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SOURCE TESTING FOR FIREPLACES, STOVES, AND RESTAURANT GRILLS IN VAIL, COLORADO

DRAFT

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CHESTER TOWERS

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1. INTRODUCTION

PEDCo-Environmental is currently providing technical assistance to four mountain communities in Colorado in preparing required air quality maintenance plans. These four communities are Vail, Aspen, Telluride, and Steamboat Springs. Preliminary work has shown that fireplaces, stoves, and restaurant grills are major air pollution sources in these communities.

Because of the high altitudes in these four areas, presently available emission factors for the above sources may not be applicable. Therefore, the current emission testing study was undertaken to provide emission factors for use in high altitude areas.

The emission tests were conducted from September 21 to 30, 1977 on two fireplaces, a stove, and a restaurant grill exhaust in Vail, Colorado. Tests were conducted under various operating conditions to establish the probable range of emission rates. Four potential particulate control methods for fireplaces were also tested. Measurements were made of total and condensable particulate, carbon dioxide, carbon monoxide, and gaseous hydrocarbons as well as the velocity and temperature of the flue gas.

Available emission estimates for these sources have been compiled for comparison with the values obtained from sampling at Vail.

2. SUMMARY

Source tests were performed on a condominium fireplace, residential fireplace, stove, and restaurant grill exhaust. A summary of particulate emissions and burning conditions is presented in Table 2-1. In all cases, samples were taken using an EPA Method 5 sampling train with a back-up filter located between the second and third impinger. A gas sample was taken from the sampling train between the third and fourth impingers. Results of the gaseous samples are presented in Table 2-2.

All test results are discussed in terms of grams of pollutant per kilogram of fuel burned, due to the variation in the amount of fuel burned. Using this basis, the results from each test run can be compared. The particulate emission rates were calculated using both the front-half and back-half catch. The condensable portion or back-half averaged 75 percent of the total particulate loadings. The gaseous portions of total hydrocarbons, shown in Table 2-2, do not include any estimate of hydrocarbons caught in the condensable portion of the particulate.

A total of fifteen tests were conducted on the condominium fireplace. These tests were conducted while burning dry pine, green pine, dry aspen, green aspen, and coal. Also, tests were run burning dry pine while using various control measures. No significant differences in emission rates of any of the pollutants were found between the two fireplaces, between dry and green wood, or between pine and aspen. All four of the controls--a glass screen, auxiliary air from the outside, underfire air, and an in-stack

Table 2-1. EMISSION RESULTS FOR ALL TESTS

Test location	Sampling location	Fuel type	Burning condition	Burning rate, kg/hr	Stack temp, °C	Flow rate, m ³ /min ^b	Pollutant mass rate, gm/hr	Emission factor, gm/kg	Control measure
1	condo-	dry pine	start-up	4.8	68	9.4	101.0	21.0	none
2	minium	dry pine	stable	8.2	119	12.1	136.2	16.6	none
3	"	dry pine	burn down	3.9	66	9.6	38.1	9.8	none
4	"	dry pine	stable	11.5	160	9.3	176.2	15.3	glass screen
5	"	dry pine	stable	10.1	124	10.9	168.2	16.7	outside air
6	"	coal	stable	3.6	123	12.2	51.8	14.4	none
7	"	dry pine	stable	11.4	157	13.6	107.8	9.5	underfire air
8	"	green aspen	stable	7.1	112	13.1	135.3	19.1	none
9	"	dry aspen	start-up	4.8	119	12.0	165.7	34.5	none
10	"	dry aspen	stable	8.1	98	12.2	128.2	15.8	none
11	"	dry aspen	burn down	2.6	87	10.3	70.8	27.2	none
12	"	green pine	start-up	3.6	72	12.0	79.9	22.2	none
13	"	green pine	stable	7.1	108	10.6	142.3	20.0	none
14	"	green pine	burn down	4.8	74	10.0	93.1	19.4	none
15	"	dry pine	stable	15.2	188	13.5	132.3	8.7	ESP
16	resi-	dry pine	stable	3.2	101	7.4	66.7	20.8	none
17	dential	dry pine	stable	3.2	126	7.5	74.0	23.1	none
18	"	green pine	stable	4.6	103	6.8	121.2	26.3	none
19	stove	dry pine	stable	6.2	212	2.2	175.7	28.3	none
20	"	coal	stable	3.6	144 ^a	2.0	57.6 ^a	16.0	none
21 ^a	grill	food	normal	a	41	168.4 ^a	244.7 ^a	a	none

^a Test 21 was conducted on a restaurant grill while preparing a variety of meats.

