SECTION 2.4 Ref. 2

Reference 12 RICHARD W. GERSTLE

R. W. GERSTLE
and D. A. KEMNITZ
The National Center for Air Pollution Control, Cincinnati, Ohio

Atmospheric Emissions From Open Burning

2.4

AP42 Reference 7 2

Emission data have been derived from the simulated open burning of municipal refuse, landscape refuse, and automobile components. The data confirm that disposal of refuse by open, uncontrolled burning invariably leads to higher emissions than incineration and creates an unnecessary air pollution problem.

Although disposal of trash by open burning is a common practice, very little quantitative information on atmospheric emissions from this source of pollution is to be found in the literature. This lack of data is largely a result of the many difficulties encountered in obtaining representative gas samples and in measuring the various combustion parameters.

In order to provide some substantive emission data on open burning, the Public Health Service, with the assistance of the Air Pollution Research Center of the University of California at Riverside, conducted a series of tests on simulated open burning of various materials often disposed of in this manner.

Apparatus

To facilitate the collection of effluent gases from the burning material, a large sheet metal, inverted funnel was used. The tower, as illustrated in Fig. 1, was designed to minimize any interference with the actual burning operation and thus to simulate open burning as closely as possible. This tower was suspended approximately 4 ft above a burning table 8 ft in diameter, positioned on an automatic scale, which continuously recorded the weight of material remaining.

Airflow was measured in the exit stack with a calibrated anemometer and continuously recorded. Temperatures were also continuously measured at this point with a thermocouple. Gas sample lines passed from the exit stack to an adjacent building, where concentrations of CO_2, CO, and gaseous hydrocarbons were continuously measured.

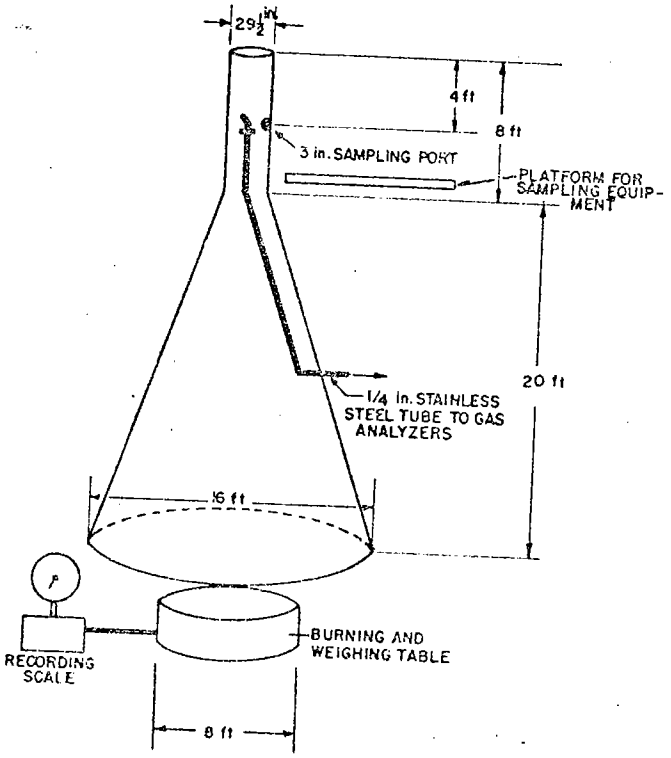

Fig. 1. Burning tower.

Procedure

The test series consisted of five 1-day tests. Two tests were conducted on municipal refuse; two on landscape refuse such as lawn clippings, leaves, and tree branches; and one on automobile components such as tires, seats, and floor mats.

Samples were taken to determine the amounts of particulate, CO_2, CO, gaseous hydrocarbons, nitrogen oxides, formaldehyde, organic acids, and polynuclear hydrocarbons present in the effluent gas stream. In addition, total gas flow, exit stack temperature, and weight of the material being burned were continuously measured.

