WASTE OIL COMBUSTION:
AN ENVIRONMENTAL CASE STUDY

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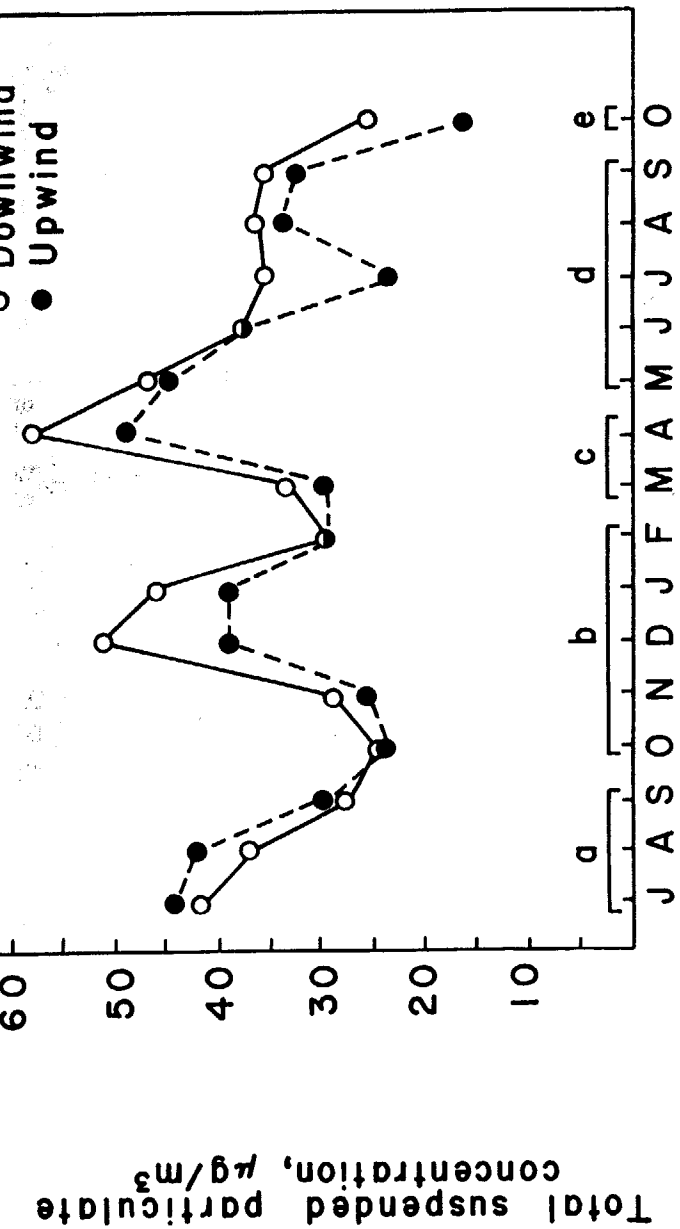

Figure 3. Ambient ground-dispersion total suspended particulate concentrations at downwind and sites. Key: (a) and (d) no waste oil (W.O.); (b) W.O. at 40 G.P.H.; at 80 G.P.H. W.O.

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During 1979, thorough study and consultation by Skidmore College engineers and other personnel revealed that there was excellent reason to believe that undiluted waste crankcase oil could be burned in the College's boiler system, if proper modifications were made.

Skidmore College, located in Saratoga Springs, New York, has a central boiler plant that provides heat and domestic hot water to approximately 800,000 square feet of floor space on campus. The central plant has four 20 x 10^6 BTU/hr. input, 500 Horse Power Cleaver-Brooks fire tube boilers, feeding a closed loop, underground high temperature hot water (HTHW) distribution system. The boilers are supplied with fuel from three 25,000 gallon tanks which, until the introduction of waste crankcase oil (W.C.O.) contained #6 residual oil exclusively. A HTHW loop in each of the three fuel tanks maintain fuel temperature and viscosity. Three of the College's four boilers have been adapted to burn W.C.O. by the installation of a parallel fuel system. The original #6 residual oil supply system to those three boilers remains undisturbed. Two of the existing tanks are used to supply W.C.O. and a third remains exclusively for #6 residual oil.

