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Air Pollution in Los Angeles County

CONTRIBUTION OF COMBUSTION PRODUCTS

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Angeles, Calif., the most disagreeable effects of ... murkiness and irritation of the eyes, noses, and ... of the inhabitants. The most apparent economic ... the damage to certain crops. Combustion prod- ... tribute materially to the atmospheric impurities. ...mately 50,000 tons per day of fuel and rubbish are ... in Los Angeles County. Public and industrial ... of these materials emits to the area each day at ...00 tons of these impurities, not including carbon ...de. Household burning of 4000 tons of trash, the biggest single source, sends 550 tons of organic materials into the air every 24 hours. Approximately two thirds of the chemicals entering the air from combustion are organic in nature. Exhaust fumes from approximately 2,000,000 automobiles, busses, and trucks in the county, which drive an average of 50,000,000 miles per day, contribute another 350 tons of organic substances as well as 30 tons of aldehydes and 40 tons of nitrogen oxides. Detailed data are presented showing the sources of the various impurities and the quantity each source emits.

...Angeles smog characteristically causes irritation to the ...es and respiratory system and is accompanied by odor ...ght haze that restricts visibility. Under certain weather ...ns, air pollutants resulting from human activity in the ...eles basin are discharged into the air faster than natural ...logical forces can carry them away. When the build-up ...ently g... smog results.

...ustion operations were studied as sources of atmospheric ...es, because they are certainly not insignificant in quan... Los Angeles; in other cities the products of combustion are ...incipal contributors to air pollution. Furthermore, ...ive analysis of the combustion products from typical in...es showed that they were similar to the impurities found ...atmosphere. Combustion products are not only those ma...ormally thought of as products of complete combustion, ...any cases are incompletely burned products, such as un... hydrocarbons that escape from automobile exhaust pipes. ...y types of combustion operations were studied, domestic ...as industrial. This paper summarizes the results of this ...nd shows, perhaps for the first time, that certain com... operations that previously had not been considered im... contribute in a major way to air pollution. This paper ... findings concerning the nature and origin of combustion ...ts that enter the Los Angeles atmosphere. The collec... analytical techniques employed are not a part of the ...discussion.

BROAD ASPECTS

...eral, an atmosphere is considered polluted if it contains ... material—gaseous, liquid, or solid—in quantities sufficient ... nuisance. During periods of smog, the Los Angeles at...re contains each of these types of impurities. It is the ...ate matter—such as the small liquid and solid particles—...ricts the visibility; the gaseous components appear to be ...esponsible for eye irritation (1).

...ntitati... study of the impurities that exist in the atmos...d a ...tative study of materials produced in combus...rations revealed that the products of incomplete com... comprise only a part of the man-made impurities found ...ir. Even combustion that is usually considered to be ...e is a source of products that are identifiable in smog. ...vey of the material burned in the Los Angeles area revealed that the products of combustion of approximately 50,000 tons per day of various materials are put into the atmosphere (Table I).

Unlike many other industrial areas, practically no coal is burned in Los Angeles. Consumption of coke, Diesel oil, and agricultural petroleum is less than 250 tons per day each, and was not considered large enough to warrant detailed investigation. During frost periods, relatively large quantities of petroleum are used to heat orchards, thus releasing considerable quantities of smoke. However, these conditions, although frequently resulting in nuisances to the surrounding area, are not occasions of typical smog.

TABLE I. ESTIMATED TOTAL DAILY TONNAGES OF MATERIALS BURNED IN LOS ANGELES

Fuel gas	20,400
Fuel oil	7,300
Gasoline	10,500
Refuse	9,165

COMBUSTION SOURCES

The data that follow are believed to be approximately representative of the over-all combustion emissions to the atmosphere. Care was taken to select as nearly representative installations as possible and to cover as wide a range of operating conditions as necessary to yield indicative average values. It is recognized that the data are not true average values for any single short-time interval. It is conceivable that such data could be obtained by means of a statistical sampling, and by taking into account all the variables contributed by the changing habits of approximately 4,000,000 people. However, accuracy of this degree was beyond the scope of the present survey.

