Updated Emissions Data for Revision of AP-42 Section 1.9, Residential Fireplaces

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1.9 Residential Fireplaces

1.9.1 General[1-11]

In 2002 there were an estimated 35 million homes with fireplaces in the United States. Fireplaces are used primarily for aesthetics and secondary heating. Only 0.2% of home occupants with fireplaces report using fireplaces as their main heat source. Survey data have shown that 17% of the homes with fireplaces have more than one fireplace suggesting a total of 41 million fireplaces nationwide. Approximately 26% of fireplaces use natural gas as a fuel. Of the 74% (30 million) solid fuel burning fireplaces, 28% have inserts, leaving 22 million true solid fuel burning fireplaces. Solid fuel fireplace inserts burning cordwood or pellets are essentially heaters and the emissions of cordwood and pellet heaters are provided in Section 1.10, Residential Wood Stoves. Among true solid fuel burning fireplaces (i.e., those without inserts), wood is the most common fuel with 30% of users reporting burning manufactured wax/sawdust firelogs some of the time along with wood and 12% using manufactured wax/sawdust firelogs exclusively. Emission factors for true fireplaces without inserts, burning both cordwood and manufactured wax/sawdust firelogs, are provided here.

Notably, many fireplaces are used infrequently. Thirty-one percent of home occupants with fireplaces report not using them in a given year and 17% report using them only one or two times during the heating season.

Fireplaces can be divided into two categories: (1) site-built masonry, and (2) prefabricated factory-built. It is estimated that about 20% of the fireplaces in homes are masonry and 80% are factory built. Both masonry and factory-built fireplaces can be installed and operated with or without doors (generally made of glass) and louvers. Doors and louvers reduce the intake of combustion air. The reduction of combustion air volume generally increases overall efficiency since less heated air is exhausted out the chimney. Some factory-built fireplaces are surrounded by ducts through which floor level air is drawn by natural convection, heated and returned to the room. Fireplaces have dampers above the combustion area to limit room air and heat losses when the fireplace is not being used.

Masonry fireplaces are generally constructed of, mortar, brick, cement blocks, cinder blocks and/or stone. The firebox is frequently constructed with firebrick or sometimes with metal. Their chimneys are often lined with chimney tiles. The chimneys are usually rectangular or square with dimensions ranging from as small as 6 inches by 6 inches to as large as 2 feet by 2 feet. Masonry fireplaces are usually an integral part of the structure.

There are two types of factory-built fireplaces. One type is the freestanding fireplace, which usually consists of an inverted sheet metal funnel and stovepipe directly above the fire bed. Only a few percent of the factory-built fireplaces are freestanding. The other type (by far the most common) is the “zero-clearance” fireplace. The zero-clearance fireplace is constructed with an iron or heavy-gauge steel firebox lined with firebrick and surrounded by multiple steel walls with spaces for air circulation. The zero-clearance models are installed on site directly into a wall. There are three common sizes of zero-clearance fireplaces. These are 36-inch, 42-inch and 48-

inch, which refer to the front width of the firebox opening. However, these are nominal size designations, in that, the height, depth and, back width are variable with models. Typical factory-built fireplace chimneys are made of round metal pipe and range in size from 6 inches in diameter to 12 inches in diameter.

Fireplace chimney heights (above the fireplace) range from about 8 feet for a mobile home to about 12 feet, 22 feet, and 32 feet for one, two, and three story frame homes, respectively. Most chimneys are topped with a chimney cap to minimize sparks from escaping and precipitation from entering the chimney. Creosote accumulates on the chimney walls but at a slower rate than for a wood stove due to the more complete combustion associated with excess air in fireplaces.

During operation, the user intermittently adds fuel to the fire by hand. Over 50 tree species are used as fuel in the U.S. Fuel moisture ranges widely depending on seasoning practices. The average cordwood moisture content of cordwood was found from numerous in-home measurements to be 24.1% on a dry basis (Table 1.9-1). Wet wood burns with less efficiency and higher emissions than properly seasoned wood. Properly seasoned wood has a moisture content of less than about 25% on a dry basis.

