pollutants in this table represent metal species measured for wood waste combustors equipped with PM controls (i.e., fabric filters, multi-cyclones, ESP, and wet scrubbers). Other metal species may also have been emitted but were either not measured or were present at concentrations below analytical limits.
[c] References 11,19-22.
[d] References 32,34-41.
[e] Based on data from one source test.
[f] References 32,34-37,39,41.
[g] References 32,34-39,41.
[h] References 32,34-35,37.
[j] References 32,34-37,40.
[k] References 40.

Table 1.6-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR BARK-FIRED SPREADER STOKER BOILERS[a]

EMISSION FACTOR RATING: D

Particle Size[b] (μm)	Cumulative Mass % ≤ Stated Size				Cumulative Emission Factor[c] (lb/ton)			
	Uncontrolled	Controlled			Uncontrolled	Controlled		
		Multiple Cyclone[d]	Multiple Cyclone[e]	Scrubber[f]		Multiple Cyclone[d]	Multiple Cyclone[e]	Scrubber[f]
15	42	90	40	92	20.2	12.6	3.6	2.64
10	35	79	36	87	16.8	11.0	3.24	2.50
6	28	64	30	78	13.4	9.0	2.7	2.24
2.5	21	40	19	56	10.0	5.6	1.72	1.62
1.25	15	26	14	29	7.2	3.6	1.26	0.84
1.00	13	21	11	23	6.2	3.0	1.0	0.66
0.625	9	15	8	14	4.4	2.2	0.72	0.40
Total	100	100	100	100	48	14	9.0	2.88

[a] Reference 45. Emission factors are based on wet, as-fired wood waste with average properties of 50 weight % moisture and 4500 Btu/lb higher heating value. Source Classification Codes are 1-01-009-01, 1-02-009-01, 1-02-009-04, and 1-03-009-01.
[b] Expressed as aerodynamic equivalent diameter.
[c] Units are lb of pollutant/ton of wood waste burned. To convert from lb/ton to kg/Mg, multiply by 0.5. To convert from lb/ton to lb/MMBtu, multiply by 0.11.
[d] With flyash reinjection.
[e] Without flyash reinjection.
[f] Assumed control efficiency for scrubber is 94%.

Table 1.6-7. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR WOOD/BARK-FIRED BOILERS[a]

EMISSION FACTOR RATING: E

Particle Size[b] (μm)	Cumulative Mass % $\leq$ Stated Size					Cumulative Emission Factor[c] (lb/ton)				
		Controlled					Controlled			
	Uncontrolled[d]	Multiple Cyclone[e]	Multiple Cyclone[f]	Scrubber[g]	DEGF	Uncontrolled[d]	Multiple Cyclone[e]	Multiple Cyclone[f]	Scrubber[g]	DEGF[g]
15	94	96	35	98	77	6.77	5.76	1.90	0.431	0.246
10	90	91	32	98	74	6.48	5.46	1.72	0.432	0.236
6	86	80	27	98	69	6.20	4.80	1.46	0.432	0.220
2.5	76	54	16	98	65	5.47	3.24	0.86	0.432	0.208
1.25	69	30	8	96	61	4.97	1.80	0.44	0.422	0.196
1.00	67	24	6	95	58	4.82	1.44	0.32	0.418	0.186
0.625	ND	16	3	ND	51	ND	0.96	0.162	ND	0.164
Total	100	100	100	100	100	7.2	6.0	5.4	0.44	0.32

[a] Reference 45. Emission factors are based on wet, as-fired wood waste with average properties of 50 weight % moisture and 4500 Btu/lb higher heating value. Source Classification Codes are 1-01-009-02, 1-02-009-02, 1-02-009-05, and 1-03-009-02. ND = no data. DEGF = dry electrostatic granular filter.

[b] Expressed as aerodynamic equivalent diameter.

[c] Units are lb of pollutant/ton of wood bark burned. To convert from lb/ton to kg/Mg, multiply by 0.5. To convert from lb/ton to lb/MMBtu, multiply by 0.11.