FUEL GAS AND FUEL OIL. Determinations of the effluents from fuel gas and fuel oil were made on typical large industrial heating units, such as power plants and oil refinery heating operations. The effluents from domestic and small commercial hot water space heating units were also determined. Typical data obtained in such tests are presented in Table II.

Approximately one third of the fuel gases consumed in the area are burned in domestic and small commercial heaters. There was little difference in the nature of products of com-

TABLE II. ANALYSIS OF FUEL GAS AND FUEL OIL COMBUSTION EFFLUENT

	Concentrations, Mg./Cu. Meter		Emission to Los Angeles Atmosphere			
			Lb./Ton		Ton/Day	
	Gas	Oil	Gas	Oil	Gas[a]	Oil[b]
Aldehydes	60	75	2	2.4	20	9
Ammonia	0.4	0.4	...	...	...	...
Nitrogen oxides	410	800	14	26	140	100
Acids (as HOAc)	75	900	2.5	30	26	100
Organics	90	300	3	10	30	35
Solids	...	16	...	0.5	...	...
Sulfur oxides	10	2000	0.3	60	3[c]	220

[a] Based on consumption rate of 20,400 tons per day of fuel gas estimated from Southern California Gas Co. report for 1949 and information from petroleum refiners in Los Angeles area.
[b] Based on consumption rate of 7300 tons per day of fuel oil estimated from 1949 U. S. Bureau of Mines report.
[c] Information from petroleum refiners indicates an additional 80 tons per day of sulfur oxides (as SO_2) emitted from combustion of their produced gas.

bustion from large scale industrial units and from small household gas-fired, hot water heaters. The quantities of impurities produced per unit quantity of gas burned were also comparable.

AUTOMOBILE EXHAUSTS. It is not unusual to sense foul odors emanating from large busses, trucks, and Diesels, or to see clouds of fume pouring forth from the exhaust pipe of an ill-conditioned jalopy. It is common knowledge that the exhaust fumes from all automotive vehicles contain toxic quantities of carbon monoxide as well as large quantities of carbon dioxide and water vapor.

It has been suspected for some time that the automobile produces exhaust fumes containing other substances which, in the aggregate, contribute in a significant manner to the air pollution in a city.

The composition of automobile engine exhaust gases was examined in tests on a blocked engine under simulated driving conditions of constant speed, acceleration, and deceleration. Tests were also conducted on actual operating vehicles. Figure 1 illustrates the manner in which the tests were made.