^b Flow rates are given in dry standard cubic meters per minute, 68°F and 29.9 in. Hg.

Table 2-2. FLUE GAS CONDITIONS

Test	HC, ^a ppmb	CO, ppmb	CO ₂ , ppmb
1	175	315	6856
2	222	269	10634
3	228	593	2780
4	2575	1308	12571
5	1337	1117	8419
6	1018	453	7874
7	731	638	15784
8	4023	1111	6004
9	730	444	7355
10	1042	659	7383
11	2525	606	3587
12	4689	536	7833
13	920	1033	4840
14	2636	791	2636
15	189	881	8624
16	4162	647	8085
17	1507	670	10883
18	451	1001	7523
19	3130	8194	115077
20	2533	1618	59386
21	20	788	2000

^a HC reported as methane.

^b Parts per million (ppm) by volume.

electrostatic precipitator--reduced particulate emission rates. However, the first two controls produced only marginal reductions while underfire air or the ESP reduced emissions by more than 50 percent.

Wood or coal burning in the stove caused higher particulate emissions than in the fireplace but lower hydrocarbon emissions. The fuel combustion emissions at high altitude were consistently higher than published emission factors from testing at low altitude. However, the restaurant grill emissions were approximately the same as other available emission estimates.

The recommended emission factors for fireplaces are 21.2 gm/kg for particulate and 100 gm/kg for carbon monoxide. Test data for gaseous hydrocarbons were highly erratic.

3. SAMPLING METHODOLOGY

FIREPLACE OPERATION

Tests were conducted under start-up, stable, and burn-down conditions. Start-up conditions were taken as initial starting of the fire until a stable fire had been achieved. The stoker would start the fire and stoke it as necessary to maintain a fire. Under the start-up condition, the stack temperature and velocity were increasing. Stable conditions were taken to be when a continual flame was present and a relatively constant stack temperature was maintained. The stack temperature would fluctuate cyclically during testing and was an indication that a stable burn was being maintained. Wood was added and the fire stoked when necessary to maintain the stable burn condition. The burn-down condition was taken to be when there were only periodic surface flames apparent in the fireplace.

Wood burning rates were determined from data collected during each sampling run. Prior to sampling, the wood was weighed and labeled. The fire was started with a known amount of wood and more was added to maintain the desired burning condition. Weight of the wood and the time the wood was added were recorded by the stoker. At the end of each test run, the stoker would estimate the amount of wood burned during the test run. It should be pointed out that the amount of wood burned during a test run could only be estimated because the amount remaining at the end of the test could not be weighed. Each day of sampling was begun with a clean fireplace.

Samples of each type of wood were taken to the laboratory for analysis of moisture content, percent ash, and heating value. These values are summarized in Table 3-1. As indicated by data in Table 3-1, the green pine burned in these tests was not freshly cut; there is a local ordinance in Vail preventing cutting of a live tree.

SAMPLING APPARATUS

Sampling procedures followed those described in Method 5 of the Federal Register.¹

The particulate sampling train used in these tests met design specifications established by EPA and was assembled by PEDCo personnel. It consisted of:

Nozzle - Stainless steel (316) with a sharp, tapered, leading edge and accurately measured round opening.

Probe - Pyrex glass with a heating system capable of maintaining a minimum gas temperature of 250°F at the exit end of the probe.

Pitot tube - Calibrated type S attached to the probe to monitor stack gas velocity.

Front filter holder - Pyrex glass located in a heating system capable of maintaining a filter temperature of approximately 300°F.

