1.10 Residential Wood Stoves

1.10.1 General[1-2]

Wood stoves are enclosed wood heaters that control burning or burn time by restricting the amount of air that can be used for combustion; they are commonly used in residences as space heaters. They are used both as the primary source of residential heat and to supplement conventional heating systems. Based on known variations in construction, combustion, and emission characteristics, there are five different categories of residential wood burning devices: (1) the conventional wood stove; (2) the noncatalytic wood stove; (3) the catalytic wood stove; (4) the pellet stove; and (5) the masonry heater.

The conventional stove category comprises all stoves without catalytic combustors not included in the other noncatalytic categories (i. e., noncatalytic and pellet). Conventional stoves do not have any emission reduction technology or design features and, in most cases, were manufactured before July 1, 1986. Stoves with various airflow designs may be in this category, such as updraft, downdraft, crossdraft, and S-flow.

Noncatalytic wood stoves are those units that do not employ catalysts but that do have emission reducing technology or features. Typical noncatalytic design includes baffles and secondary combustion chambers.

Catalytic stoves are equipped with a ceramic or metal honeycomb device, called a combustor or converter, that is coated with a noble metal such as platinum or palladium. The catalyst material reduces the ignition temperature of the unburned volatile organic compounds (VOC) and carbon monoxide (CO) in the exhaust gases, thus augmenting their ignition and combustion at normal stove operating temperatures. As these components of the gases burn, the temperature inside the catalyst increases to a point at which the ignition of the gases is essentially self-sustaining.

Pellet stoves are those fueled with pellets of sawdust, wood products, and other biomass materials pressed into manageable shapes and sizes. These stoves have active air flow systems and unique grate design to accommodate this type of fuel. Some pellet stove models are subject to the 1988 New Source Performance Standards (NSPS), while others are exempt due to a high air-to-fuel ratio (i. e., greater than 35-to-1).

Masonry heaters are large, enclosed chambers made of masonry products or a combination of masonry products and ceramic materials. These devices are exempt from the 1988 NSPS due to their weight (i. e., greater than 1764 lb). Masonry heaters are gaining popularity as a cleaner-burning, heat-efficient form of primary and supplemental heat, relative to some other types of wood heaters. In a masonry heater, a complete charge of wood is burned in a relatively short period of time. The use of masonry materials promotes heat transfer. Thus, radiant heat from the heater warms the surrounding area for many hours after the fire has burned out.

1.10.2 Emissions

The combustion and pyrolysis of wood in wood stoves produce atmospheric emissions of particulate matter (PM), CO, nitrogen oxides (NO_x), VOC, mineral residues, and to a lesser extent, sulfur oxides (SO_x). The quantities and types of emissions are highly variable, depending on a

number of factors, including stage of the combustion cycle. During initial burning stages, after a new wood charge is introduced, emissions (primarily VOCs) increase dramatically. After the initial period of high burn rate, there is a charcoal stage of the burn cycle characterized by a slower burn rate and decreased emissions. Emission rates during this stage are cyclical, characterized by relatively long periods of low emissions and shorter episodes of emission spikes.

Particulate emissions are defined in this discussion as the total catch measured by the EPA Method 5H (Oregon Method 7) sampling train.[1] A small portion of wood stove particulate emissions includes "solid" particles of elemental carbon and wood. The vast majority of particulate emissions are condensed organic products of incomplete combustion equal to or less than 10 micrometers in aerodynamic diameter (PM-10). Although reported particle size data are scarce, one reference states that 95 percent of the particles emitted from a wood stove were less than 0.4 micrometers in size.[3]

SO_x are formed by oxidation of sulfur in the wood. NO_x are formed by oxidation of fuel and atmospheric nitrogen. Mineral constituents, such as potassium and sodium compounds, are released from the wood matrix during combustion.

The high levels of organic compounds and CO emissions result from incomplete combustion of the wood. Organic constituents of wood smoke vary considerably in both type and volatility. These constituents include simple hydrocarbons of carbon numbers 1 through 7 (C1 - C7) (which exist as gases or which volatilize at ambient conditions) and complex low-volatility substances that condense at ambient conditions. These low volatility condensable materials generally are considered to have boiling points below 572°F.