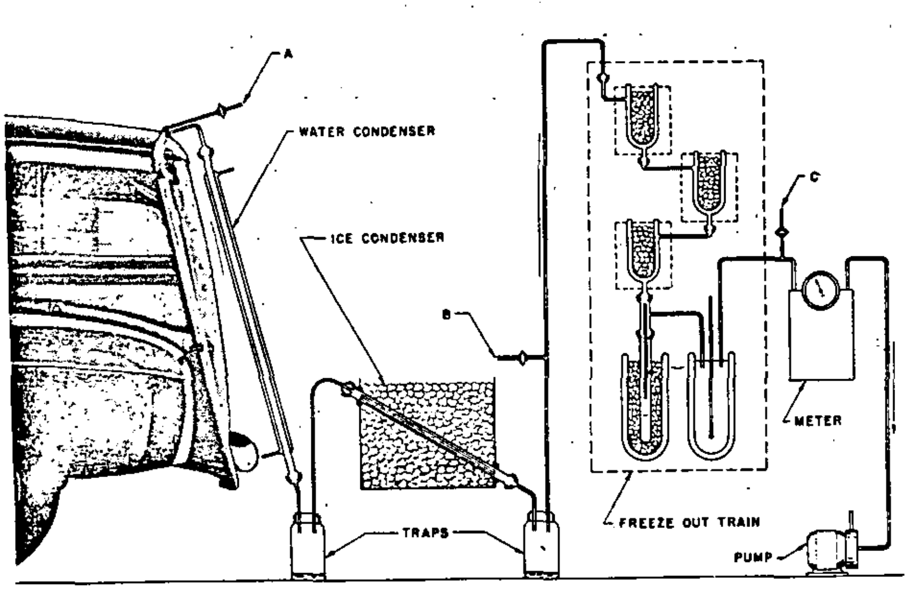

Figure 1. Sampling Procedure for Automobile Exhaust Gases

Sampling equipment consisted of a condensing system to remove most of the water and a freeze-out train composed of vessels cooled successively with ice and dry ice. A measured stream of exhaust gas was drawn through this system. Samples of gas for analysis were taken at points *A*, *B*, and *C* in the diagram.

The condensates and materials frozen out were analyzed for aldehydes, acids, nitrogen oxides in solid carbonaceous materials, and volatile organic matter. The results are shown in Table III.

The results of these tests showed that the predominant emission is volatile organic material, representing almost [illegible] of gasoline consumed. The method of collecting and analyzing the material resulted in a measure of only the material boiling above the C_4 hydrocarbon types (approximately 40° C.).

Measurements have been continued on the effluent hydrocarbons from automobile exhausts, employing a more rigorous statistical approach to the problem and using mass spectrometer gas analyses for a more detailed measurement and identification of the various constituents. These results will be published at a later date. Although they are not yet complete, they show that automobile operations in the Los Angeles area [illegible] hydrocarbons than were indicated by the technique mentioned above.

The data further show that the emissions of organic material as well as of oxides of nitrogen vary considerably with engine operating conditions. Under conditions of idling, acceleration, or deceleration, the combustion is much less efficient (and the organic emission relatively much greater) than at constant speed power operation. The emission of the oxides of nitrogen is greatest under power conditions, probably because of the higher combustion temperatures in the cylinders. The nitrogen oxides must be produced by the fixation of atmospheric nitrogen during the combustion, as purified hydrocarbons free from organic nitrogen compounds produce similar quantities of nitrogen oxides when used in place of gasoline.

REFUSE. In the Los Angeles area, combustible refuse is disposed of by burying, burning in small incinerators at [illegible] dwelling places, burning in industrial silo-type incinerators and burning in a few engineered municipal incinerators. Data obtained in a survey of the amount of materials burned by the various methods are shown in Table IV.

DOMESTIC INCINERATORS. There are approximately [illegible] domestic incinerators in the Los Angeles area. Most of these incinerators are of a standard type with a volume of approximately 6 cubic feet. Most householders have an incinerator in the back yard for disposing of waste paper and garden and grass trimmings. The operation of the incinerator is subject to widely varying combustion conditions. More frequently than not, the incinerator is crammed full of whatever mixture of materials is at hand. The composition is usually such that the materials [illegible] smolder and eventually disappear [illegible] of the stack.

From observation of the incinerators in the area and a general knowledge of the quantities of materials disposed of by this means, it was learned that approximately half of the average charge consisted of paper and half of garden trimmings. The composition of the effluent gases depends upon many factors, such as weight, composition, and moisture content of the charge, and the draft conditions for the fire.

Tests were conducted under a variety of conditions using equipment shown in Figure 2.

In a typical test 9 pounds of paper or 6 pounds of green garden clippings were burned and samplings made of the effluent gas. The volume of air was measured with a rotating vane anemometer in the draft door. The average data obtained in several test run are shown in Table V.

