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Project Summary

Emissions from Outdoor Wood-Burning Residential Hot Water Furnaces

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Modern outdoor residential wood-burning hot water furnaces are free-standing units situated outside the envelope of the structure to be heated. They typically consist of a firebox and water reservoir, assembled in a horizontal configuration. Hot combustion gases flow from the firebox at one end, through channels or tubes in the water reservoir, to the stack. The gases may pass through the water reservoir once to the stack at the end opposite the firebox (one pass) or an additional set of pipes may bring the gases back to the stack located above but isolated from the combustion chamber (double pass). The heated water is pumped through radiators in the dwelling or through a heat exchanger in the heating, ventilation, and air-conditioning (HVAC) duct in response to the home thermostat. A separate pipe coil in the water reservoir may be used to provide domestic hot water, year-round if desired. The furnace draft is controlled by a thermostat monitoring the temperature of the water in the reservoir. Central heating furnaces of all types are exempt from the EPA wood heater (wood stove) standard. In this project, emissions were measured from a single-pass and a double-pass furnace at average heat outputs of 15,000 and 30,000 Btu/hr (4.4 and 8.8 kW) while burning typical oak cordwood fuel. One furnace was also tested once at each heat output while fitted with a prototype catalytic unit installed in the combustion chamber. Emissions measured included: EPA Method 5G particulate, semivolatile and condensible organics, 20 target polycyclic aromatic hydrocarbon (PAH) compounds, and carbon monoxide (CO). Emission results are presented in terms of rate per hour, quantity per unit weight of wood burned, and quantity per unit of heat delivered. Delivered efficiencies are also presented. Compared to a wide range of residential heating options, these furnaces' emissions were of the same order as other stick wood burning appliances.

This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In the early 1980s, the State of Oregon began developing methods for characterizing source emissions from residential wood combustion units. The developed methods have since blossomed into test methods used to audit and certify wood-burning heaters. From these beginnings, the U.S. Environmental Protection Agency (EPA) has established emission performance standards for residential wood heaters.

The federal regulations established by the EPA in 1988 limit emissions from residential wood heaters, such as wood stoves, pellet stoves, and factory built fireplace inserts. These regulations, however, do not include all wood-fired heating appliances. For example, central heating furnace/boilers are not covered under the current regulations.

In general, emissions from the combustion of wood in stoves and furnaces contain significant levels of CO and fine particulate matter (PM) consisting, in part, of mutagenic PAHs. If atmospheric conditions are conducive for accumulating smog-like clouds of emissions, the wood smoke could pose a health hazard. With the potential for such a condition under consideration, the EPA established maximum acceptable emissions levels for the certification of most residential wood-fired heaters.

Typically, the modern outdoor residential wood-burning hot water furnace is a freestanding unit situated outside the envelope of the structure to be heated. The unit consists of a closed combustion chamber surrounded by a water tank and vented through a stack. A wood burning fire is contained and controlled in the combustion chamber or firebox of the furnace. During the combustion process, heat is transferred through the walls of the chamber into the water. The hot water from the furnace tank can then be circulated through radiators or air-handling heat exchangers to transfer heat into the residence. Some central heating furnaces are equipped with additional plumbing to provide domestic hot water.

Most commercial central heating furnaces are supplied with an 8- to 10-ft (2.4 to 3.0 m) tall stack. Typical indoor wood burning stoves have chimneys which extend through the roof of a home to heights of 20 to 30 ft (6.1 to 9.1 m). The relatively low chimney height of the central heating furnace/boiler, compared to the conventional wood stove installations, creates a greater potential for the localization of objectionable emissions in and around residences. Additionally, concerns have been raised about the manner in which the combustion process is controlled and how the control affects the emissions.

The State of Wisconsin has asked the Control Technology Center of EPA's Air Pollution Prevention and Control Division (APPCD) for assistance in determining whether the need exists to regulate these furnaces. Therefore, the EPA has undertaken the task of evaluating the emissions from the central heating furnaces and the manner in which the combustion is controlled. The objective is to develop baseline emission factors for comparison with other residential heating systems.

In the full report, Section 2 describes the experimental approach and sampling and analytical methods employed. Steps to ensure project quality are described in Section 3. Data, results, and discussion are presented in Section 4. The appendices contain the detailed data.

Project Description

Two types of furnaces were selected as representative of the industry. The type of furnace is defined by the configuration of the unit. The flue gases exit the combustion chamber by way of a flue that passes through the water tank. A single-pass furnace allows the flue gases to pass once through the flue in the water tank before exiting through the chimney. As the hot flue gases pass through the flue, heat is transferred to the water in the tank. In a double-pass furnace, flue gases pass through the water tank twice before exiting through the chimney. The second pass of the stack provides more surface area and more contact time between the hot flue gases and the water in the tank. Representative furnaces of both types were provided to EPA/APPCD for testing.

The outdoor residential wood-burning hot water furnaces were tested following EPA Reference Method 28 (M28–40 CFR Part 60, Appendix A), the test method used to certify and audit wood-fired heaters (stick and pellet burning woodstoves). The method specifies fuel preparation, furnace operation, and the reporting of the results. Method 28 requires Method 5G or 5H (CFR Part 60, Appendix A) to determine the concentrations of oxygen (O_2), carbon dioxide (CO_2), CO, and PM in the emissions.