The fuel supply apparatus for the waste oil system was designed using components that are readily available on the market. The system was designed to accomplish settling and filtration operations analogous to those used by many waste oil reprocessors. Subsequent to settling and water removal, the oil is circulated through a continuous loop, including passage through a succession of basket type filters of decreasing mesh size. The W.C.O. is heated, during this phase, to approximately 100°F, to facilitate particulate settling and lower oil viscosity. The basket type filters also include magnetic inserts to accomplish removal of ferrous particulates, which could harm pumps and clog burner nozzles. The intact system effectively reduces particulates entering the burner, as well as avoiding plating of heat transfer surfaces and reduction of pipe or nozzle orifice size. Previous studies[1,2] have produced data on various attempts to utilize waste oils for fuel uses, but none have included details on any system design capable of on-site oil conditioning such as that described above.

In September 1979, an application was submitted by Skidmore College to the New York State Department of Environmental Conservation (NYSDEC) for permission to modify and operate the pre-existing boiler operation using undiluted waste crankcase oil as a primary fuel source.

Experimental

A preliminary investigation was prepared for Skidmore by Capital Materials Testing (C.M.T.) of Latham, New York. A fuel flow of 150 g.p.h. (maximum theoretical flow rate for each boiler) was assumed throughout, as well as a stack height of 5 feet above building level. (Before stack testing, the Skidmore stacks were raised to a height of 24 feet above building level.) U.S. Environmental Protection Agency information[1] was used and was correlated with Albany, New York Airport wind and weather data, as well as laboratory analysis of W.C.O. samples.

The ground level lead concentrations were computed by use of the "Gaussian diffusion model" for elevated point source emission.[3] The maximum ground level lead concentrations were correlated to multi-sector "wind rose" analysis using weather bureau data for Albany Airport. Based on Capital Materials Testing's initial evaluation that the ground level

lead concentration would not exceed 0.3 $\mu g/m^3$ as a 90 day average, the testing group was instructed by NYSDEC to proceed with mathematical modeling to include downwash effects. Calculations, completed by C.M.T. and NYSDEC Meteorology Section, utilizing a Climatological Dispersion Model, revealed that ground level lead concentrations of 3-14 $\mu g/m^3$. Stack heights were raised and fuel flow rate was lowered, in order to meet the National Ambient Air Quality standard of 1.5 $\mu g/m^3$ quarterly. On-site stack tests and field ambient analyses were required by NYSDEC.

Under the supervision of the NYSDEC Region V, Office of Environmental Quality, stack emission tests were conducted on January 16, 1980 and on June 3, 1980 on Skidmore College's boilers to determine lead and particulate emissions, while utilizing waste crankcase oil as fuel under different fuel firing rates.

During each stack test, three trials were run (all on a single boiler) at a firing rate of about 40 gallons per hour (g.p.h.), a relatively low efficiency firing rate, and three trials were run at 80 gallons per hour, an efficient rate for the boiler utilized.

The standard E.P.A. methods and procedures[4] were used with slight modification for lead sampling. The modification was that 0.05N nitric acid was used as scrubbing solution in the first three impingers to remove metals from the gas stream and minimize absorption of metals on the impinger walls. The sampled filters, wet catches, washes from probes and impingers were analyzed for lead and other metals using atomic absorption techniques. Flue gas analyses for CO_2, CO, N_2 and O_2 were performed using an Orsat Analyzer. The Teledyne oxygen analyzer was also used to monitor oxygen concentration continuously for cross-reference. The stack temperature was continuously monitored at each point with an Omega digital thermometer. Four oil samples were collected during each run, at a port located just before the burner. Each set of four oil samples were combined into one composite sample and analyzed for lead content.