On a weight basis, organics were found to be the largest class of materials in the effluent. The organic materials [illegible]

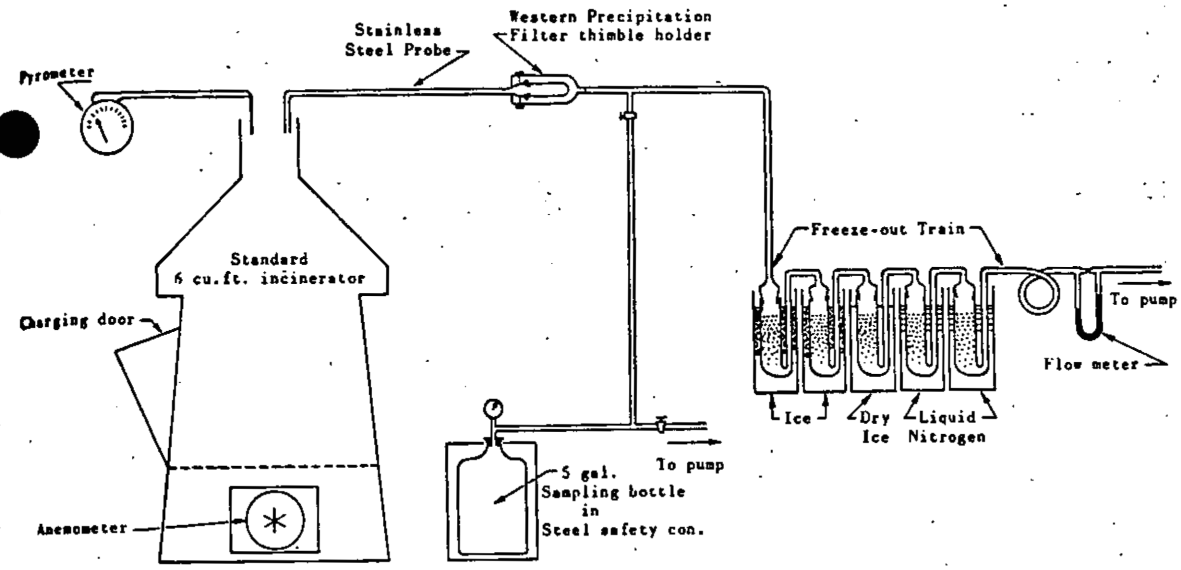

Figure 2. Diagram of Equipment Used to Test Effluents from Backyard Incinerators

particulate material, including tars and carbonized prod- . Aldehydes and acids were present in considerable quan- in the materials emitted by the paper fires. Effluents the garden clippings contained appreciable quantities of and possibly amines.

Attempts were made to differentiate between tarlike particu- matter and solid materials. It was not possible to make a separation between the tar and the solid carbonaceous and particles. However, microscopic observations made it that the solid materials comprised a relatively small n of the total particulate matter.

INDUSTRIAL WOOD WASTE INCINERATORS. A typical silo- industrial wood waste incinerator is shown in Figure 3. The obtained in tests on emissions from such an incinerator are in Table VI.

MUNICIPAL INCINERATOR. A municipal incinerator, rated at tons per 24 hours, was also sampled to obtain data on the third major source of combustion products from refuse. The data obtained in the tests are shown in Table VII.

Solid emissions are indicated to be high, but this may have been due to the manual agitation of the fire bed during the period of the tests, as the mechanical agitator was out of order.

For purposes of comparison, the quantities of the various components found in the effluent from a ton of refuse burned in each of the three principal processes are presented in Table VIII.

TABLE III. ANALYSIS OF AUTOMOBILE EXHAUST

	Operating Conditions: Road Speed	Accel.-Decel.	Idling Speed	Emissions of Chemicals to L.A. Atmosphere[a]: Lb./ton gasoline burned	Tons/day[b]
	Concentration, mg./cu. meter				
(CHO)	200	250	100	6	30
(NH_3)	50	5	15	0.7	4
oxides (NO_2)	750	1	25	8	40
HOAc)	18	25	18	0.6	3
	100	5000	2000	70	350
carbon)	3	6	6	0.1	0.5
oxides					30[c]

[a] Calculated on basis of 40% fuel used under road speed conditions, 40% acceleration-deceleration, and 20% at idling speed.
[b] Based on consumption of 10,500 tons per day of automotive gasoline.
[c] Calculated on basis of sulfur in gasoline currently marketed.