A combined sample for solid particulate and polynuclear hydrocarbons was obtained by use of the sample train illustrated in Fig. 2. To insure collection of all polynuclear hydrocarbons, the gas stream must be cooled to at least 65°F.[1]

Particulate samples were taken isokinetically at a single point near the center of the exit stack. The particulate found on the sample train filters; that filtered from the bubbler water, and that removed by brushing and washing

components were combined
ment of the total particulate
r drying in a desiccator.
ve all traces of polynuclear
ions from the sampling train,
ponents were rinsed with re-
benzene after being washed with
The f[illegible] from the bubbler
wash-wa[illegible] filtration was then
with [illegible] benzene in a
ratory fu[illegible] to remove the soluble
hydrocarbon[illegible] he benzene used to
rinse the [illegible] benzene-soluble frac-
tion of [illegible] filtrate, and the total
solid p[illegible] were then extracted
with b[illegible] and analyzed for poly-
nuclear [illegible] carbons by ultraviolet-
visible [illegible] ectroscopy.[2]

Carbon monoxide and carbon dioxide were continuously measured with infrared analyzers. Hydrocarbons, measured as total carbon, were measured continuously with a flame ionization analyzer. Three grab samples of nitrogen oxides were taken in 2-liter flasks during each test at various intervals and analyzed by the phenoldisulfonic acid method.[3] Formaldehyde samples were collected over a 40 min period in water and analyzed by the chromotropic acid procedure.[4]

For determination of organic acids, gas samples were collected for about 40 min in [illegible]-cc impingers, containing 100 cc of a [illegible]% sodium hydroxide solution. The collected samples were acidified and the [illegible] organic acids extracted with ether in a liquid-liquid extractor.[5] The organic acids in the ether were then titrated with a standard base.

In [illegible] tests the initial weight of material charged on the burning table ranged from [illegible] to 125 lb. The active burning period lasted 60–90 min and was followed by a slow smouldering period, which lasted from 1½ to about 12 hr.

Total emissions of carbon dioxide, carbon monoxide, and gaseous hydrocarbons were determined by taking average values of the gas concentration over a short time increment and multiplying this value by the corresponding air flow in standard cubic feet* for that same time increment. Time increments ranged from 20 sec to 1 min depending on the rate of change of concentration. Emissions of formaldehyde, organic acids, and particulate were determined by multiplying the total airflow corrected to standard conditions during the first hour of burning by the average pollutant concentration.

To convert these concentrations to emission rates on a per unit of initial fuel weight basis, the pounds of pollutant emitted during the first hour were multiplied by the total weight loss divided by the weight lost during the first hour, and this figure then divided by the initial weight present, that is;

$$\frac{\text{pounds pollutant emitted}}{\text{tons of material initially present}} = P_1 \times \frac{W_T}{W_1 \cdot W_6}$$

where

P_1 = pounds of pollutant emitted during first hour
W_T = total pounds of material burned
W_1 = pounds of material burned during first hour
W_6 = tons of material initially present

This calculation assumes that the emissions per pound of material burned during the first hour remained constant for the balance of the slow burning period in which no samples were taken. In almost all cases the ratio of total pounds of material burned to the pounds of material burned during the first hour was about 1.1.

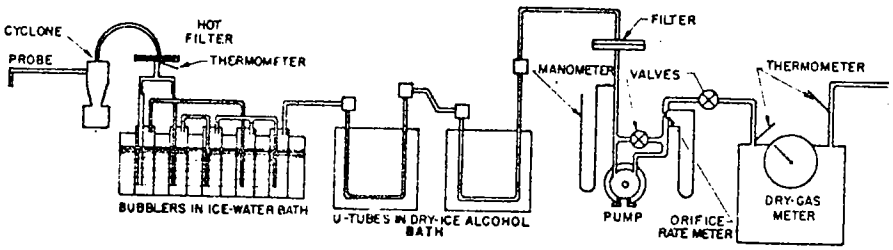

Fig. 2. Sampling train for particulate and polynuclear hydrocarbons.

Results

CO_2, CO, and Gaseous Hydrocarbons

Figures 3–5 show the variation of CO_2, CO, gaseous hydrocarbons, and temperature with time. All of the tests were characterized by an initial rapid rise in temperature and carbon dioxide.

For the tests on municipal refuse, a relatively small carbon monoxide peak of 0.05% occurred 5 min after ignition, followed by a gradual rise in hydrocarbon concentrations. Carbon dioxide concentrations reached 1.6% after about 2 min. The tests on the landscape refuse were characterized by a high hydrocarbon and carbon monoxide peak occurring approximately 8 min after

