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Project Summary

Effects of Appliance Type and Operating Variables on Woodstove Emissions

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This project was conducted in support of the Integrated Air Cancer Project (IACP) to provide data on the specific effects of appliance type and operating variables on woodstove emissions. Samples of particulate material and volatile organic compounds (VOCs) were collected. Particulate samples were analyzed for different organic fractions, including specific polynuclear aromatic hydrocarbon (PAH) compounds. Inorganic matter on the filters was also analyzed. Results were calculated for pollutant concentrations, emission rates, and emission factors. Twelve test runs were conducted on a conventional stove, and two runs were conducted on a catalyst-equipped stove. Operating variables included fuel type (oak and pine), altitude (80 and 800 m), and burn rate (high and low).

Test data were analyzed using analysis of variance and linear regression procedures. Although the data do not show strong statistical significance due to variability of results, some general trends do appear to be present and conclusions can be drawn as to the effects of various operating variables on woodstove emission. At the 99% confidence bound (CB), oak fuel reduced emissions of total PAH compounds relative to pine fuel. Emisssions of carbon monoxide (CO) showed a significant decrease from low to high burn rates, and a small decrease when oak, rather than pine, fuel was used. The catalytic stove (with a used combustor) reduced emissions of CO, but did not show significant reductions of total particulate material at the 99% CB. No altitude effects were noted at the 99% CB.

At the 95% CB, oak fuel reduced the concentration, emission rate, and emission factor for many individual PAH compounds, and reduced the emission factor for total PAH compounds. Marginal decreases in benzene were also attributed to the use of oak, rather than pine, fuel.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in two separate volumes of the same title (see Project Report ordering information at back).

Introduction

During the winter of 1986-87, the U.S. Environmental Protection Agency (EPA) conducted an emission measurement program in Boise, Idaho, as part of the Integrated Air Cancer Project (IACP). The program was designed to identify the potential mutagenic impact of residential wood burning on ambient and indoor air. One aspect of the field sampling effort involved obtaining emission samples from chimneys serving wood burning appliances in Boise. This project was

undertaken as a parallel project in an instrumented woodstove test laboratory to quantify woodstove emissions typical of Boise conditions.

The purpose of this laboratory project was to quantify the effect of several variables on emissions from woodstoves so that operational conditions of stoves in the field could be inferred by existing data bases. The variables included fuel species, burn rate, and altitude (barometric pressure). A conventional woodstove, typical of many existing stove models in the Boise area, was used as the test appliance. Limited testing was also conducted on a catalytic woodstove. A modified half-factorial test matrix was used to obtain test results most useful to the IACP.

A woodstove dilution sampler (Woodstove Sampling System, or WS[2]) was used to collect particulate samples, while a modified ambient sampler was used to collect aldehyde and volatile organic compound (VOC) samples. Particulate samples were analyzed for total mass, polynuclear aromatic hydrocarbons (PAHs), semicondensible organics (grav), total chromatographical organic (TCO) compounds, and inorganic compounds. Concentrations of carbon monoxide (CO), carbon dioxide (CO_2),and oxygen (O_2) in flue gases were recorded. Samples of wood fuel and residual ash were analyzed for elemental composition.

Summary of Test Results

Total particulate capture values were substantial, ranging from about 2-16g of material. Although the grav-plus-TCO values were expected to be similar to the total capture values because of the high organic content of woodsmoke, these values were typically 45-70% of total capture values. It is not clear why the unextractable fractions from the filter catches were so high.

Table 1 lists particulate emissions as total capture, grav, and TCO fractions. Total capture emission rates for the conventional stove ranged from 10.9 g/hr (pine fuel, low elevation, low burn) to 50.7 g/hr (pine fuel, high elevation, low burn). While some replicate runs showed close agreement (Runs 1 and 3, and 7 and 8), other runs showed considerable differences: Runs 2 and 4, 6 and 14, and 9 and 10 varied by factors of 3 to 4 (Figure 1). Agreement and discrepancies between the replicate runs were similar when reported as grams per kilogram.