TABLE IV. ESTIMATED DAILY TONNAGES OF REFUSE BURNED IN LOS ANGELES AREA

Domestic incinerators[a]	
Garden trimmings	2000
Paper[b]	2000
Industrial wood waste[c]	5000
Municipal incinerators[d]	165
	9165

[a] d on typical weighings for 1947–48 for City of Long Beach, Calif.
[b] burned based on data from paper importers, salvage operators, Government bureau figures on national paper movements.
[c] Based on Los Angeles County Air Pollution Control District survey of handling industries, 1948.
[d] Based on weighings and estimates at four municipal incinerators.

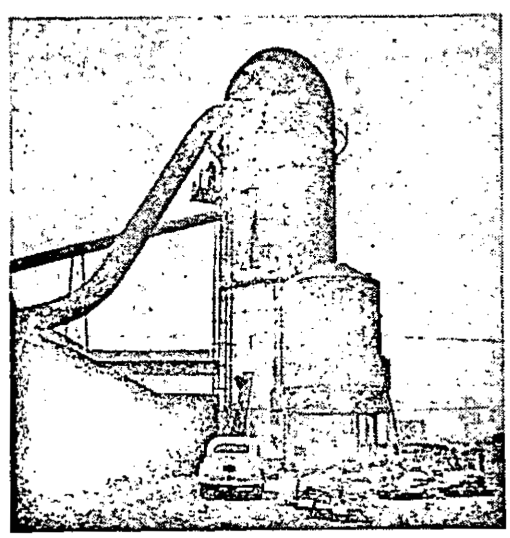

Figure 3. Typical Silo-Type Industrial Wood Incinerator

Field chemist at work on sampling platform

The greater emission of organic material and the lesser emission of nitrogen oxides from the domestic incinerator are clearly evident.

DROPLETS FROM COMBUSTION SOURCES. Combustion operations also release to the atmosphere large numbers of liquid droplets. It has not been possible to measure the mass of the material emitted in this form, but their possible importance is suggested by the close resemblance of many of the droplets that are found in the atmosphere to those that are produced by combustion operations (2). Figure 4 shows a photograph of droplets collected from the Los Angeles atmosphere on a glass slide by an

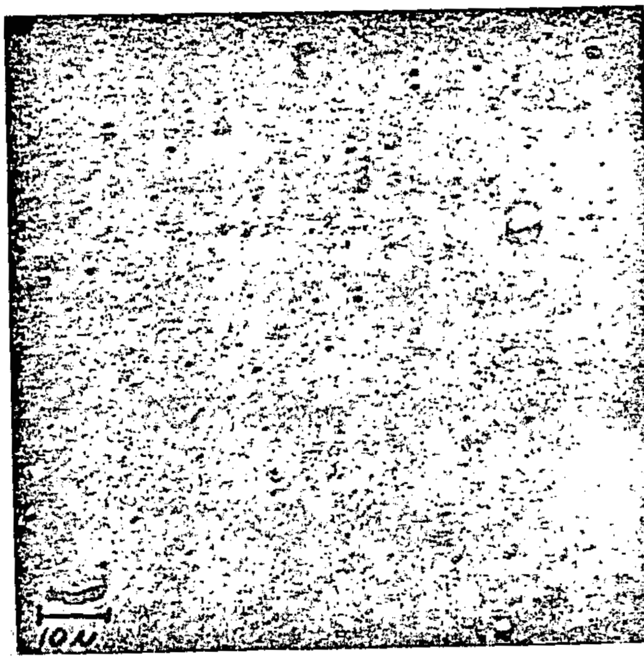

Figure 4. Droplets Collected on Glass Slide by Alternating Potential Electrostatic Precipitator

March 9, 1951. 550×, oblique illumination

alternating current electrostatic precipitator. Figure 5 shows liquid material collected from the atmosphere on a glass slide by a jet impactor. Shown in Figure 6 are globules of liquid material collected from a stack gas produced by an oil-fired boiler at an industrial power plant. These droplets are hydrophilic, are much less volatile than water, and produce a charred residue on mild heating. Droplets such as these are produced by all the combustion operations studied. They are present in the effluent of pure methane burning with a clear blue flame. The skin, shown clearly in Figure 6, is characteristic of all the droplets observed.