The most common commercially available manufactured firelogs are composed of 40% to 60% petroleum wax with the remaining portion being sawdust. The moisture content of wax/sawdust firelogs is about one-tenth that of typical cordwood (Table 1.9-1) and their heat content per unit mass is nearly twice that of cordwood. Consequently, the manufacturers' instructions and the commensurate aesthetic/radiant heat satisfaction level for wax/sawdust firelog use is a one-at-a-time burning scenario. Other types of manufactured logs made of biomass and recycled material are sometimes used in fireplaces, but their usage is very small as compared to wax/sawdust firelogs.

The mean burn rate for cordwood in fireplaces in the U.S. was determined to be 5.13 dry kg/hr. The median and mode burn rate values were considerably less than the mean value due to the preponderance of smaller zero-clearance fireplaces in use (Table 1.9-2). Firelog burn rates are much smaller than cordwood burn rates due to their higher heat content per unit mass and their one-at-a-time usage (Table 1.9-2).

The aesthetic warming and space heating effects from fireplaces are primarily from radiant heat. Little heat is gained from convection or conduction. The efficiency of a fireplace without a door is often cited as 7% and with a door it is in the 30% range. Both these efficiency values are quite variable depending on home and fireplace construction as well as operational practices and weather. The low efficiencies are primarily from the large amount of excess air heated and lost out the chimney (see Table 1.9-2 for chimney flow rates) which is made up by cold air infiltrating into the house. Efficiency also tends to be low due to the fact that fireplaces are generally on outside walls rather than in the center of a structure, hence radiant and convective heat transfers are not efficient.

It should be noted that two other appliance types are frequently confused with fireplaces. One of these types is the wood stove which is certified and made to look like a fireplace. These are sometimes call "high technology fireplaces." The other type is the masonry heater. Masonry heaters look similar to a masonry fireplace, but are constructed and operated differently. They have air tight doors, a large mass to absorb and re-radiate heat, and have folded exhaust channels to facilitate heat transfer to their "heat sink." Masonry heaters operate by burning wood at a high burn rate for short period. Once their large mass is heated it then re-radiates the heat for a long time period after the active fire is out. The emission factors for both high technology fireplaces (wood stoves) and masonry heaters are provided in Section 1.10, Residential Wood Stoves.

1.9.2 Emissions and Controls

Fireplace pollutant emissions are caused by the incomplete combustion of fuel. The key pollutants are particles, carbon monoxide and organic compounds, emitted both as particles and as gases. Some of the organic compounds are hazardous air pollutants (HAPs), notable among them are formaldehyde, benzene, and polycyclic organic matter (POM). Because the fuel sources, wood or firelogs, are made up of primarily organic compounds, a variety of other organic products of incomplete combustion have been measured. These include numerous aldehydes, phenols, alcohols, ketones, carboxylic acids, and hydrocarbons. Measurable levels of the simple organic compounds of methane, ethane, methanol, ethanol, formaldehyde, acetaldehyde, acrolein, phenol, cresol, formic acid and acetic acid have been well documented. In addition, many dozens of other more complex organic compounds, many produced by build-up by radical chains, have been measured at trace levels.

The nitrogen, sulfur, halide and metal contents of the cordwood and wax/sawdust firelogs are low, therefore air emissions of compounds containing them are also low. However, as with any combustion process in the presence of atmospheric nitrogen, some nitrogen oxides are produced.

The particles that are emitted are primarily submicron. Approximately 90% of the total particles emitted are PM_{10} and 84% are $PM_{2.5}$. Elemental carbon makes up between 10% to 30% of the particulate emissions, depending on combustion conditions. Inorganic salts contribute only a few percent to the total particulate emissions. These are principally benign salts composed of sodium, magnesium, potassium, calcium, zinc and ammonium cations with sulfate, chloride, carbonate, and nitrate anions. The remaining and by far the largest fraction of particulate emissions are made up of organic compounds.

Fireplace emissions are acidic because they contain carboxylic acids and phenols. Combustion residues (ash) are basic because they contain alkaline earth and alkali metal oxides. Creosote formed on the inside of chimneys is a mixture of organic compounds, elemental carbon and inorganic salts. The organic compound content of creosote formed by fireplaces is lower than that formed by wood stoves, due to less pyrolysis occurring in the oxygen rich conditions of a fireplace environment as compared to that of a wood stove.