[d] From data on underfeed stokers. May also be used as size distribution for wood-fired boilers.

[e] From data on spreader stokers with flyash reinjection.

[f] From data on spreader stokers without flyash reinjection.

[g] From data on Dutch ovens. Assumed control efficiency is 94%.

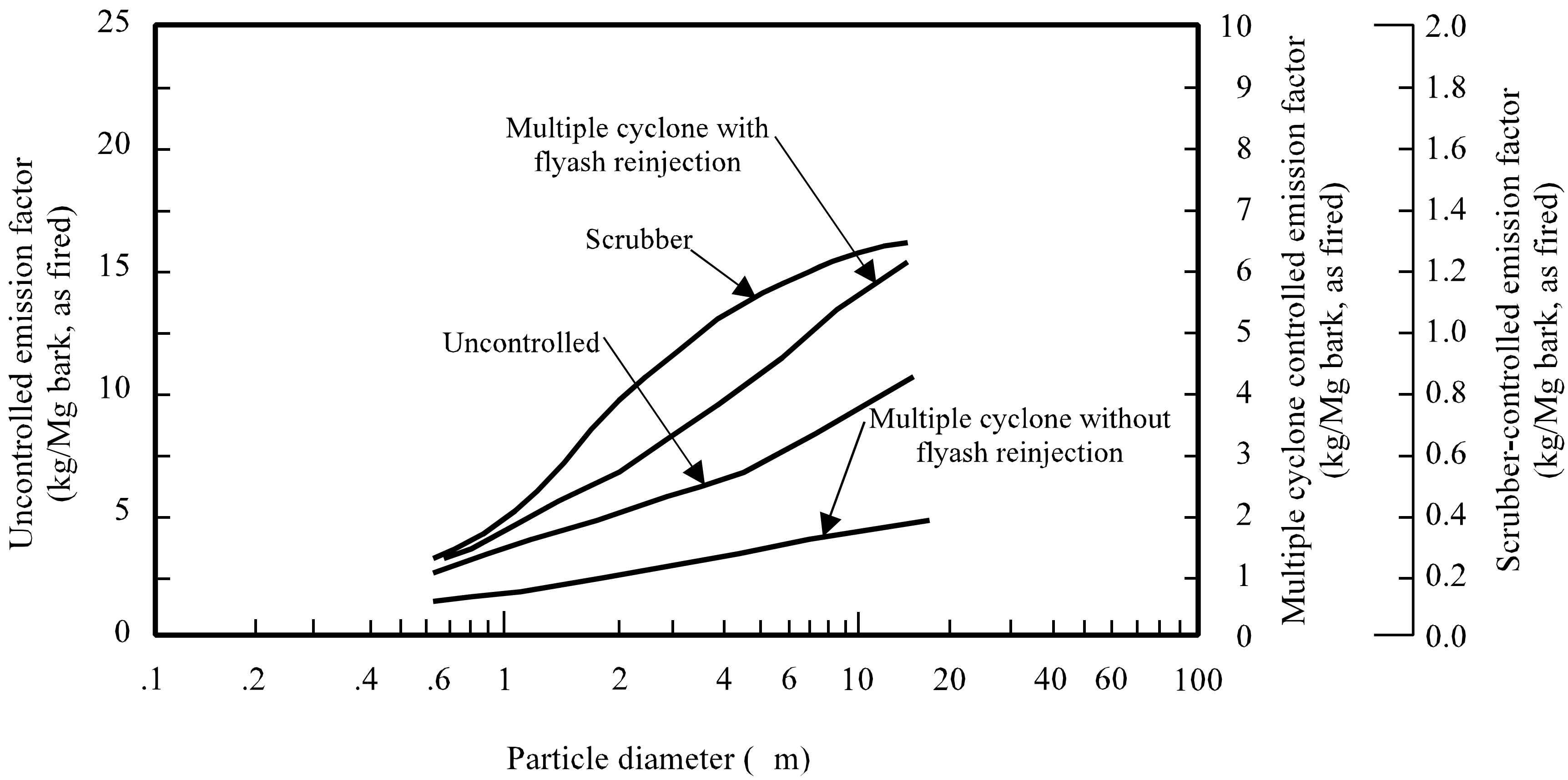

Figure 1.6-1. Cumulative size-specific particulate matter emission factors for bark-fired boilers.