Droplets that appear to be largely aqueous and immiscible with kerosene or chloroform are present in the atmosphere on all days, but in much greater quantities during periods of smog. Some

TABLE V. DOMESTIC INCINERATOR EFFLUENT

	Concentrations[a], Mg./Cu. Meter		Emission to Los Angeles Atmosphere: Lb./Ton		Emission to Los Angeles Atmosphere: Tons/Day[b]		
	Paper	Trimmings	Paper	Trimmings	Paper	Trimmings	Total
Aldehydes	60	125	2.1	5.7	2	6	8
Ammonia	3	100	0.1	4.4	0.1	4	4
Nitrogen oxides	13	13	0.5	0.6	0.5	0.6	1
Acids	44	....	1.5	....	1	...	1.5
Organics	4000	9000	145	415	150	400	550
Solids	130	...	4.7	...	5	...	5[c]
Sulfur oxides	90	0	1.2	0	3.5	....	4

[a] Estimated average concentrations for duration of fire.
[b] Based on consumption of 4000 tons per day of refuse by domestic incinerators.
[c] Indefinite, because it is difficult to measure emission accurately from combustion of trimmings.

TABLE VI. WOOD WASTE INCINERATOR EFFLUENT

	Concentration, Mg./Cu. Meter	Emission of Chemicals to Los Angeles Atmosphere: Lb./ton of wood burned	Emission of Chemicals to Los Angeles Atmosphere: Tons/day[a]
Aldehydes	44	1.8	5
Ammonia	0.8	0	0
Nitrogen oxides	33	1.3	3
Acids (HOAc)	11	0.4	1.5
Organics	500	20	50
Sulfur oxides	3	0.15	0.4

[a] Based on combustion of 5000 tons per day of wood waste.

TABLE VII. MUNICIPAL INCINERATOR EFFLUENT

	Concentration, Mg./Cu. Meter	Emission of Chemicals to Los Angeles Atmosphere: Lb./ton of waste	Emission of Chemicals to Los Angeles Atmosphere: Tons/day[a]
Aldehydes	60	1.1	0.1
Ammonia	20	0.3	0
Nitrogen oxides	120	2.1	0.2
Acids (HOAc)	35	0.6	0.05
Organics	80	1.4	0.1
Solids	1300	23	2
Sulfur oxides	95	1.9	0.2

[a] Based on combustion of 165 tons per day of material in municipal incinerators.

TABLE VIII. EMISSION PER TON OF REFUSE BURNED IN DIFFERENT MANNERS

	Domestic: Paper	Domestic: Trimmings	Municipal	Industrial Wood Waste
Aldehydes	2.1	5.7	1.1	1.8
Ammonia	0.1	4.4	0.3	0
Nitrogen oxides	0.5	0.6	2.1	1.3
Acids	1.5	...	0.6	0.4
Organics	145	415	1.4	20
Solids	4.7	...	23	...
Sulfur oxides	1.2	0	1.9	0.15

oil-miscible droplets also exist in the Los Angeles atmosphere, but those that are oil-immiscible appear to be present in far greater numbers. They exist in the atmosphere at relative humidities as low as 20%. The impurities present in them range from complex organic substances to simple inorganic materials such as ammonium sulfate. These impurities probably account in part for the incomplete evaporation of the droplets in dry air.

SUMMARY OF FINDINGS

The various contributions to air pollution of the several types of materials widely burned in Los Angeles are tabulated in Table IX. A division has been made between industrial and general, or public, sources.