Back filter holder - Pyrex glass located between the second and third impingers, at ambient temperature.

Draft gauge - An inclined manometer made by Dwyer with a readability of 0.001 in. of H₂O in the 0-0.25 in. range was used.

Impingers - Four impingers connected in series with glass ball joints. The first, third, and fourth impingers were of the Greenburg-Smith design, modified by replacing the tip with a 1/2 in. I.D. glass tube extending 1/2 in. from the bottom of the flask.

Metering system - Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within ±5°F, dry gas meter with ±2 percent accuracy, and

Table 3-1. WOOD AND COAL ANALYSIS, AS RECEIVED

Sample	Moisture, %	Ash, %	Sulfur, %	Btu/lb
Coal	5.7	14.15	.94	10,681
Dry pine	7.49	0.16	a	8,065
Green pine	7.70	0.22	a	7,945
Dry aspen	7.16	0.72	a	7,689
Green aspen	20.18	0.59	a	6,729

^a Analyses for sulfur in wood samples were not performed.

related equipment to maintain an isokinetic sampling rate and to determine sample volume. The dry gas meter is made by Rockwell and the fiber vane pump is made by Gast.

Gaseous sampling equipment - Leak-free vacuum pump connected to a Tedlar bag (5 cu ft capacity) to take a sample from the sampling train between the third and fourth impinger.

SAMPLING PROCEDURE

Two sampling trains were employed simultaneously in 12 of the 15 tests at the condominium fireplace to provide duplicate samples.

After selecting the sampling site and the number of traverse points, the stack pressure, temperature, moisture, and range of velocity head were measured according to procedures described in the Federal Register.

Approximately 100 gm of silica gel were weighed in a sealed impinger prior to each test. Only 100 gm of silica gel was used due to the low moisture content expected. Glass fiber filters (Gelman Type A 3" diameter) were desiccated for at least 24 hours and weighed to the nearest 0.1 mg on an analytical balance. One hundred ml of distilled water were placed in the first two impingers; the third impinger was initially dry; the back-up filter was placed between the second and third impingers; and the fourth impinger containing the silica gel was placed next in series. The train was set up with the probe as shown in Figure 3-1. The sampling train was leak checked at the sampling site prior to sampling by plugging the inlet to the nozzle and pulling a 15 in. Hg vacuum. At the conclusion of the sampling, the sampling train was leak checked at the highest vacuum reached during the test. Leakage rates of less than 0.02 cfm were recorded in all cases. Crushed ice was placed around the impingers to keep the temperature of the gases leaving the last impinger at 68°F or less.

