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Particulate Emissions From Apartment House Boilers And Incinerators

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Abstract

The body of information presented in this paper is directed to researchers in stack testing methodology and to those concerned with reduction of emissions through equipment upgrading programs. An extensive number of tests were made using the U.S. Environmental Protection Agency's Method 5 stack sampling train to obtain emission factors for existing apartment house boilers and incinerators in the City of New York. In addition to calculating emission factors, stack emission data were examined to compare results of simultaneous emission tests and to compare the dry particulate catch of the sampling train with the total particulate catch which included the impinger catch.

Conclusions reached as a result of the testing were that published emission factors for boilers burning moderately high-sulfur residual oil are applicable to New York City boilers burning low-sulfur residual oil. In addition, it was found that the back half of the sampling train -- the impinger section -- collects a relatively constant amount of material when sampling oil-fired boilers. This may be due to absorption of SO_2 and SO_3 in the impingers and the subsequent formation of sulfuric acid. Comparision of simultaneous boiler tests indicated that the sampling train may be sensitive to variations in operating personnel, sampling conditions, and boiler operation.

From tests of on-site incinerators, it was determined that previously published emission factors may be too high for well-maintained and properly operated incinerators. The back half particulate catch was found to be relatively large which was likely a result of condensation of unburned organics from the burning waste material.

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Introduction

Sources of particulates in the South Bronx and Upper Manhattan area of New York City include more than 5000 non-upgraded residual oil-fired boilers and 2000 non-upgraded flue-fed incinerators. These installations are estimated to contribute significantly to the area's total particulate emissions. The South Bronx and Upper Manhattan area has been experiencing annual suspended particulate levels in excess of the primary national ambient air quality standard of 75 micrograms per cubic meter (ug/m3).[1] Consequently, the State of New York in its State Implementation Plan placed primary reliance on the use of low-sulfur residual oil and the upgrading of existing oil-fired boilers, as well as the sealing or upgrading of existing on-site incinerators to reduce the ambient levels of particulates for achievement of primary standards.

In order to determine the expected reduction in emissions from this control strategy, a reliable emission factor was needed for existing sources. Apartment house sized boilers and incinerators have been tested previously,[2,3,4,5,6] but only minimal data is available for non-upgraded primitive installations tested with the U.S. Environmental Protection Agency's (EPA) Method 5 particulate sampling train. A non-profit corporation, Environmental Conservation Research, Inc., maintained by New York State Department of Environmental Conservation, was contracted by EPA to source test approximately 25 boilers and 25 incinerators in the South Bronx and Upper Manhattan for use in establishing particulate emission factors. Stack test results were used not only to determine the overall emission factors, but also to examine the relationship between the front half catch of the sampling train with the total catch, the influence of equipment upgrading on source performance, the uniformity in particulate catch from simultaneous tests, and the effect of boiler soot blowing on emissions.

Experimental Methods

Description of Test Units

Sites representative of the variety of non-upgraded installations in the study area were selected for testing. Moreover, several upgraded sites, certified by the New York City Department of Air Resources for meeting minimum performance and design criteria,[7,8,9] were also tested. The installations ranged in age from less than 1-year to 50-years old. Some were well maintained while others were almost totally neglected. Boiler firing rates ranged from 16 to 100 gallons per hour. All boilers tested were equipped with horizontal rotary cup burners, some had windboxes, and most had either a sequential draft controller or barometric damper. Incinerators were of single flue design and most consisted of only one combustion chamber. Several units had auxiliary burners and gas scrubbers.

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Sampling and Measurements

Particulates were sampled with the EPA Method 5 procedure and sampling train, and optional impinger section, as noted in December 23, 1971, Federal Register. Sampling therefore included both dry and total catches. The dry catch consists of all particulate matter obtained from washings of the probe and cyclone and particulate collected by the filter. This is the same as the particulate catch of the EPA sampling train. The sum of the dry catch particulate and the particulate found in the impinger section of the sampling train is the total particulate catch.

In many stack tests, a 12-foot-long stack insert with a 12-inch-square cross section and built-in ports was placed in the chimney. The insert was used to prevent reentrainment during testing of particulate matter found adhered to the chimney wall and to impart a needed higher exhaust gas velocity so that tests could be conducted efficiently. Fiber glass insulation was used to secure a seal between the insert plate and stack exit.