The division between industrial and public sources is necessarily an arbitrary one. In general, fuel gas and fuel oil combustion products from large industrial users, power plants, and

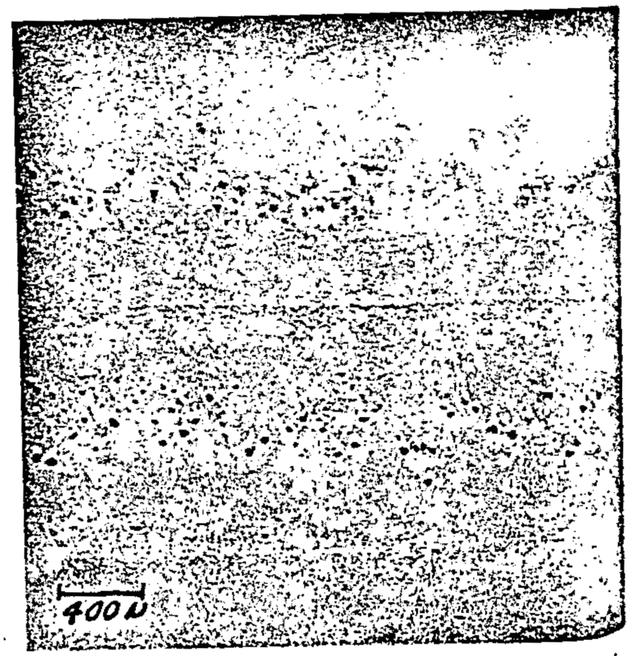

Figure 5. Liquid Aerosol Collected from Los Angeles Atmosphere

Showing particularly distinct liquid globules
20×, oblique illumination

IX. Tons of Pollutants Evolved Daily to Los Angeles Atmosphere by Combustion Processes

	Aldehydes	Ammonia	Nitrogen Oxides	Sulfur Oxides	Acids	Organics	Solids
…rial							
…al gas	13.5	4	93	84	17	20	0.5
…al oil	6.5	...	73	160	73	25	...
…se	5	0.2	3	0.5	1	50	...
…tal	25	4.2	169	244.5	91	95	0.5
…							
…al gas	6.5	...	47	...	9	10	...
…al oil	2.5	...	27	60	27	10	0.5
…oline	30	4	40	30	3	350	0.5
…use	8	4	1	2	2	550	...
Total	47	8	115	92	41	920	1

…ries are classed as industrial emissions. Refuse burned in …trial and large commercial incinerators is also classed as …trial. All gasoline consumption, whether by private indi…als in pleasure cars or commercial vehicles such as delivery …s and taxi cabs, is classed as public. Refuse burned in …hold incinerators is considered a responsibility of the public. …ed on the findings of this study, the total amount of pollu…s put into the Los Angeles atmosphere by combustion sources …ges 1850 tons per day. Approximately 70% of this total …anic in nature, 15% consists of the oxides of nitrogen, and … consists of sulfur dioxide.

IMPORTANCE OF COMBUSTION PRODUCTS

…urvey of impurities introduced into the atmosphere is of … practical value without knowledge of the effects of the …ous substances. To assess their relative importance as com…ents of smog it is necessary to understand the manner in …ch they act and the type of nuisance value of the various …rials. There is considerable disagreement among indi…uals as to what is most bothersome. Although progress has … made toward correlating combustion products with smog … much more remains to be learned.

…liquid droplets produced by all combustion processes, the … of sulfuric acid, and the carbon and tar particles in com…ion effluents are important factors in restriction of visibility. … eye irritation in the city is produced at least partially by the …ous products of combustion (*1*). It would be unwise to say … all the gaseous impurities in smog have been discovered, but …an combinations of those that have been identified are known … cause eye irritation at the concentrations at which they are …ent.