Most of the measured PAH compounds were lower-molecular weight compounds, with low emission rates of high molecular weight compounds. Naphthalene accounted for almost half of the emissions of measured PAH compounds in many samples (Runs 4, 6, 14, 16, 10, 7, 8, 12, 13). ,A very large fraction of total PAH compounds were recovered from the filter and XAD-2 resin extract fractions, with a relatively small contribution from the probe rinse fraction.

Total VOC emissions (C_1-C_7 hydrocarbons) ranged from 9 g/hr (Runs 4 and 6) to 40 g/hr (run9). Replicate VOC samples for Runs 5 and 16 and Runs 7 and 8 were in relatively close agreement. Other replicate tests showed considerable variation. Methane was the largest single fraction of most samples, although Run 1 had no reported methane.

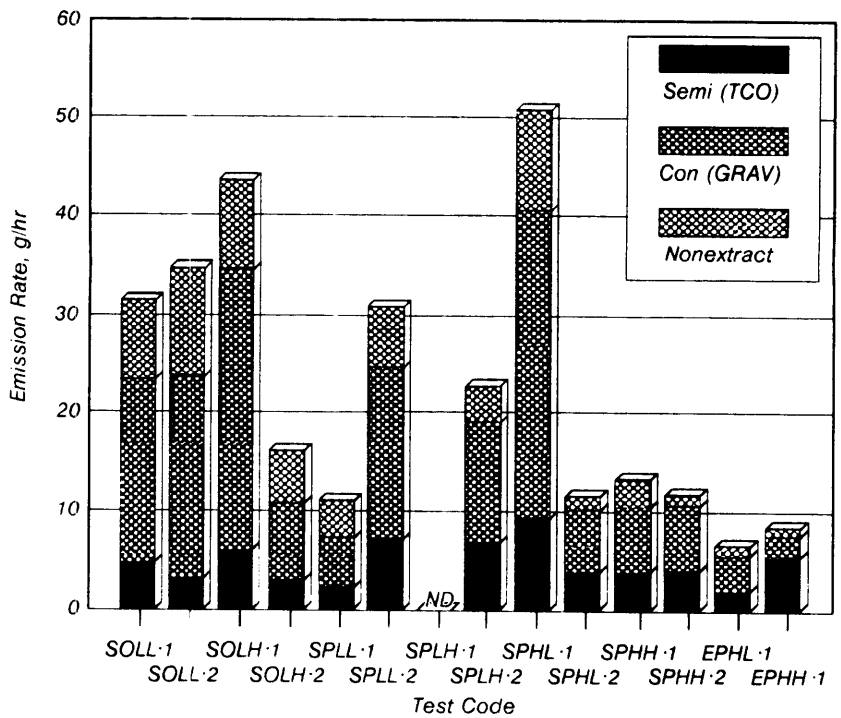

Figure 1. Emission rates for particulate capture fractions.

Table 1. *Particulate Matter Emissions*

Run No.	Sample Code[a]	Flue Gas Flow (dscmh)[b]	Sample Volume (l)[c]	Particulate Concentration (g/m³)[d]			Particulate Emission Rate (g/hr)[e]			Particulate Emission Factor (g/kg)[f]		
				Total[g]	Grav.[h]	TCO[i]	Total[g]	Grav.[h]	TCO[i]	Total[g]	Grav.[h]	TCO[i]
1	SOLL-1	15.368	3,315.6	2.052	1.218	0.306	31.5	18.7	4.7	23.3	13.9	3.5
3	SOLL-2	14.042	3,330.8	2.471	1.687	0.220	34.7	23.7	3.1	27.1	18.5	2.4
2j	SOLH-1	18.872	1,590.0	2.309	1.522	0.312	43.6	28.7	5.9	16.8	11.1	2.3
4	SOLH-2	17.248	3,385.6	0.919	0.445	0.166	15.6	7.7	2.9	7.5	3.7	1.4
6	SPLL-1	11.589	3,080.9	0.941	0.430	0.190	10.9	5.0	2.2	6.6	3.0	1.3
14	SPLL-2	10.642	3,344.0	2.886	1.634	0.668	30.7	17.4	7.1	18.4	10.4	4.3
5	SPLH-1	14.535	2,979.3	k	k	0.339	k	k	4.9	k	k	2.1
16	SPLH-2	20.252	2,965.9	1.113	0.599	0.334	22.5	12.1	6.8	7.7	4.1	2.3
9	SPHL-1	11.077	3,579.0	4.574	2.844	0.817	50.7	31.5	9.0	43.0	26.7	7.6
10	SPHL-2	12.018	2,870.0	0.928	0.510	0.303	11.2	6.1	3.6	6.9	3.7	2.2
7	SPHH-1	18.986	2,800.6	0.678	0.341	0.188	12.9	6.5	3.6	4.1	2.0	1.1
8	SPHH-2	18.652	2,821.5	0.608	0.351	0.198	11.3	6.5	3.7	3.6	2.1	1.2
12	EPHL-1	10.305	3,661.4	0.601	0.344	0.140	6.2	3.5	1.4	4.7	2.6	1.1
13	EPHH-1	13.384	3,518.8	0.601	0.166	0.367	8.0	2.2	4.9	4.1	1.1	2.5