Oil flow meters were installed by licensed servicemen at all the boiler test sites. Most boiler installations required two meters, one each in the oil supply and return lines. Oil samples were obtained at each site for analysis of sulfur, ash, Btu, and carbon content, as well as oil viscosity and specific gravity. All fuel was found to be low-sulfur (less than 0.5 percent sulfur) residual oil with low ash content. Two or three 1-hour sample runs were completed at each boiler site. Some of the boiler emission tests were conducted with two sampling trains operating simultaneously.

The stack test runs at incinerator sites were conducted consecutively with each test lasting approximately 1-hour. Three tests were attempted at each installation. Where gas burners were present, their firing rates were calculated from existing gas meters. The length of time of the burner operation was also recorded.

Equipment Operating Procedures

The major objective of the program was to obtain emission data for residual oil-fired boilers and on-site flue-fed incinerators during their typical modes of operation. All installations were tested in an "as found" condition. Except for the use of stack inserts, no adjustments were made to the existing equipment. Where possible, units were placed on manual controls so that operation could coincide with testing. Modifications to normal boiler and incinerator operations were kept to a minimum.

Boilers. Stack sampling started immediately upon burner startup, so there was no attempt to achieve steady state conditions. The boilers were allowed to operate until boiler pressure reached optimum safety levels, typically 5 to 10 psi. Boiler operation was discontinued during the port changes. To ensure that sampling and boiler operation coincided, constant communication via intercom was maintained between personnel on the roof and in the boiler room.

Soot blowing of boiler tubes was regularly performed at several sites using compressed air jets. The soot blowing equipment was normally activated three times daily for a duration of 30 minutes. To measure the effect of the soot blowing on particulate emissions, tests at these sites were conducted during both soot blowing and non-soot blowing periods. On days of soot blow testing, boiler operating personnel were advised to postpone their early morning soot blowing operation until time of testing.

Incinerators. The quantity of refuse charged was determined from the volume of the combustion chamber. Assuming an average refuse density of 4.1 pounds per cubic foot,[7] the weight of refuse charged was determined by filling the combustion chamber to one-half its volume. Though the amount of refuse normally charged in apartment house varies considerably, charging the combustion chamber to half its volume introduced some uniformity to the incinerator tests. The refuse used during testing was actual waste generated by tenants of the buildings being tested, and, if needed, from nearby apartment houses. The typical practice of using a prepared standard waste[9] was therefore, not followed. All charges approximated type 2 waste.

Before the first test run at a site, the sizes of the chamber and grate were measured, and although not typical of normal operation, the combustion and cleanout chambers were completely cleared of ash. All the weighed refuse was then charged and ignited, either by match or gas burner. Since composition of the refuse varied between tests, it was difficult to estimate accurately the length of time for each burn. If after 1-hour a significant amount of refuse remained, each sampling point was sampled again for a period of 3 to 4 minutes to allow for more complete burn-down of material. The fire was stoked only to continue a burn to finish a test.

After a test was completed, the remaining refuse, which was often still burning or smoldering, was sprayed with a minimum of water from a precalibrated garden hose. Half the water was assumed to be evaporated or run-off, and the remainder absorbed by the ash. After the fire was extinguished, the ashes were placed in cans and weighed. In later stages of the study, the procedure was modified so that the still-burning refuse was shovelled into cans which were immediately covered to smother the flame. This method eliminated the need for water and the uncertainty factor related to its use. The waterless procedure, however, increased the safety risk from exploding aerosol cans and permitted the continued burning of some refuse after the test was completed. At the conclusion of each test run, the incinerator was cleaned and charged for the next test.

Charging hopper doors on each floor of the apartment buildings were sealed with tape, and trash bags were provided for use by the tenants. This practice prevented unknown amounts of refuse from being added to the incinerator and disturbing the fire during testing.

Discussion of Results

Boilers Emission Results

Emissions for boilers are reported in two ways. For the purposes of determining the emission factors, the results are reported in kilograms per thousand liters ($kg/10^3\ \ell$) of residual oil burned. This number can be compared with published emission factors. Some of the emission tests were conducted with two sampling trains operated simultaneously. For comparison of these test runs and for comparison of dry catch to total catch, the emissions are expressed as milligrams per dry standard cubic meter (mg/dscm).