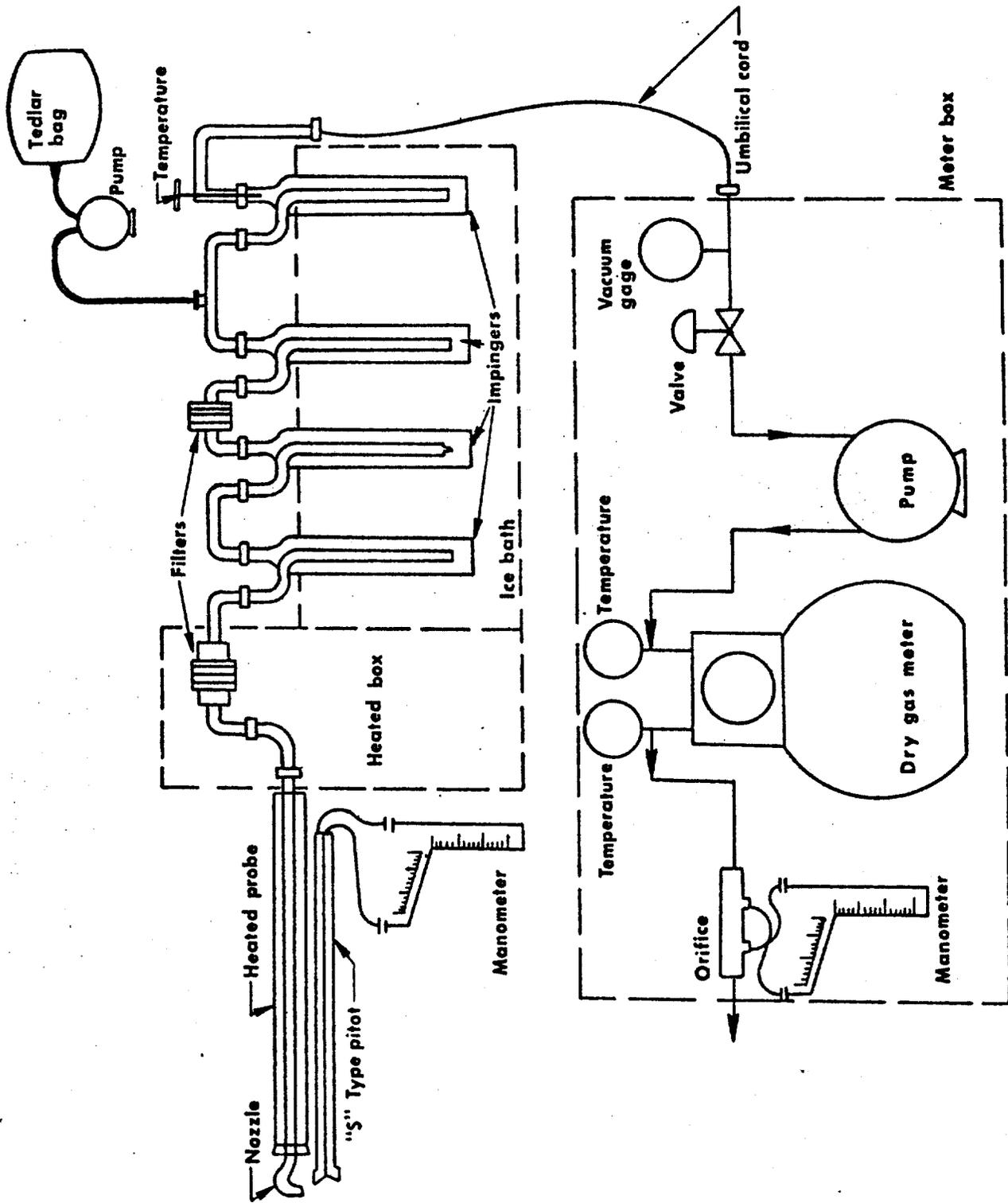


Figure 3-1. Sampling train used in tests.

During sampling, the stack gas and sampling train data were recorded at each sampling point and when significant changes in stack flow conditions occurred. Isokinetic sampling rates were set throughout the sampling period with the aid of a nomograph. All test results reported were collected within ± 10 percent of isokinetic conditions.

SAMPLE RECOVERY PROCEDURE

The sampling train was moved carefully from the test site to the cleanup area. Samples of the acetone and distilled water used in sample recovery were taken for use as blanks. The sample fractions were recovered as follows:

Container No. 1 - The front filter was removed from its holder and placed in a petri dish.

Container No. 2 Loose particulate and acetone washings from all sample-exposed surfaces prior to the filter were placed in a glass jar and sealed. Particulate was removed from the probe with the aid of a brush and acetone rinsing.

Container No. 3 - The back-up filter was removed from the holder and placed in a petri dish and sealed.

Container No. 4 - The water from the first three impingers was measured for volume and placed in a glass jar. The back half of the front filter holder, all the connecting glassware, and the first three impingers were rinsed with distilled water and the washings were placed in the same glass jar.

Container No. 5 - The back half of the front filter holder, all the connecting glassware, and the first three impingers were rinsed with acetone and the washings placed in a glass jar and sealed.

Container No. 6 - The Tedlar bag was capped off and transported to the lab to be analyzed. The silica gel from the fourth impinger was weighed and discarded.

ANALYTICAL PROCEDURES

The following procedures were used to analyze the sample fractions:

Container No. 1 and 3 - The front and back-up filters and any loose particulate matter from these containers were placed into a tared glass weighing dish, desiccated to a constant weight, and weighed to the nearest 0.1 mg.