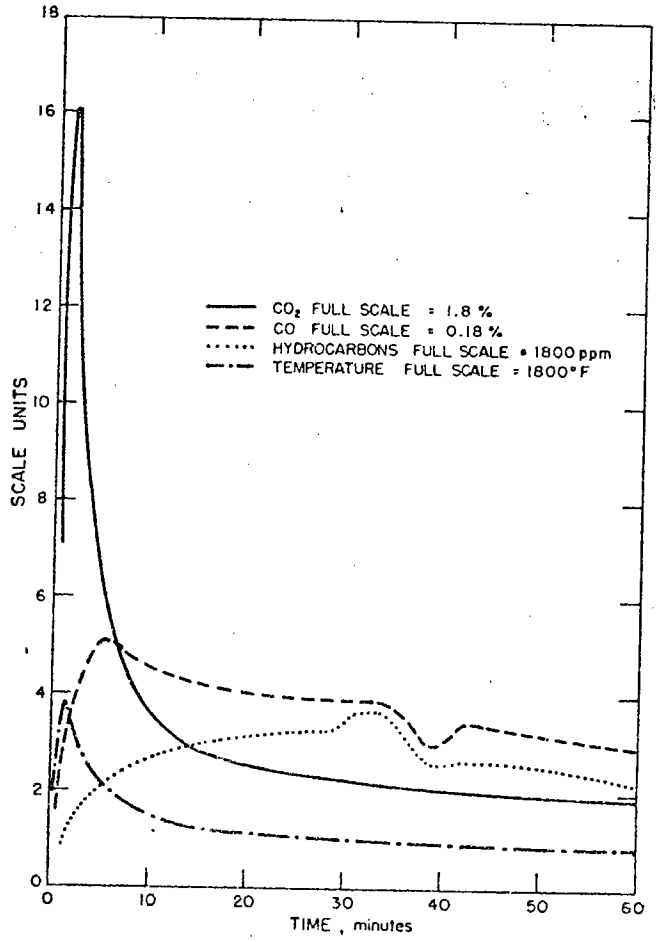

Fig. 3. Variations in CO_2, CO, hydrocarbons, and temperature with time during burning of municipal refuse.

* Standard conditions are 70°F and 29.9 in. Hg.

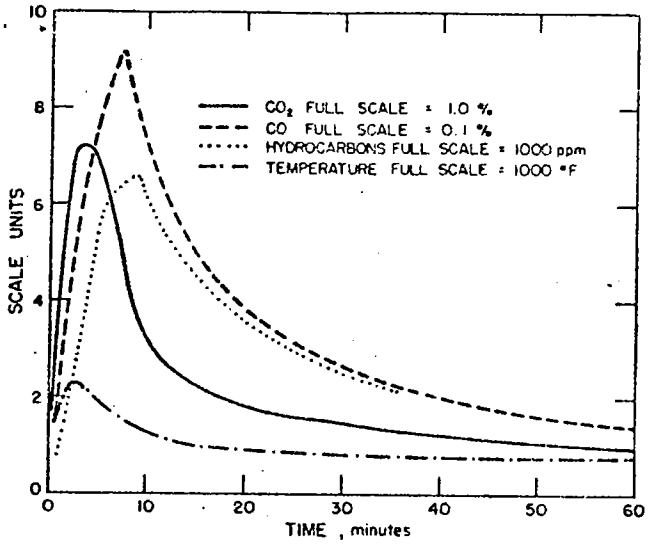

Fig. 4. Variations in CO_2, CO, hydrocarbons, and temperature with time during burning of landscape refuse.

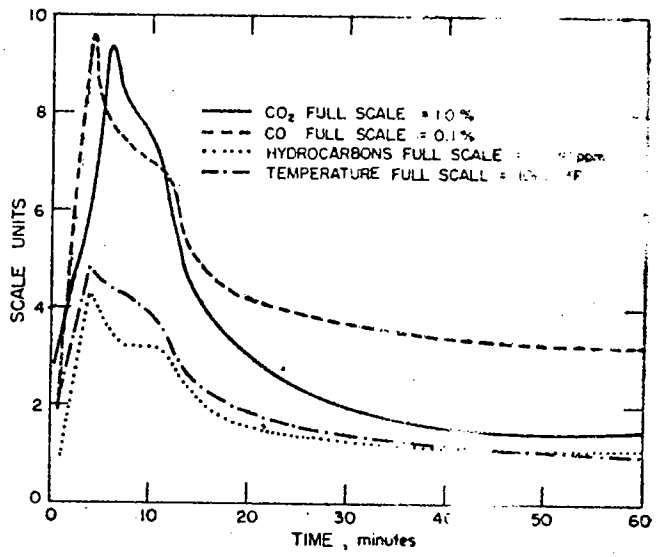

Fig. 5. Variations in CO_2, CO, hydrocarbons, and temperature with time during burning of auto components.

ignition. After the initial rapid burning period, the concentrations of these gases were similar to those found in burning municipal refuse. The single test on auto components showed a rapid initial burning period characterized by high temperatures and high emission rates for carbon dioxide and carbon monoxide.