The dry catch emission factor determined from the stack tests of the apartment house boilers was 2.78 $kg/10^3\ \ell$. Including the impinger catch as part of the total particulate emissions results in an emission factor of 3.98 $kg/10^3\ \ell$. Though all boilers tested burned low-sulfur fuel, the dry catch compares favorably with the emission factor of 2.75 $kg/10^3\ \ell$ published in the "Compilation of Air Pollutant Emission Factors".[11] This factor was associated with fuel oil of moderately high sulfur content. Results from a recent study of boilers burning low-sulfur residual oil suggest that a dry catch emission factor of 1.5 $kg/10^3\ \ell$ might be more appropriate for such fuel.[4] This emission factor may apply only to well-maintained boilers but is consistent with the results obtained from many of the better performing installations tested. Table I shows the emission factors for all boiler tests reported as dry catch and total catch.

Emission concentrations varied greatly from site to site for non-upgraded boilers as indicated in Table II. The average emission concentration based on the dry particulate catch was 111.8 mg/dscm with a standard deviation of 172.7 mg/dscm. The average total emission factor was 150.3 mg/dscm with a standard deviation of 175.4 mg/dscm. Even though the emission factors varied greatly from site to site, the difference between the dry catch and the total catch, or the impinger catch, remained relatively constant. The average impinger catch was 38.5 mg/dscm with a standard deviation of only 15.9 mg/dscm. This represents a 41 percent deviation whereas the dry emission concentration had a deviation of over 150 percent. The relatively constant amount of material collected in the impinger section of the sampling train during boiler sampling, despite varying particulate emission levels, may suggest the presence of sulfur oxides in relatively constant concentrations in the boiler gas exhaust. Sulfur dioxide and sulfur trioxide are formed by the oxidation of sulfur in the fuel oil. These gases are possibly absorbed in the impinger solution and upon storage may form sulfuric acids.[12] The acids are then measured as particulate after evaporation of the impinger solutions. All of the oil used during the testing period had nearly the same low sulfur content; thus the sulfur oxide concentrations in the boiler exhaust would be constant depending only on varying amounts of excess air.

Data for upgraded boilers are shown in Table III. The data were insufficient to show any significant difference between upgraded boiler emissions and non-upgraded boiler emissions.

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Emissions determined during the soot blowing periods are shown in Table IV. The average dry emission concentration found during soot blowing was 24.2 mg/dscm. The average dry emission concentration from the same sites during normal conditions was 21.6 mg/dscm. Data from these sites were insufficient to show any significant difference in emissions during soot blowing periods and during other periods. Only four sites were sampled during soot blowing and the results were varied. Though previous literature[13] indicates that soot blowing substantially increases emissions, the failure to find such an effect may be attributed to excellent maintenance practices at the soot blowing sites, the frequency at which the soot blowing is conducted, and the low ash content of the fuel. A larger number of emission samples would be needed, however, to determine the difference in emissions during soot blowing and normal operating periods.

During the program, 15 of the boiler emission tests were conducted with two sampling trains operating simultaneously in the same stack. The trains were operated along different traverses and not at the same sampling point. Table V shows the data from these tests. To obtain some measure of the relative difference between paired sampling runs, the ratio of difference in concentrations to the average of the two concentrations was calculated for all of the tests. The average value for the variation factor was 53 percent. Seven of the 15 runs had a variation factor of less than 25 percent. The greater variation in the other duplicate test runs may be due in part to the variation in equipment operators, sampling sites, and boiler operating parameters. The variation may also be due to incomplete or insufficient traversing of the stack cross-section. As noted previously, the two sampling trains were operated in different parts of the stack.

Incinerator Emission Results

Incinerator emissions are reported in two ways. For the purposes of determining the emission factors, the results are reported in kilograms per metric ton (kg/MT) of refuse burned. This number can be compared with published emission factors. For comparison of dry catch to total catch, the emissions are expressed, as for boilers, in milligrams per dry standard cubic meter (mg/dscm).

The emission factor for flue-fed single chamber incinerators reported in the "Compilation of Air Pollutant Emission Factors"[11] is 15 kg/MT of material burned. For the emission tests conducted at non-upgraded incinerators in New York City the average emission factor was 10.4 kg/MT based on the dry catch of the sampling train. Using the total particulate catch of the sampling train produces an emission factor of 17.9 kg/MT. For this project the incinerators were operated at optimum conditions and charges were carefully weighed and charged. This was done to obtain an accurate measure of burning rate. These factors may account for the difference between previously published values and the emission factors determined during this program. Table VI shows the emission factor data for incinerators.