a- Sample codes describe the variables used in testing:

1. First position	*- Stove type:*	*S = Scott Stove, the conventional-technology stove*
		E = Earth Stove, the catalytic stove
2. Second position	*- Fuel type:*	*O = oak*
		P = pine
3. Third position	*- Altitude:*	*L = low altitude or high barometric pressure*
		H = high altitude or low barometric pressure
4. Fourth position	*- Burn rate:*	*L = low*
		H = high

b-Dry standard cubic meters per hour. Flue gas flow rate was calculated using Equation 5H-8, EPA Reference Method 5H.
c- Liters. Product of average sample flowrate and net sampling time.
d-Grams of particulate material per standard cubic meter.
e-Grams of particulate material per hour.
f-Grams of particulate material per dry kilogram fuel burned.
g-Consists of total net weight of filters plus gravimetric and TCO values from probe rinse and XAD-2 resin.
h-Gravimetric particulate catch. Sum of values from filters, probe and XAD-2 residual when processed by "grav" procedures.
i-Total chromatographable organics. Sum of values from filters, probe rinse and XAD-2 residual when processed for TCO.
j-Test was interrupted at 246 minutes by a lengthy power outage. Test ended with 1.9 kg fuel remaining (12% of total mass burned).
k-Gravimetric probe rinse portion of Run 5 lost during laboratory handling.

Ethylene emission rates were second highest for most samples.

Analysis of variance (ANOVA) tests were run to determine main effects of test variables on the parameters of particulate material, PAHs, VOCs, CO, and inorganic material. ANOVA tests were conducted on all units of measure: concentration (mass/volume), emission rate (mass/ time), and emission factor (mass/ mass fuel). Main effects were calculated at a 95% confidence bound (CB).

Most of the main effects observed were attributable to fuel. The second most frequent interaction was fuel/burn rate, followed by burn rate. Other interactions were negligible. Surprisingly, no main effects were seen due to the stove interation at the 95% CB. No main effects were seen with any particulate material parameters. This is thought to be due to the variability of stove performance, which may have masked actual main effects.

The total PAH emission rate showed a -702 mg/hr main effect at the 95% CB. Many individual PAH compounds showed emission rate main effects with oak fuel, ranging from -3 mg/hr (benzo-[k]fluoranthene) to -138 mg/hr (phenanthrene). Main effect reductions in individual PAH compound emission factors spanned a similar range. Reductions in benzene and o-xylene concentrations were attributable to oak fuel, showing reductions of 98 and 21 $\mu g/m^3$, respectively.

As mentioned previously, no main effects were found for any particulate material parameter. Particulate emissions decreased by 16.8 g/hr when the catalytic stove was used, though this was not significant at the 95% confidence bound due to the variability of emissions from the conventional stove.

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The complete report, entitled "Effects of Appliance Type and Operating Variables on Woodstove Emissions," Volume I. Report and Appendices A-C: (Order No. PB90 151457/AS; Cost: $23.00, subject to change). Volume II. Appendices D-F: (Order No. PB90 151465/AS; Cost: $31.00, subject to change) will be available only from:
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