Container No. 2 and 5 - The acetone rinses were placed in tared glass beakers, evaporated to dryness at ambient temperature, desiccated to a constant weight, and weighed to the nearest 0.1 mg.

Container No. 4 - An ether-chloroform extract was made on the impinger water and water washings. The ether-chloroform extract was placed in a tared beaker, evaporated at ambient temperature, desiccated to a constant weight, and weighed to the nearest 0.1 mg. The remaining water was evaporated, desiccated to a constant weight, and weighed to the nearest 0.1 mg.

Container No. 6 - The gas sample was analyzed for total hydrocarbons (as methane) using a flame ionization detector and the carbon monoxide and carbon dioxide concentrations were determined using an NDIR analyzer.

Blanks were taken on the acetone, ether, chloroform, and distilled water samples and subtracted from the respective sample results.

4. RESULTS

EMISSIONS FOR VARIOUS OPERATING CONDITIONS

The calculated emission rates for each of the tests are presented in Table 4-1. For six of the tests in which valid duplicate samples were obtained, both values are shown in the table. These double values were averaged in Table 2-1. For the other six tests where duplicate samples were taken, some problem was encountered with one of the samples causing it to be voided.

Particulate Matter

The particulate emission rates for duplicate samples differed by an average of 24.1 percent, so any variations in emission rates under different fireplace operating conditions would have to be of at least that magnitude in order to be significant.

The average uncontrolled particulate emission rates for the two fireplaces that were tested--condominium and residential--were 20.6 and 23.4 gm/kg. This is only a 12.7 percent difference and indicates that emission rates from different fireplaces are approximately the same.

Average emissions from burning aspen and pine were 24.2 and 19.9 gm/kg, respectively, a difference of 19.5 percent. Again, this difference does not appear to be significant. Most of the wood burned in the Vail area is pine.

As indicated in the preceding chapter, the "green" pine used in the tests was not much different in composition (moisture content, Btu value) than the seasoned or dry pine. Therefore, a significant difference in emission rates

Table 4-1. EMISSION RATES FOR SOURCE TESTS

Test	Emission rates, gm/kg					
	Particulate		HC		CO	
1	23.2	18.8	14.6	12.7	44.6	41.7
2	16.6		13.1		27.8	
3	9.8		22.4		102.2	
4	15.3		83.3		74.0	
5	15.3	18.1	17.6	97.8	80.6	88.1
6 - coal	14.4		138.0		107.5	
7	9.1	9.9	10.4	59.4	49.5	57.1
8	19.1		296.9		143.5	
9	34.5		73.0		77.7	
10	14.7	16.9	56.8	68.8	74.8	64.2
11	35.9	18.6	296.3	503.9	160.8	175.2
12	22.2		625.2		125.1	
13	20.0		54.9		108.0	
14	19.4		219.7		115.4	
15	7.8	9.6	5.7	7.7	47.0	62.6
16	20.8		385.0		104.7	
17	23.1		141.3		109.9	
18	26.3		26.7		103.6	
19	28.3		44.4		203.5	
20 - coal	16.0		56.3		62.9	

would not be expected. This was confirmed by average emission rates of 21.4 gm/kg for green wood and 21.1 gm/kg for seasoned wood.

Samples taken during the three stages of the fire-- start-up, stable, and burn down--showed more variation than any of the comparisons above. The average emission rates for the three stages were 25.9, 20.2, and 18.8 gm/kg. The difference between the highest and lowest rates is 32.8 percent. However, this variation is still not of a magnitude that would warrant a correction to the emission factor, especially considering that the emission rate during stable burning conditions is near the time-weighted average of the three stages.

The recommended value for a particulate emission factor for wood burning in fireplaces is 21.2 gm/kg. This is the mean of the 13 tests run without control techniques on fireplaces in Vail.

The single test for wood burning in a stove produced a higher particulate emission rate than the average rate for fireplaces. The value was 28.3 gm/kg. This higher apparent emission rate may have been influenced somewhat by the sampling location; the probes had to be inserted in the pipe directly above the stove rather than at the flue outlet on the roof.