Non-upgraded incinerators averaged 209.3 mg/dscm in dry emission concentration or more than twice the upgraded incinerator emissions concentration of 99.6 mg/dscm. This indicates that upgrading of New York City apartment house incinerators leads to substantial reductions in air pollutant emissions. The difference between concentrations based on dry catch and concentrations based on total catch for non-upgraded incinerators was 148.4 mg/dscm with a standard deviation of 64.5 mg/dscm. The relatively large back half catch could be expected because of the potentially large amount of condensible organic material generated during burning of waste. This organic material would condense in the impinger solutions and be measured as part of the total mass. The standard deviation of the back half catch was greater than that found for the boilers. This might also be expected since the refuse was not as consistent in composition as the fuel oil. Table VII shows the emission concentration data for non-upgraded incinerators and Table VIII shows similar data for upgraded incinerators. Upgrading of incinerators reduced not only the front half particulate catch but also reduced the impinger catch. This suggests that unburned condensible organics may be controlled by auxiliary burners or wet scrubbers which were installed in the upgraded incinerators.

Conclusions

Several conclusions about the EPA Method 5 sampling train and its application to sampling apartment house boilers and incinerators can be made. The data indicate that the amount of particulate captured in the impinger section of the sampling train is relatively constant and is independent of the amount of dry particulate catch found during boiler emission sampling. This possibly results from the absorption of sulfur dioxide in the impingers and the subsequent formation of relatively constant quantities of sulfuric acid. Possibly because of the variation in refuse composition, no similar effect on impinger catch was noted with the incinerator emission data. The relatively large impinger catch found in the incinerator tests is consistent with the expectation that organics condense and are collected in the impinger section of the sampling train.

The varied emission results of paired simultaneous tests on 15 of the boilers may only be indicative of variations in operating personnel, sampling conditions, and boiler operation. The paired test runs were made simultaneously in the same stack, but not at the same point in the gas stream, suggesting that traverses done in different parts of the same stack may not produce identical results. An effort should be made to isolate the reasons for the observed variations in the test results.

The emission factor determined during the New York City boiler tests compares favorably with the published values found in the "Compilation of Air Pollutant Emission Factors".[11] For incinerators, however, the emission factor determined during testing was less than the published value. This may indicate that the incinerators were operated during the testing at or near optimum conditions by experienced operators.

Upgrading has an apparent minimum effect on the emissions from apartment house boilers. This might be attributable to the fact that many of the upgraded boilers tested were not maintained in optimum operating condition. Upgraded incinerators had substantially lower emissions than did non-upgraded units. This implies that auxiliary burners and wet scrubbers may be effective in reducing emissions of unburned hydrocarbons that are emitted from apartment house incinerators.

Table I Emission factor results from emission tests of apartment house boilers.

Site	Emission Factor dry[a] kg/10^3 ℓ	Emission Factor total[b] kg/10^3 ℓ	Difference kg/10^3 ℓ
1	1.57	3.20	1.63
2	3.24	4.36	1.12
3	0.92	2.98	2.06
4	5.03	7.90	2.87
5	3.67	4.81	1.14
6	2.54	4.60	2.06
7	1.57	3.06	1.49
8	1.99	3.00	1.01
9	1.13	2.26	1.13
10	1.41	2.00	0.59
11	0.53	0.89	0.37
12	0.61	2.35	1.74
13	2.04	2.68	0.64
14	0.97	1.83	0.86
15	17.08	17.71	0.63
16	1.40	2.46	1.06
17	0.99	1.41	0.42
18	4.09	5.27	1.18
19	2.04	2.91	0.87
20	4.10	5.18	1.08
21	0.65	1.04	0.39
22	2.13	3.08	0.95
23	9.38	10.08	0.70

[a]Based on particulate catch of probe, cyclone, and filter

[b]Based on particulate catch of probe, cyclone, filter and impingers

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Table II Emission concentrations from emission tests of non-upgraded apartment house boilers.

Site	Emis. Conc. dry[a] mg/dscm	Emis. Conc. total[b] mg/dscm	Difference mg/dscm
1	31.0	63.8	32.8
2	141.8	190.9	49.1
3	10.2	32.9	22.7
4	71.0	111.9	40.6
5	78.4	102.9	24.5
6	62.2	111.8	49.6
7	60.6	118.9	57.9
8	67.9	102.2	34.3
9	48.0	96.8	48.8
10	121.1	172.0	50.9
11	47.8	79.9	32.1
12	6.9	27.5	20.6
13	38.5	50.9	12.4
14	35.7	67.3	31.6
15	804.8	834.6	29.8
16	50.3	88.7	38.4
17	44.8	63.3	18.5
18	246.6	317.5	70.9
19	155.8	222.6	66.8

a Based on particulate catch of probe, cyclone, and filter

b Based on particulate catch of probe, cyclone, filter and impingers

Table III Emission concentrations from emission tests of upgraded apartment house boilers.