In terms of greenhouse gases, carbon dioxide, methane and a variety of non-methane volatile organic compounds (NMVOC) are emitted. Roughly equal amounts of methane and NMVOC are emitted. As with the complete combustion of any organic material, carbon dioxide and water are the end products of complete combustion. (Even the much smaller amount of carbon monoxide as compared to carbon dioxide that is emitted is oxidized to carbon dioxide in the atmosphere.) The combustion efficiency in fireplaces is over 90%, consequently the carbon dioxide emission levels can be estimated from the carbon content of the fuel. Typical cordwood contains 51% carbon. A typical wax/sawdust firelog contains 72% carbon. Because the combustion of biomass recycles recent carbon rather than introducing fossil carbon into the atmosphere and because usually more mature trees are harvested for fuel which are replaced by younger more rapidly photosynthesizing trees, the burning of cordwood and the sawdust component of firelogs has less of a greenhouse effect than the carbon dioxide emissions alone would suggest.

There are a few practical control measures for fireplace emissions. About 11% of particulate emissions (and a high fraction of other pollutants) occur during the very short kindling phase of a fire due to incomplete combustion that occurs before optimal temperatures are reached. Measures that shorten the kindling phase tend to reduce pollutant emissions. These include the use of natural gas starter grates, wax starter logs and forced air grates. Forced air grates also tend to reduce emissions throughout the fire by enhancing combustion. Some masonry fireplaces with specially shaped fireboxes also have been shown to reduce emissions. Natural gas and electrically heated after burner devices have been shown to be effective, but because of the large amount of energy that is needed to treat dilute particulate and organic gas emissions at high flow rates characteristic of fireplaces, they are not practical for most residential applications. The most practical pollutant emission reductions are related to fuel. Properly sized, clean, well-seasoned (dry) cordwood produces the lowest emissions for cordwood. Notably, significant reductions, as compared to cordwood, are achieved through the use of manufactured fuels. Wax/sawdust firelogs are the most common, readily available, type of manufactured fuel for residential fireplaces currently in use.

Key pollutant emissions for cordwood burned in fireplaces are provided in Table 1.9-3. The mean, standard deviation, median, and "n" value for each pollutant are provided based on a review of values provided in available publications and reports. The n value varies for each pollutant depending on the number of measurements that have been reported for it. Different particulate measurement methods have been used in the various studies. The different measurement methods produce different particulate values primarily due to the differential capture of condensible organic compounds. Consequently, all particulate data have been converted to a EPA method 5H equivalent value, following conversion equations developed by the EPA. Also, the particulate material (PM) values shown in Table 1.9-3 are for total particles. For fireplace emissions, studies have shown that a conversion factor of 0.90 should be used to convert total PM to PM_{10} and a conversion factor of 0.84 should be used to convert total PM to $PM_{2.5}$.

Fireplace nitrogen oxides emissions are primarily a mixture of nitrogen dioxide (NO_2) and nitric oxide (NO) with trace levels nitrous oxide (N_2O). The sum of all nitrogen oxides is reported as nitrogen dioxide in Table 1.9-3.

The 16-PAH and 7-PAH conventions have been used to characterize polycyclic organic matter (POM) emissions and their values are tabulated in Table 1.9-3. The 16 polycyclic aromatic hydrocarbons (16-PAH) were designated by the EPA as compounds of interest under a suggested procedure for reporting test measurements. They are a subset of the almost infinite number of POM compounds that can occur in air emissions from the combustion of biomass and they are routinely used as an indicator of total POM emissions for a variety of air pollutant sources. A subset of seven (7-PAH) of the 16 compounds has been identified by the International Agency for Research on Cancer (IARC) as animal carcinogens. The seven compounds have been studied by the EPA as potential human carcinogens. To provide uniformity and permit comparisons of data compiled for other air pollutant sources the 16-PAH and 7-PAH values are provided here for fireplace emissions.

The emissions for fireplaces burning wax/sawdust firelogs are provided Table 1.9-4. The mean, standard deviation, median, and n values are provided for the same pollutants as have been compiled for fireplaces burning cordwood in Table 1.9-3. The mode is not provided, as it is with cordwood, because the number of reported measurements is much smaller for fireplaces burning wax/sawdust firelogs then it is for fireplaces burning cordwood. In addition to the standard mean and median emission factors, a wood equivalent emission factor is also provided. Less mass of wax/sawdust firelogs is burned during a given time period as compared to cordwood due to their higher heat content, lower moisture content, and their one-at-a-time pattern. For this reason, the wood equivalent emission factors are provided to permit the direct calculation of the change in emissions if wax/sawdust firelogs are burned in lieu of cordwood in fireplaces.