Coal burned in the stove had an emission rate of 16.0 gm/kg. The same coal burned in a fireplace had an emission rate of 14.4 gm/kg, so the stove again produced the higher emission rate. Only one test was run for each of the coal burning periods.

The weight of particulate matter collected on the two filters in the sampling train was, on the average, divided about 25 percent on the first filter and 75 percent on the second one (in the impinger section). In other words, 75 percent of the particulate was initially emitted as a gas

and then condensed when cooled to form particulate matter. A previous comprehensive study of fireplace emissions at low altitude reported an average of 66.3 percent of particulate emissions was from the back half of the sampling train.²

Hydrocarbons

The hydrocarbons (HC) measured by the procedure described in Chapter 3 are gaseous HC leaving the sampling train. This would not include all HC originally emitted because some would be condensed, caught on the second filter, and measured as condensable particulate.

The duplicate HC samples for six of the tests showed highly erratic readings. The average variation between the data pairs for the same test was 65.6 percent. There were also very large variations in emission rates for the different tests, as shown in Table 4-1. None of the test operating conditions appeared to be responsible for these variations:

<u>Test conditions</u>	<u>Av HC emission rates, gm/kg</u>	<u>% difference</u>
Different fireplaces	178.2, 184.3	3.4
Aspen vs pine	208.2, 166.9	22.0
Green vs seasoned	244.7, 138.9	55.2
Fire stages (start-up, stable, burn down)	237.3, 140.1, 214.1	49.3

The mean HC emission rate for all the fireplace tests without controls was 180 gm/kg; the median rate was 73 gm/kg.

The HC emission rate for wood burning in a stove was 44.4 gm/kg. Coal burned in a stove produced 56.3 gm/kg of hydrocarbons. In a fireplace, coal emitted 138.0 gm/kg.

Carbon Monoxide

There was much less variation in CO emission rates than in HC rates. The average difference between duplicate samples was only 13.6 percent and the range of rates for the 13 tests was 28 to 168 gm/kg. The mean value and recommended emission factor is 100 gm/kg.

The CO emission rate does not appear to vary excessively with any of the operating conditions:

<u>Test conditions</u>	<u>Av CO emission rates, gm/kg</u>	<u>% difference</u>
Different fireplaces	98.0, 106.1	7.9
Aspen vs pine	114.7, 93.3	20.6
Green vs seasoned	119.1, 87.9	30.1
Fire stages (start-up, stable, burn down)	82.0, 95.3, 128.5	45.6

CO concentrations (ppm) in the stove exhaust gases were an order of magnitude higher than in the fireplace exhaust, as shown in Table 2-2. CO₂ concentrations were also much higher for the stove. Although the lower flow rate partially explains the higher concentrations, the emission rate of 203.5 gm/kg is still much higher than that for any of the fireplace tests. The high apparent emission rate may be related to the sampling location in the stove pipe.

Coal burning in the stove produces lower emission rates than wood--62.9 gm/kg. However, coal burned in the fireplace emits slightly more CO than wood burning--107.5 gm/kg.

EFFICIENCIES OF CONTROL TECHNIQUES

Four techniques were evaluated primarily as particulate control measures for fireplace emissions: a glass screen, auxiliary air from outside, underfire air, and an in-stack

electrostatic precipitator. However, the limited data available indicate that all four controls reduced HC emission rates substantially (greater than 50 percent) and CO emission rates marginally (less than 50 percent).

Dry pine was burned under stable conditions in all the control measure tests, and all were conducted at the condominium fireplace. As indicated above, the average particulate emission rate for fireplace burning with no controls in Vail is 21.2 gm/kg.

Particulate emission rates for each of the tests employing controls are as follows:

Glass screen	- 15.3 gm/kg
Auxiliary air from outside	- 16.7
Underfire air	- 9.5
Electrostatic precipitator	- 8.7

All four values showed some reduction from the uncontrolled emission rate. Emissions with the glass screen and outside air were only marginally lower--27.8 and 21.2 percent, respectively--and may not be significant in view of the 24 percent average difference in duplicate particulate samples for the fireplace tests. However, underfire air and the electrostatic precipitator showed substantial reductions in particulate emission rates of 55 and 59 percent, respectively.