Polycyclic organic matter (POM) is an important component of the condensable fraction of wood smoke. POM contains a wide range of compounds, including organic compounds formed through incomplete combustion by the combination of free radical species in the flame zone. These compounds are classified as hazardous air pollutants under Title III of the 1990 Clean Air Act Amendments, which contains the sub-group of hydrocarbons called polycyclic aromatic hydrocarbons (PAH).

1.10.3 Controls[4]

To decrease PM and CO emissions from wood stoves, combustion efficiency must increase. Both catalytic and noncatalytic control techniques increase efficiency and decrease emissions. Catalytic combustors reduce emissions by using a ceramic catalyst coated with a noble metal (e. g., palladium or platinum) which allows organics and other combustibles to burn at temperatures much lower than required in a noncatalytic firebox.

Older, noncatalytic wood stoves reduce emissions by directing unburned hydrocarbons (HCs) and CO into a secondary chamber, where mixing with fresh, preheated makeup air enhances further combustion. Current noncatalytic wood stoves inject fresh secondary air into the top of the primary combustion chamber, allowing ignition of the HCs. Multiple air channels, some with their own controls, coupled with baffles which trap and retain heat in the top of the firebox facilitate this combustion.

Emission factors and their ratings for wood combustion in residential wood stoves, pellet stoves, and masonry heaters are presented in Tables 1.10-1, 1.10-2, 1.10-3, 1.10-4, 1.10-5, 1.10-6, and 1.10-7. 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 17.3 MMBtu/ton. The analysis leading to the revision of these emission factors is contained in the emission factor documentation.[4] These tables

include emission factors for criteria pollutants (PM-10, CO, NO_x, SO_x), carbon dioxide (CO_2), total organic compounds (TOC), speciated organic compounds, PAH, and some elements. The emission factors are presented by wood heater type. PM-10 and CO emission factors are further classified by stove certification category. Phase II stoves are those certified to meet the July 1, 1990, EPA standards; Phase I stoves meet only the July 1, 1988, EPA standards; and Pre-Phase I stoves do not meet any of the EPA standards but in most cases do necessarily meet the Oregon 1986 certification standards.[1]

The emission factors for PM and CO in Tables 1.10-1 and 1.10-2 are averages, derived entirely from field test data obtained under actual operating conditions. Still, there is a potential for higher emissions from some wood stove, pellet stove, and masonry heater models. Particulate emissions are presented as the total PM emissions equivalent to that collected by EPA Method 5H. This method employs a heated filter followed by three impingers, an unheated filter, and a final impinger. Conversions are employed, as appropriate, for data collected with other methods.

Table 1.10-5 shows net efficiency by device type, determined entirely from field test data. Net or overall efficiency is the product of combustion efficiency multiplied by heat transfer efficiency. Wood heater efficiency is an important parameter that is used, along with emission factors and percent degradation, to calculate PM-10 emission reduction credits. Percent degradation is related to the loss in effectiveness of a wood stove control device or catalyst over a period of operation. Control degradation for any stove, including noncatalytic wood stoves, may also occur as a result of deteriorated seals and gaskets, misaligned baffles and bypass mechanisms, broken refractories, or other damaged functional components. The increase in emissions which can result from control degradation has not been quantified.

1.10.4 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

No changes.

Supplement B, October 1996

- Text was added concerning controls.
- Reference 15 was corrected.
- The emission factor for phenanthrene was corrected.
- Information was incorporated concerning methane and nonmethane-HC.