Mass emission rates for carbon dioxide, carbon monoxide, gaseous hydrocarbons, formaldehyde, and organic acids are presented in Table I. Emissions from various types of incinerators have been found to vary from 1 to 25 lb/ton of refuse for carbon monoxide and from less than 1 to approximately 4 lb of hydrocarbons expressed as methane/ton of refuse.[6]

Based on very limited analysis of the gaseous hydrocarbons on a gas chromatograph in which only low-carbon, straight-chain compounds were analyzed, unsaturated compounds accounted for 30–40% of the compounds found.

Table I—Gaseous Emissions from Open Burning

Test No.	Material Burned	Gaseous Emissions—Pounds per Ton of Material Initially Present				
		CO_2	CO	HC[a]	Formaldehyde	Organic Acids[b]
1	Municipal refuse	1250	90	30	0.095	14
2		1210	80	30	0.094	16
Avg.		1230	85	30	0.095	15
3	Landscape refuse	860	80	35	0.005	18
4		550	50	25	0.006	8
Avg.		700	65	30	0.006	13
5	Automobile components	1500	125	30	0.030	16

[a] Gaseous-hydrocarbons expressed as methane.
[b] Organic acids expressed as acetic acid.

Table II—Nitrogen Oxide Emissions

Material Burned	Test No.	NO_x Emissions, ppm	Pounds per Ton of Material Burned[a]	Time Elapsed After Fire Started, min
Municipal refuse	1	9	8	33
		7	6	54
		8	9	75
	2	127	27	3
		11	9	43
		2	4	83
Landscape refuse	3	20	4	3
		2	1	27
		1	1	48
	4	16	4	2
		<0.5	<0.5	40
Automobile components	5	84	17	0
		5	5	24
		1	2	52

[a] Calculated on the basis that all of the nitrogen oxides are nitrogen dioxide.

Formaldehyde and Organic Acids

Formaldehyde and organic acids are formed by the incomplete combustion of the burning material. Neither of these pollutants were produced in excessively large quantities, although emissions were greater than those found in more efficient combustion devices.

Incinerator effluents of formaldehyde have been found to be in the range of 0.0014 to 0.016 on a pound/ton basis.[6]

Nitrogen Oxides

In open burning, temperatures are fairly low and the high-intensity burning necessary for the oxidation of atmospheric nitrogen exists only during the short initial burning period.

Nitrogen oxides concentrations are shown in Table II as parts per million and also as pounds/ton of material burned while the sample was taken. The accuracy of the latter figure is somewhat limited since sampling extended over only a 5-min period.

Particulate

As evidenced by the smoke plume, particulate emissions were fairly heavy during the initial burning period and then slowly decreased during the burn.

The particulate matter emitted from the burning of municipal refuse and that from lawn and tree trimmings was light gray and contained approximately 65% by weight of benzene-soluble material. Particulate emissions from the burning of auto components were very black and sooty; they contained 8% by weight of benzene-soluble material.

Average particulate emissions expressed in various ways are shown in

Table III—Particulate Emissions from Open Burning

	Material Burned	Average Emissions: Grains per scf[a] At Stack Conditions	Grains per scf[a] Corrected to 50% Excess Air	Pounds per ton of Original Material	Pounds per ton of Weight Loss	Pounds per 1000 lb Flue Gas Corrected to 50% Excess Air
1	Municipal refuse	0.04	1.3	14	22	2.4
2		0.05	1.8	18	26	3.4
Avg.		0.045	1.55	16	24	2.9
3	Landscape refuse	0.07	2.8	23	28	5.3
4		0.05	2.5	12	19	4.8
Avg.		0.06	2.65	17	24	5.0
5	Auto components	0.23	7.7	100	150	14.7

[a] Standard conditions are 70°F and 29.9 in. Hg.