The underfire air was provided by a commercially-available blower connected by a manifold to the tubular grates used to increase heat transfer from fireplaces. The cost of the blower/grate combination is about \$90. Small holes were drilled in the sides of the tubes and the other end of the tubes were capped.

The electrostatic precipitator was also a commercially-available unit (Smog-Hog, Model 10XB, United Air Specialists, 10000 cfm). Its selling price is about \$850. A

diagram of the precipitator is shown in Figure 4-1. During the test, the unit was mounted in a stack extension. Permanent installation of such a unit in an existing fireplace would present a more difficult problem.

RESTAURANT GRILL EMISSIONS

One test was run on the exhaust from the hood over a gas-fired grill, griddle, and oven area in a restaurant kitchen. The flow rate through the exhaust duct was about 7000 acfm, higher than average for grills. Emission rates for the test were:

<u>Pollutant</u>	<u>Emission rate, lb/hr</u>
Particulate	0.539
HC	0.30
CO	20.4

During the 60 minute sampling period, approximately 2.6 kg of meat were cooked on the grill; the griddle was not in use. The emission rate determined for the sampling period would only occur during peak cooking times, estimated to be about 6 hours per day.

COMPARISON OF MEASURED EMISSION RATES WITH OTHER EMISSION FACTORS

The emission rates for the testing at Vail were checked by comparing them with other available emission data. It was anticipated that the values obtained at Vail would be higher than previously reported emission rates because of incomplete combustion that occurs at high altitudes.

Emission rates from the sampling at Vail and other published emission factors are summarized in Tables 4-2, 4-3, and 4-4 for wood burning, coal burning, and restaurant

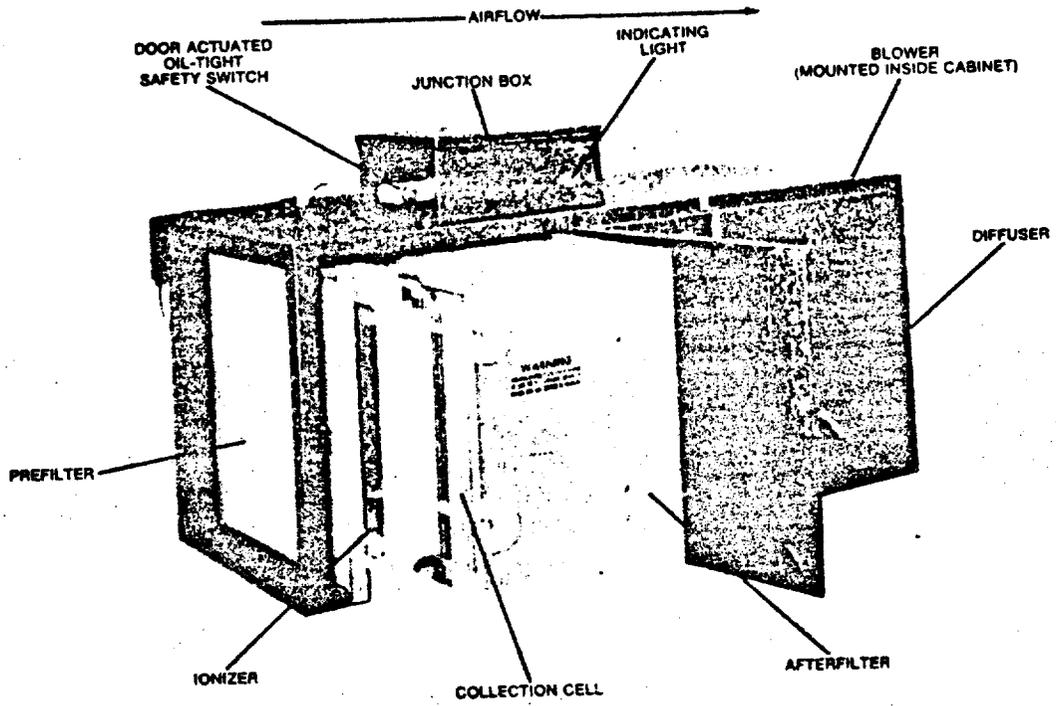


Figure 4-1. Electrostatic precipitator used in fireplace.