In order to establish actual long-term field ambient concentrations of lead and total suspended particulates, NYSDEC located two Hi-volume air samplers on the Skidmore campus. The upwind (control) unit is located approximately 100 meters from the emission source and the downwind (test) unit is situated approximately 300 meters from the emission source. Both units were located using local "wind rose" vectors as guides, and have operated from January 1980 to the present on an every sixth-day schedule. Analysis of the filters is done by the laboratory of the New York State Department of Health.

Results

A summary of determined stack test boiler standard measurements for lead and particulate emission levels for both the January and June 1980 tests is seen in Table I. The boiler performance characteristics were all well within the ranges found in previous studies.[1,2] When fuel flow rates were doubled, lead input increased commensurately by 96.7%. However, for the combined January-June two-test average, the increase in total weight of lead sampled on test filters was only 3.2% and although lead emission rates increased, as expected, by 125.0%, the percentage of lead output divided by input increased by only 13.1%. These apparent incongruencies are explainable when the data are viewed from the perspective of utilizing the boiler at near maximum efficiency mode, at 80 g.p.h., versus the lower efficiency setting of 40 g.p.h.. Similar results have been seen in previous studies.[5,6] Particulates appeared to act similarly in the Skidmore tests, with total particulate emission rates increasing by 65.3% as the fuel flow rate was doubled from 40 to 80 g.p.h., but with average particulate concentrations sampled on filters actually dropping by 16.3%.

Analysis of test filters and experimental levels of other metals are seen in Table II. Results show all metal concentrations to be well within, and sometimes below, levels reported during stack emission testing at other sites.[2] Again, results show mixed, but generally downward trending concentrations of metals on tested filters, as fuel firing rate increases raised boiler efficiencies.

It should be noted that the actual emissions of Cr, Mg, Fe (as indicated in the filter analysis data) were higher than the levels reported in the laboratory analysis of the fuel for those elements. The discrepancy was attributed to the fact that only the soluble organic portions of the metals were analyzed by atomic absorption for the raw liquid waste oil samples. Consequently, an appreciable amount of the insoluble metal component was not accounted for in the reported waste oil levels.

Waste oil physical characteristics and metal concentration levels established by laboratory analysis of Skidmore waste automotive oils are compared in Table III, to respective levels established in E.P.A. studies.[1] The concentration levels measured during the Skidmore tests were uniformly within, but generally on the low end of, the ranges established during the reported studies to which they were compared. Certain elements, including barium, phosphorous, chromium, nickel, cadmium and silver showed concentration levels lower than any reported in comparison studies. The higher than previously reported level of manganese is probably due to the use of a Mn-based combustion-enhancing additive during the period in which the tests were conducted.

Test-determined levels of gas emissions during stack testing are reported in Table IV. Percentages of CO_2, O_2, CO and N_2 were all within ranges reported in previous studies.[2] Sulfur levels averaged 0.33% at fuel flow rates of both 40 and 80 g.p.h.. This is consistent with all previous reports,[2] which show the sulfur concentration range to be 0.21 to 0.34% in waste oils. In Skidmore tests, the range was 0.29 to 0.36%. The data indicated that waste oil may be considered for combustion in areas where atmospheric sulfur levels are of particular concern, and where other particulate levels (specifically lead) are lower.

Subsequent to the initial Skidmore stack emission tests, a permit to burn waste crankcase oil in the school's pre-existing boilers, was issued by Region V of NYSDEC. (The initial allowance of 40 g.p.h. has subsequently been increased to 80 g.p.h.) Testing requirements were established at that time that mandated analysis of each tank of waste oil, by an independent testing laboratory, before the oil could be burned. The required tests and maximum allowable concentration levels established were: lead - not to exceed 3,000 parts per million (p.p.m.); P.C.B. - not to exceed 50 p.p.m. and total chloride - not to exceed 1.0%. (This parameter has been decreased to 0.50%.)