Table III. These values are all high when compared to emissions from small incinerators, which ranged from 4 to 8 lb/ton.[6] When compared to the emissions from an incinerator specifically designed for the burning of tree trimmings, leaves, etc., these particulate emissions from open burning were 25 times as high.[7,8] When automobile bodies were burned in an enclosed incinerator designed for this purpose, emissions were 0.5 lb/1000 lb of flue gas at 50% excess air, or only 3.4% of the value found in open burning.[9]

Polynuclear Hydrocarbons

Another result of poor combustion is the formation of polynuclear hydrocarbons. These heavy hydrocarbons have received increased attention over the past few years because of their carcinogenic properties.[10]

Emissions of polynuclear hydrocarbons are given in Table IV. Open burning of municipal refuse and landscape refuse produced 0.3 g/ton of material burned, comparable to emissions from small commercial incinerators.[6] For burning auto components, the benzopyrene concentrations rose to 26 g/ton, which exceeds the high emissions of 12 g/ton found for a coal-burning hand-fired furnace.[6]

Summary

Atmospheric emissions from open burning are characterized by high emission of products of incomplete combustion. Carbon monoxide was given off in appreciable quantities, namely; 85 lb/ton of material burned when municipal refuse was burned, 65 lb/ton when landscape refuse was burned, and 125 lb/ton when auto components were burned. These values are all very high when compared to emissions from municipal incinerators or other combustion processes.

Gaseous hydrocarbon emissions paralleled the carbon monoxide concentrations and averaged 30 lb/ton of material burned for all tests. The organic acid concentrations were also fairly high, averaging about 15 lb/ton of material originally present in all tests. Formaldehyde concentrations varied from 0.095 lb/ton for municipal refuse to as low as 0.006 lb/ton for the landscape refuse. These formaldehyde concentrations also exceed those normally found in incinerators.

Emissions of nitrogen oxides varied widely and depended on the intensity of burning. Highest values occurred during the initial burning period when temperatures were high. After the initial intense burning period of about 10 min, the nitrogen oxide concentrations dropped off rapidly.

Particulate emissions averaged 16 lb/ton of material burned when municipal refuse was burned and 17 lb/ton when landscape refuse was burned. Emissions jumped to 100 lb/ton when auto components were burned.

Emissions of polynuclear hydrocarbons were also quite high, but for municipal or landscape refuse they were comparable to emissions from small commercial incinerators. For auto components, the concentrations were very high, comparable to those found in emissions from small coal-burning furnaces.

Table IV—Polynuclear Hydrocarbon Emissions from Open Burning, Grams per Ton of Material Initially Present

	Municipal Refuse 1	Municipal Refuse 2	Landscape Refuse 3	Landscape Refuse 4	Automobile Components 5
	—[a]	—	—	—	1.9
	—	—	—	—	13.2
	0.78	1.19	0.77	0.64	33.4
	0.89	1.28	1.31	0.87	46.9
	0.25	0.34	1.01	0.42	14.5
	0.17	0.21	0.26	—	19.4
	0.19	0.22	0.31	0.13	17.8
	0.13	0.16	0.12	0.08	9.0
	—	—	0.05	—	1.6
	—	0.19	0.21	—	12.2
	—	—	0.03	—	1.4
	—	—	—	—	1.5

[a] The compound was not detected.

REFERENCES

1. R. L. Stenburg, *et al.*, "Sample Collection Techniques for Combustion Source—Benzopyrene Determination," *American Ind. Hygiene Assoc. J.*, **22**: 271–275 (August 1961).
2. E. Sawicki, *et al.*, "The Detection and Determination of Polynuclear Hydrocarbons in Urban Air-Borne Particulates—1. The Benzopyrene Fraction," *International J. Air. Poll.*, **2**: 273–282 (1960).
3. ASTM Standards Part 23, Method D 1608 (1965).
4. A. P. Altshuller, "Determination of Formaldehyde in Gas Mixtures by the Chromotropic Acid Method," *Anal. Chem.*, **33**: 621 (April 1961).
5. Laboratory Methods Manual, Los Angeles County Air Pollution Control District (1958).
6. R. P. Hangebrauck, *et al.*, "Emissions of Polynuclear Hydrocarbons and Other Pollutants from Heat-Generation and Incineration Processes," *J. Air Poll. Control Assoc.*, **14**: 265 (July 1964).
7. M. Sterling, "Brush and Trunk Burning Plant in the City of Detroit," *J. Air Poll. Control Assoc.*, **15**: 380 (December 1965).
8. C. L. Palmer, "Smokeless Brush Disposal," *Public Works*, **96**: 90–92 (May 1965).
9. E. R. Kaiser, "Smokeless Burning of Automobile Bodies" *J. Air Poll. Control Assoc.*, **12**: 64–73 (February 1962).
10. J. L. Hartwell, "Survey of Compounds Which Have Been Tested for Carcinogenic Activity," U. S. Public Health Service Publication No. 149 (1951).