For these tests, some of the fuel preparation procedures under Method 28 were modified in favor of preparing the fuel and operating the furnace as recommended by the manufacturer. Cordwood was used instead of the dimensioned lumber specified for wood heater certification. Method 28A was used to calculate the stack gas dry molecular weight, as required for flow measurements. Method 5G was the primary sampling method used for the test. The sampling method, Method 5G, was modified by adding an XAD-2 absorbent trap to collect organics; this modified sampling method will hereafter be referred to as Modified Method 5G (MM5G). The collected MM5G samples were analyzed for total PM, total semivolatile organics [sometimes referred to as total chromatographable organics (TCOs)], condensible organics as measured by gravimetric analysis (GRAV), and PAHs. The efficiencies of the units were measured as a secondary objective for reporting emissions relative to the input heating value of the wood and to their heat output from the furnace.

Each furnace was tested at two heat output levels, 15,000 and 30,000 Btu/hr (4.4 and 8.8 kW). Each test was run in duplicate for a total of four runs per furnace. In addition, two high heat output scoping runs were performed on Furnace A. Furnace A was also tested once at each heat output while fitted with a prototype catalytic device in the combustion chamber, giving a total of 12 runs.

Results

Two basic furnace designs (single- and double-pass boiler heat exchangers) were chosen for these tests to see if the design impacted emissions. Table 1 presents the particulate and PAH emission factor data and efficiency aggregated by furnace and operating mode. Furnace B showed much less variability in operation and emissions data compared to Furnace A. Whether this is due to (1) furnace design, (2) the way the fuel was loaded, and/or (3) the differences in the draft on/off cycles cannot be determined without further tests; more than likely, all three variables exerted significant influence.

Table 2 lists the emission results for various residential combustion devices. The results from this investigation (see bottom row in Table 2) were included as an average from all the tests. Based on this very limited test, it appears that the total particulate emission factor is comparable to that for conventional wood stoves. Note that all particulate values have been converted to the EPA Method 5H equivalent. The PAH emission factor appears to be generally the same as that for EPA certified wood stoves. The data presented in Table 2 were originally generated by different researchers using a variety of sampling and analytical methodologies. A number of assumptions had to be made to “normalize” the data for comparison. Consequently, only order of magnitude differences should be considered significant. Readers are encouraged to review the reference cited in the footnote for a more thorough understanding of the data.

Conclusions

There were several data quality problems with tests of Furnace A, all of which, though significant, are thought to be small enough to not bias the results for Furnace A sufficiently to cause an order of magnitude error. Tests of Furnace B had no reported data quality problems. All tests of Furnace B particulate matter emissions were in the range of 36.5 to 37.6 g/hr (high heat removal rate - tests B-1 and B-2) and 14.3 to 15.5 g/hr (low heat removal rate - tests B-3 and B-4). Particulate matter emissions from Furnace A appear consistently higher; but, within the limits of these tests, experimental error, and considering the testing problems previously discussed that may have compromised the data quality for Furnace A, a direct comparison of Furnace A and Furnace B emissions is without adequate foundation and, therefore, is not meaningful. However, from Table 2, it is evident that all wood-burning home heating combustion equipment, including wood stoves, boilers, or fireplaces, has much higher particulate matter emissions than gas- or oil-fired home heating furnaces.

Table 1. Comparison Data Aggregated by Operating Mode and Furnace [Range in ()]

Operating Mode	Furnace A	Furnace B	Parameter
High Heat	19.6 (14.8-24.5)	12.0 (10.8-13.3)	M5G Particulates, g/kg
	0.347 (0.216-0.478)	0.319 (0.315-0.324)	PAH, g/kg
	45.6 (38.8-53.4)	53.8 (50.5-57.1)	Delivered Efficiency, %
Low Heat	16.6 (15.9-17.3)	9.35 (9.2-9.5)	M5G Particulates, g/kg
	0.236 (0.228-0.245)	0.283 (0.235-0.332)	PAH, g/kg
	44.4 (42.4-46.4)	55.2 (55.1-55.4)	Delivered Efficiency, %

Table 2. Overall Comparison of Residential Wood, Oil, and Gas Combustion Emissions[a]

Combustion Device	M5H Particulate mg/MJ input	PAHs mg/MJ input	Mutagenicity[b] krev/MJ input
Natural gas furnace			
Conventional	0.44	0.000124	0.007[c]
High Efficiency	0.43	0.000028	ND[c,d]
Oil furnace			
Retention head	3.2	—[e]	6
Conventional	15.1	—	20
Conventional wood stove	786	40	600
Certified wood stove			
Non-catalytic	383	28	100
Catalytic	425	24	—
Pellet (certified)	110	0.082	—
Pellet (exempt)	176	0.014	—
Fireplace	907	41	—
Wood furnace			
Cordwood - Swedish lab tests			
Intermittent firing	1862	—	—
Continuous firing	182	15.3	148[f]
Chips (dry)	45.3	<0.02	0.48[f]
US EPA lab tests			
Furnace A[g]	*1048*	*15.6*	—
Furnace B	*681*	*16.1*	—

[a] All data except that in italics taken from: McCrillis, R.C., “Review and Analysis of Emissions Data for Residential Wood-Fired Central Furnaces,” In Proceedings of the 88th Annual Meeting of the AWMA, Air & Waste Management Association, San Antonio, TX, June 1995, Paper No. 95-RP137.04.
[b] Microsuspension assay, TA98+S9 unless otherwise noted.
[c] Ames plate incorporation assay, TA98+S9.
[d] ND means not detected.
[e] No data available for this parameter.
[f] Ames plate incorporation assay, TA100+S9.
[g] Only includes comparison data.

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The complete report, entitled "Emissions from Outdoor Wood-Burning Residential Hot Water Furnaces," (Order No. PB98-127087; Cost: $41.00, subject to change) will be available only from:
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