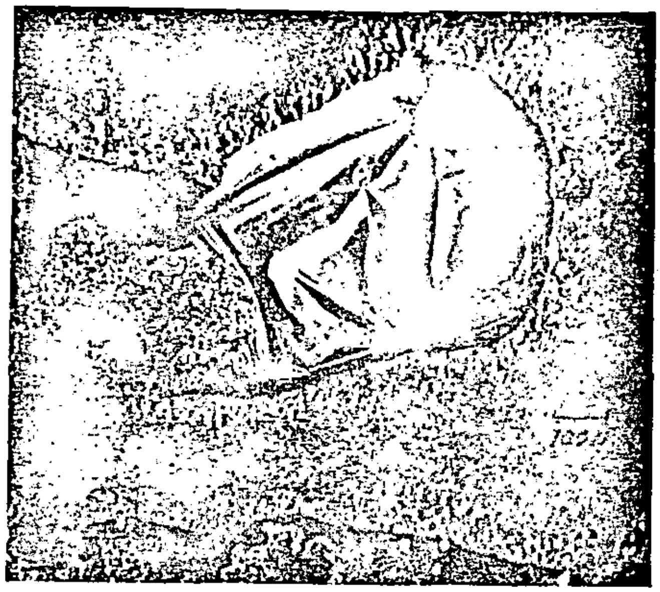

Figure 6. Liquid Material Collected with Jet Impactor from Stock Gas from Oil-Fired Boiler

Oblique illumination

Further studies are needed to show the origin of what appears to be unaccountably large amounts of ozone (or at least some material similar to ozone in that it produces severe cracking of rubber) in the Los Angeles atmosphere. The mechanism by which the aldehydes are formed in the atmosphere, and the sources and significance of the organic products that are principally responsible for their existence also need further attention.

ACKNOWLEDGMENT

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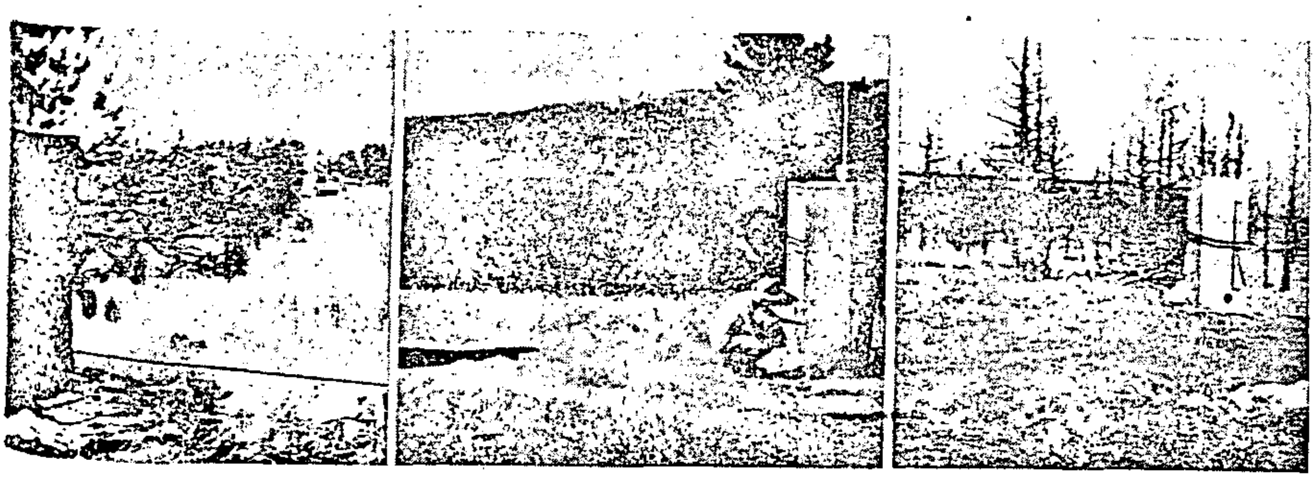

Air Sampling Stations in Ponderosa Pine Blight Area of Spokane County, Wash. (See page 1356)