Table 1.9-1. Fuel Moisture

Parameter	Cordwood Percent Moisture (DB)[1,2]	Firelog Percent Moisture (DB)[1,3]
Mean	24.1	2.2
Standard Deviation	12.9	0.4
Median	21.4	2.2
Mode	17.0	2.2
n	820	30

1. DB = dry basis, i.e, the mass of water divided by the mass of dry wood.
2. Data from references 12-34.
3. Data from references 35-46.

Table 1.9.2. Fireplace Burn Rate and Chimney Flow Rate

Parameter	Cordwood[1]		Firelogs[2]	
	Burn Rate (dry kg/hr)	Flow Rate (std m^3/min)	Burn Rate (dry kg/hr)	Flow Rate (std m^3/min)
Mean	5.13	6.42	0.74	4.24
Standard Deviation	3.03	4.16	0.28	1.18
Median	4.20	4.58	0.70	4.27
Mode	3.50	3.90	0.58	4.10
N	557	275	28	10

1. Data from references 24, 29, 47-65.
2. Data from references 35-46.

Table 1.9-3. Fireplace Cordwood Emission Factors[1]

Pollutant	Emission Factor Data (g/ dry kg)[2]			
	Mean	Standard Deviation	Median	n
Particles (PM)[3]	11.1	8.9	9.3	552
Carbon Monoxide	72.9	44.3	69.0	491
Nitrogen Oxides[4]	1.6	1.3	1.3	48
Methane	6.7	6.0	5.6	15
Benzene	0.30	0.27	0.31	17
Formaldehyde	1.2	1.4	0.7	24
16-PAH[5]	0.62	1.2	0.26	49
7-PAH[6]	0.11	0.28	–	21

1. Data from references 24, 39, 47-65.
2. To convert g/kg to lb/ton multiply by 2.00.
3. All particulate data converted to 5H equivalent values. PM from fireplaces has been shown to be approximately 90% PM_{10} and 84%$PM_{2.5}$ (references 61 and 66).
4. Nitrogen oxide values reported as NO_2.
5. The 16-PAH (Polycyclic Aromatic Hydrocarbon) value is the sum of: naphthalene, acenaphthene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene,

benzo(ghi)perylene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

6. The 7-PAH (Polycyclic Aromatic Hydrocarbon) value is the sum of: benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoanthene, benzo(a)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene.

Table 1.9-4. Firelog Emission Factors[1]

Pollutant	Emission Factors (g/ dry kg)[2]			Wood Equivalent[3] (g/ dry kg)	n
	Mean	Standard Deviation	Median		
Particles (PM)	21.2	13.9	17.6	4.5	26
Carbon Monoxide	58.5	41.8	51.0	12.4	26
Nitrogen Oxides[4]	2.0	1.4	1.6	0.42	4
Methane	27.0	-	-	5.7	2
Benzene	0.84	0.60	0.71	0.18	3
Formaldehyde	1.2	0.2	1.3	0.26	3
16-PAH[5]	0.06	0.03	0.05	0.01	5
7-PAH[6]	nd[7]	nd	nd	nd	5

1. Data from references 35-46.
2. To convert g/kg to lb/ton multiply by 2.00.
3.. The wood equivalent emission factors were calculated by multiplying the mean emission

factors by the ratio of the mean firelog burn rate (0.74 dry kg/hr) and the mode of the cordwood burn rates (3.5 dry kg/hr). For example, the usage wood equivalent emission factor for PM = 21.2 g/ dry kg X(0.74/3.5) = 4.5 g/dry kg. The mode was used for estimating the central tendency for the burn rate for cordwood in fireplaces rather than the mean or medium since fewer firelogs are burned in the very large fireplaces with the highest burn rates. The most common fireplace size (nominal 36 inch) is also the smallest.

4. Nitrogen oxide values reported as NO_2.
5. The 16-PAH (Polycyclic Aromatic Hydrocarbon) value is the sum of: naphthalene, acenaphthene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(ghi)perylene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene.
6. The 7-PAH (Polycyclic Aromatic Hydrocarbon) value is the sum of: benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoanthene, benzo(a)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene.
7. All 7-PAH compounds were below the detection limits of the methods reported in studies.

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