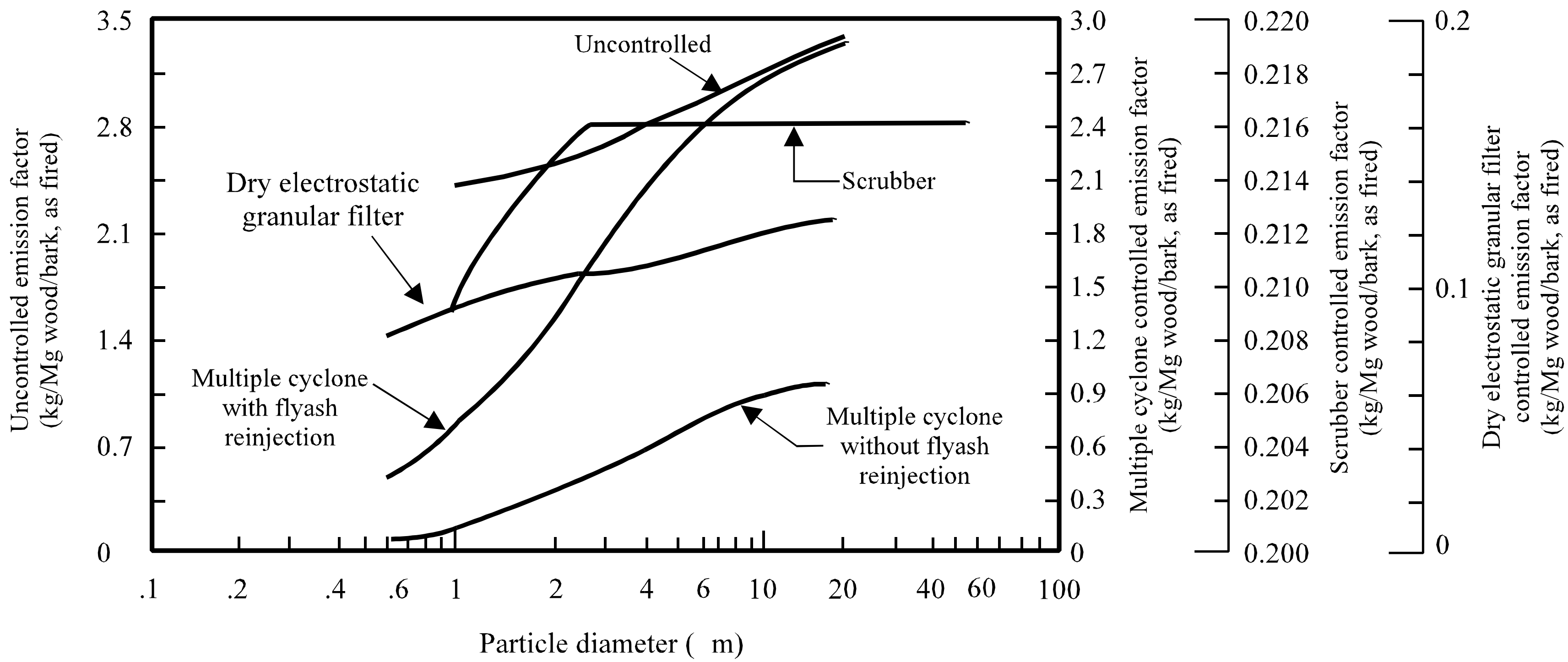

Figure 1.6-2. Cumulative size-specific particulate matter emission factors for wood/bark-fired boilers.

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