Table 4-2. COMPARISON OF PUBLISHED EMISSION FACTORS FOR
WOOD FIRED COMBUSTION

Pollutant	PEDCo study		Other studies		Reference
	Emissions, gm/kg Fireplace	Stove	Emissions, gm/kg Fireplace	Stove	
Particulate	21.2	28.3	10.0		6
HC	180.0	44.4	8.5		7
	(mean)		11.7 ^a		2
	(median)		9.0		8
CO	1793 ppm	3130 ppm	4.8 ppm		2
	100.0	203.5	57.0		8
	667 ppm	8194 ppm	55.0		7
NO _x			375 ppm		2
	-	-	6.1		8

^a Average of all types of wood burned and all burning conditions.

Table 4-3. COMPARISON OF EMISSION FACTORS FOR COAL FIRED COMBUSTION

Pollutant	PEDCO study		Other studies		Reference
	Emissions, gm/kg Fireplace	Stove	Emissions, gm/kg Fireplace	Stove	
Particulate	14.4	16.0	7.4 ^a	9	
			10.5 ^a	3	
HC	138.0	56.3	22.4	2	
			6.4 ^a	2	
CO	107.5	62.9	3-20 ^a	3	
			25 ^a	Unpublished data	
NO _x	-	-	5-45 ^a	3	
			3.4 ^a	Unpublished data	
		1.5-3 ^a	3		

^a Bituminous coal.

Table 4-4. COMPARISON OF PUBLISHED EMISSION FACTORS FOR RESTAURANT GRILLS

Pollutant	PEDCO study		Other studies		References
	Emission rate	Type of cooking equipment	Test condition	Type of cooking equipment	
Particulate	0.539 lb/hr	restaurant grill	wire mesh filter	char-broiler	5
				charcoal grill	10
HC	0.30 lb/hr			wood fired BBQ grill	11
	20 ppm			BBQ oven	12
CO	20.4 lb/hr			direct gas-fired burner	5
				wood fired scrubber/ESP (94 percent efficiency)	11
NO _x				charcoal no control, prep of hamburger; afternoon, slack period; supper, steak	10
				charcoal no control, grill	10

^e Estimated gas flow rate.

grills, respectively.

The expectation of higher emission rates at high altitudes was proven out in the case of wood burning fireplaces and stoves. For particulate and CO, emission rates in Vail were approximately twice that of values found in the literature. Hydrocarbon emission rates were even higher in comparison with published values. Because of the erratic nature of the HC test readings, it is recommended that the median value of 73 gm/kg be used as an emission factor rather than the mean value of 180 gm/kg.

Coal burning in fireplaces and stoves also produced generally higher emission rates at high altitudes. Particulate emissions were higher than factors shown in EPA's Compilation of Air Pollution Emission Factors³ and an EPA source assessment document still in preparation,⁴ but less than the average emission rate measured in a recent comprehensive fireplace testing study.² Since the data in the former documents may have been developed from emission tests on residential furnaces rather than fireplaces or stoves, the high altitude emission factors are actually lower than the most appropriate other emission factor. However, both the HC and CO emission rates were considerably higher than previously reported values. The ratios of the high altitude rates to normal rates are roughly the same as corresponding rates for wood burning in fireplaces and stoves.

The particulate emission rate for the restaurant grill in Vail is approximately the same as other results for similar types of cooking equipment. There was no data for mass emission rates of HC, but one reference reported concentrations in the exhaust gas of 30 ppm.⁵ This corresponds well with the 20 ppm measured in the grill exhaust at Vail. CO emission rates were considerably higher than those shown for previous studies.

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