Composite drip samples, from each tank of waste oil to be burned, are taken as oil delivery is in progress. Analysis is conducted by Environment

One Laboratories of Latham, New York.

Lead analysis is accomplished via atomic absorption spectroscopy. Figure 1 shows lead concentrations in delivered oil from April 1980 (tank 3) through January 1982 (tank 14). Ongoing analysis of oil is also accomplished by taking samples of oil periodically during the "life" of each tank. This allows comparison of waste oil as delivered and after on-site settling and filtration operations have occurred. The samples are drawn from a fuel line port, located just prior to the point where the oil enters for ignition in the burner. Figure 1 shows several phenomena worth noting. The lead concentrations in Skidmore unprocessed waste crankcase oil, in less than 2 years, has dropped from the 2,500-2,800 p.p.m. range to the 800-1,000 p.p.m. range. Published reports[7,9,10] have predicted lead concentrations in waste crankcase oils to drop to the 800-1,000 p.p.m. level by 1985. The oils tested at Skidmore College indicate that these levels may already have been reached. Of further interest is the fact that average lead levels for newly delivered waste oil were 1,800 p.p.m., whereas lead concentrations in oil, which had undergone settling and filtration within the Skidmore system, averaged 1,470 p.p.m.. The 22.4% difference has been experimentally shown to be divided approximately equally between tank bottom sludge and filter catchings. These findings lead to the supposition that lead, which when in solution tends to exist in relatively stable low-molecular weight configurations, is being bound or physically trapped within the matrices of large, loosely bonded chelated ferrous complexes. Thus, some lead would be removed either by settling or by magnetic filtration or both. Recent oil analyses (tanks 12-14), which indicate higher lead concentration in samples after processing, may be reflecting the effects of lead being drawn from tank bottom sludge, which had built up and which contained slightly elevated lead concentrations.

P.C.B. analysis was accomplished via gas chromatography/electron capture. To date twelve analyses for P.C.B. content, in waste crankcase oil delivered to Skidmore, have averaged 26.50 p.p.m.. In no cases did the amount exceed the standard of 50 p.p.m. that was set by NYSDEC and federal requirements. Fuller, et.al.[8] indicates that most studies show that P.C.B.'s are not normally present in waste crankcase oils. However, contamination is possible and care should be taken to assess P.C.B. levels in any waste oil to be used for combustion.

Total chloride analysis was done using bomb calorimetry (ASTM D808-62), followed by determination of chloride by potentiometric titration. Ten analyses have resulted in an average of 0.33% total chloride per sample.

Ambient ground-level lead concentrations are graphically displayed in Figure 2. The data were accumulated from July 1980 through October 1981. Sixteen monthly analyses reveal a downwind average lead concentration of 0.19 $\mu g/m^3$ and an upwind average of 0.16 $\mu g/m^3$. If these are broken down according to waste crankcase oil fuel firing rates, the following lead concentrations are seen:

Waste Oil Firing Rate (g.p.h.)	Period	Avg. Ground-Level Lead Concentration ($\mu g/m^3$) Upwind	Downwind	Difference ($\mu g/m^3$)
0	July-Sept. '80; May-Sept. '81	0.166	0.305	0.033
40	Oct. '80-Jan. '81*	0.188	0.245	0.057
80	Mar., Apr., & Oct. '81	0.097	0.193	0.097

*February 1981 readings were determined to be questionable, and were not included in calculations.

The 0.024 $\mu g/m^3$ average difference in ground level lead concentrations recorded at the downwind versus upwind site with waste crankcase oil burned at 40 g.p.h. versus no waste oil burned, and the 0.064 $\mu g/m^3$ average difference at 80 g.p.h. versus no waste oil burned are both significant when analyzed via "least-squares" testing. However, at no time was the National Ambient Air Quality Standard of 1.5 $\mu g/m^3$, quarterly, approached. The accumulated data indicate that lead emitted from the carefully monitored and regulated waste oil burning source at Skidmore College contributes less than 0.10 $\mu g/m^3$ quarterly to downwind lead concentrations, even at the maximum allowable firing rate. For other sites, it must be noted that this phenomenon is highly site sensitive, and can be greatly effected by local geographical and meteorological conditions, as well as background lead concentration levels.