Table 1.10-1. EMISSION FACTORS FOR RESIDENTIAL WOOD COMBUSTION[a]

Pollutant/EPA Certification[b]	EMISSION FACTOR RATING	Wood Stove Type Emission Factor (lb/ton)			Pellet Stove Type,[c] Emission Factor (lb/ton) (SCC 21-04-008-053)		Masonry Heater, Emission Factor (lb/ton) (SCC 21-04-008-055)
		Conventional (SCC 21-04-008-051)	Noncatalytic (SCC 21-04-008-050)	Catalytic (SCC 21-04-008-030)	Certified	Exempt	Exempt[d]
PM-10[e]							
Pre-Phase I	B	30.6	25.8	24.2	ND	ND	ND
Phase I	B	ND	20.0	19.6	ND	ND	ND
Phase II	B	ND	14.6	16.2	4.2	ND	ND
All	B	30.6	19.6	20.4	4.2	8.8	5.6
CO							
Pre-Phase I	B	230.8	ND	ND	ND	ND	ND
Phase I	B	ND	ND	104.4	ND	ND	ND
Phase II	B	ND	140.8	107.0	39.4	ND	ND
All	B	230.8	140.8	104.4	39.4	52.2	149.0
NO_x		2.8[f]	ND	2.0[g]	13.8[g]	ND	ND
SO_x	B	0.4	0.4	0.4	0.4	ND	ND
CO_2[j]	C	ND	ND	ND	2952	3671	3849
TOC[k]	C	83	28	26.6	ND	ND	ND
Methane	C	30	16	11.6	ND	ND	ND
TNMOC	C	53	12	15	ND	ND	ND

[a] To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data. TNMOC = total nonmethane organic compounds.
[b] Pre-Phase I = Not certified to 1988 EPA emission standards; Phase I = Certified to 1988 EPA emission standards; Phase II = Certified to 1990 EPA emission standards; All = Average of emission factors for all devices.
[c] Certified = Certified pursuant to 1988 NSPS; Exempt = Exempt from 1988 NSPS (i. e., air-to-fuel ratio > 35:1).
[d] Exempt = Exempt from 1988 NSPS (i. e., device weight >800 kg).
[e] References 5-18. PM-10 is defined as equivalent to total catch by EPA method 5H train.
[f] EMISSION FACTOR RATING: C.
[g] EMISSION FACTOR RATING: E.
[h] References 12, 15-18.
[j] CO_2 emitted from this source may not increase total atmospheric CO_2 because the emissions may be offset by the uptake of CO_2 by regrowing biomass.
[k] References 12, 19-22. Data show a high degree of variability within the source population. Factors may not be accurate for individual sources.

Table 1.10-2. ORGANIC COMPOUND EMISSION FACTORS FOR RESIDENTIAL WOOD COMBUSTION[a,b]

EMISSION FACTOR RATING: E

Compounds	Wood Stove Type Emission Factor (lb/ton)	
	Conventional (SCC 21-04-008-051)	Catalytic (SCC 21-04-008-030)
Ethane	1.470	1.376
Ethylene	4.490	3.482
Acetylene	1.124	0.564
Propane	0.358	0.158
Propene	1.244	0.734
i-Butane	0.028	0.010
n-Butane	0.056	0.014
Butenes[c]	1.192	0.714
Pentenes[d]	0.616	0.150
Benzene	1.938	1.464
Toluene	0.730	0.520
Furan	0.342	0.124
Methyl Ethyl Ketone	0.290	0.062
2-Methyl Furan	0.656	0.084
2,5-Dimethyl Furan	0.162	0.002
Furfural	0.486	0.146
o-Xylene	0.202	0.186

[a] Reference 19. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code.

[b] Data show a high degree of variability within the source population. Factors may not be accurate for individual sources.

[c] 1-butene, i-butene, t-2-butene, c-2-butene, 2-me-1-butene, 2-me-butene are reported as butenes.

[d] 1-pentene, t-2-pentene, and c-2-pentene are reported as pentenes.