Site	Emis. Conc. dry[a] mg/dscm	Emis. Conc. total[b] mg/dscm	Difference mg/dscm
20	176.0	222.3	46.3
21	34.4	55.1	20.7
22	80.9	116.9	36.0
23	457.8	491.5	33.7

a Based on particulate catch of probe, cyclone, and filter

b Based on particulate catch of probe, cyclone, filter, and impingers

Table IV Emission concentrations from emission tests of apartment house boilers during soot blowing.

Site	Emis. Conc. dry[a] mg/dscm	Emis. Conc. total[b] mg/dscm
	With soot blowing	
1	26.2	72.7
3	38.5	83.5
12	11.2	29.8
13	20.9	42.4
	No soot blowing	
1	31.0	63.8
3	10.2	32.9
12	6.9	27.5
13	38.5	50.9

a Based on particulate catch of probe, cyclone, and filter

b Based on particulate catch of probe, cyclone, filter, and impingers

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Table V. Emission concentrations from simultaneous emission tests of apartment house boilers.

Site	Emis. Conc. Run 1 mg/dscm	Emis. Conc. Run 2 mg/dscm	Difference mg/dscm	Diff./average %
2	134.8	148.8	14.0	9.9
6	41.0	83.5	42.5	68.3
7	53.4	67.8	14.4	23.8
8	72.0	63.7	8.3	12.2
9	47.5	48.6	1.1	2.3
10	183.6	58.5	125.1	103.3
11	21.0	74.6	53.6	112.1
12	10.3	12.1	1.8	16.1
13	65.4	11.6	53.7	140.7
15	945.9	663.7	282.2	35.1
16	53.9	46.7	7.2	14.3
17	36.0	53.6	17.6	39.3
19	77.1	234.4	157.3	101.0
21	51.2	17.6	33.6	97.7
23	414.6	499.7	85.1	18.6

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Table VI. Emssion factors from emission tests of apartment house incinerators.

Site	Emis. Factor dry[a] kg/MT	Emis. Factor total[b] kg/MT	Difference kg/MT
1	10.4	17.6	7.2
2	5.6	10.4	4.8
3	10.4	17.2	6.8
4	14.0	22.4	8.4
5	10.7	16.9	6.2
6	10.4	22.0	11.6
7	9.3	16.1	6.8
8	12.6	17.4	4.8
9	10.2	17.1	13.9
10	22.5	30.5	8.0
11	5.0	13.6	8.6
12	5.2	9.1	3.9
13	6.9	15.8	8.9
14	16.6	33.1	16.6
15	9.0	15.0	6.0
16	8.4	15.0	6.6
17	9.6	15.1	5.5
18	10.0	17.4	7.4
19	4.8	8.8	4.0
20	4.4	7.8	3.4
21	1.7	3.6	1.9
22	3.0	4.6	1.6

a. Based on particulate catch of probe, cyclone, and filter

b. Based on particulate catch of probe, cyclone, filter, and impingers

Table VII. Emission concentrations from emission tests of non-upgraded apartment house incinerators.

Site	Emis. Conc. dry[a] mg/dscm	Emis. Conc. total[b] mg/dscm	Difference mg/dscm
1	123.6	215.0	91.4
2	133.5	246.1	112.6
3	240.7	398.0	157.3
4	218.6	344.4	125.8
5	208.9	338.7	129.8
6	140.2	300.5	160.5
7	192.8	348.3	155.5
8	415.2	572.8	157.6
9	230.9	374.2	143.3
10	324.3	439.3	115.0
11	58.2	154.6	96.4
12	130.4	228.8	98.4
13	220.5	487.8	267.3
14	364.2	705.5	341.3
15	157.2	263.1	105.9
16	163.5	297.3	133.8
17	234.8	366.1	131.3

a. Based on particulate catch of probe, cyclone, and filter

b. Based on particulate catch of probe, cyclone, filter, and impingers

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Table VIII. Emission concentrations from emission tests of upgraded apartment house incinerators.

Site	Emis. Conc. dry[a] mg/dscm	Emis. Conc. total[b] mg/dscm	Difference mg/dscm
18	220.7	384.6	163.9
19	98.8	182.0	83.2
20	63.1	105.8	42.7
21	37.9	81.0	43.1
22	77.7	120.3	42.6

a. Based on particulate catch of probe, cyclone, and filter

b. Based on particulate catch of probe, cyclone, filter, and impingers

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