Table 1.10-3. PAH EMISSION FACTORS FOR RESIDENTIAL WOOD COMBUSTION[a,b]

EMISSION FACTOR RATING: E

Pollutant	Stove Type Emission Factor (lb/ton)			
	Conventional[c] (SCC 21-04-008-051)	Noncatalytic[d] (SCC 21-04-008-050)	Catalytic[e] (SCC 21-04-008-030)	Exempt Pellet[f] (SCC 21-04-008-053)
PAH				
Acenaphthene	0.010	0.010	0.006	ND
Acenaphthylene	0.212	0.032	0.068	ND
Anthracene	0.014	0.009	0.008	ND
Benzo(a)Anthracene	0.020	<0.001	0.024	ND
Benzo(b)Fluoranthene	0.006	0.004	0.004	2.60 E-05
Benzo(g,h,i)Fluoranthene	ND	0.028	0.006	ND
Benzo(k)Fluoranthene	0.002	<0.001	0.002	ND
Benzo(g,h,i)Perylene	0.004	0.020	0.002	ND
Benzo(a)Pyrene	0.004	0.006	0.004	ND
Benzo(e)Pyrene	0.012	0.002	0.004	ND
Biphenyl	ND	0.022	ND	ND
Chrysene	0.012	0.010	0.010	7.52 E-05
Dibenzo(a,h)Anthracene	BDL	0.004	0.002	ND
7,12-Dimethylbenz(a)Anthracene	ND	0.004	ND	ND
Fluoranthene	0.020	0.008	0.012	5.48 E-05
Fluorene	0.024	0.014	0.014	ND
Indeno(1,2,3,cd)Pyrene	BDL	0.020	0.004	ND
9-Methylanthracene	ND	0.004	ND	ND
12-Methylbenz(a)Anthracene	ND	0.002	ND	ND
3-Methylchlolanthrene	ND	<0.001	ND	ND
1-Methylphenanthrene	ND	0.030	ND	ND
Naphthalene	0.288	0.144	0.186	ND
Nitronaphthalene	ND	BDL	ND	ND
Perylene	ND	0.002	ND	ND
Phenanthrene	0.078	0.118	0.048	3.32 E-05
Phenanthrol	ND	BDL	ND	ND
Phenol	ND	<0.001	ND	ND
Pyrene	0.024	0.008	0.010	4.84 E-05
PAH Total	0.730	<0.500	0.414	2.38 E-04

[a] To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data. BDL = below detection limit. < = values are below this detection limit.

[b] Data show a high degree of variability within the source population and/or came from a small number of sources. Factors may not be accurate for individual sources.

[c] Reference 19.

[d] References 20,23-25.

[e] References 13,19-20,23,26.

[f] Reference 18. Exempt = Exempt from 1988 NSPS (i. e., air-to-fuel ratio > 35:1).

Table 1.10-4. TRACE ELEMENT EMISSION FACTORS FOR RESIDENTIAL WOOD COMBUSTION[a,b]

EMISSION FACTOR RATING: E

Element	Wood Stove Type Emission Factor (lb/ton)		
	Conventional (SCC 21-04-008-051)	Noncatalytic (SCC 21-04-008-050)	Catalytic (SCC 21-04-008-030)
Cadmium (Cd)	2.2 E-05	2.0 E-05	4.6 E-05
Chromium (Cr)	<1.0 E-06	<1.0 E-06	<1.0 E-06
Manganese (Mn)	1.7 E-04	1.4 E-04	2.2 E-04
Nickel (Ni)	1.4 E-05	2.0 E-05	2.2 E-06

[a] References 19,25. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. < = values are below this detection limit.
[b] The data used to develop these emission factors showed a high degree of variability within the source population. Factors may not be accurate for individual sources.

Table 1.10-5. SUMMARY OF WOOD STOVE NET EFFICIENCIES[a]

Wood Heater Type	Source Classification Code	Net Efficiency (%)	Reference
Wood Stoves			
Conventional	21-04-008-051	54	16
Noncatalytic	21-04-008-050	68	7,10,16
Catalytic	21-04-008-030	68	16,27
Pellet Stoves			
Certified[b]	21-04-008-053	68	9
Exempt[c]		56	17
Masonry Heaters			
All	21-04-008-055	58	18

[a] Net efficiency is a function of both combustion efficiency and heat transfer efficiency. The percentages shown here are based on data collected from in-home testing. References 5,8,10-11,17-18,28.
[b] Certified = Certified pursuant to 1988 NSPS.
[c] Exempt = Exempt from 1988 NSPS (i. e., air-to-fuel ratio >35:1).

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