Figure 3 shows a graphic representation of ambient ground-level concentrations of total suspended particulates (T.S.P.) at Skidmore College from July 1980 through October 1981. Sixteen monthly analyses reveal a downwind average total suspended particulate concentration of 37.5 $\mu g/m^3$ and an upwind average of 33.8 $\mu g/m^3$. If these are broken down according to waste crankcase oil firing rates, the following ground-level total suspended particulate concentrations are seen:

Waste Oil Firing Rate (g.p.h.)	Period	Avg. Ground-Level Total Suspended Particulate Concentration ($\mu g/m^3$) Upwind	Downwind	Difference ($\mu g/m^3$)
0	July-Sept. '80 May-Sept. '81	36.05	37.51	1.46
40	Oct. '80-Jan. '81	31.62	36.36	4.74
80	Mar.-Apr.; Oct. '81	31.53	39.33	7.80

The 3.28 $\mu g/m^3$ average difference in ground-level total suspended particulate concentrations recorded at the downwind versus upwind site with waste crankcase oil burned at 40 g.p.h. versus no waste oil burned, and the 6.34 $\mu g/m^3$ average difference with waste crankcase oil burned at 80 g.p.h. versus no waste oil burned, are both significant when analyzed via "least-squares" testing. The local allowable T.S.P. levels of 55 $\mu g/m^3$, annually, were never exceeded during this study.

Discussion and Conclusions

Recent reports[2,11,12,13] have placed the amount of waste oils generated per year in the United States at between 2.21 and 2.84 x 10^9 gallons. Using the lower limit of these estimates, the disposition of waste oils is generally as follows: 439 x 10^6 gallons directly to fuel use; 652 x 10^6 gallons to fuel use via reprocessing; 146 x 10^6 gallons directly to uses such as road oiling and dust control; 78 x 10^6 gallons to other uses from reprocessing and 45 x 10^6 gallons from rerefining back to lubricating oils. The remaining, unaccounted for, oils are lost through engine or process use or as environmental losses. The production of waste oils is projected to remain virtually constant through 1990[2].

It is evident from the above statistics that waste oils represent a large source of potentially difficult to manage disposal products. This is made even more clear by the fact that the U.S. rerefining industry is currently capable of processing only 5 to 10% of generated waste oils yearly. Thus 90 to 95% of waste oils generated annually in the U.S. are either burned or wind up in the environment via landfills; road oiling or direct "dumping" into waterways[2].

There has been no comprehensive survey of U.S. facilities currently burning waste oils. However, it is almost certain that much of the waste oils are burned in steam boilers, usually blended with #2 through #6 fuel oils[2]. Some waste oils are also burned in cement kilns, asphalt plants and incinerators[14]. Estimates place the number of steam boilers utilizing waste oils at over 50,000, two-thirds of which operate at 5 x 10^6 B.T.U./hr. or greater[2].

The studies conducted at Skidmore College, together with other reported findings, seem to indicate that it is currently possible to consider combustion of waste oils as a viable disposal option. Of fundamental importance in consideration of any point emission source desiring a permit to burn used oils are location, geography, meteorological conditions and background metal, and particulate levels. It is also of prime importance to establish firm, monitorable criteria for oil constituents and mandate testing programs for each permitted emission source.

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References

1. S. Chansky, et.al., "Waste Automotive Lubricating Oil Reuse as a Fuel," Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C., EPA-600/5-74-032. (September 1974).

2. "Used Oil Burned as a Fuel," U.S. Environmental Protection Agency, SW-892, 1980.

3. B. D. Turner, "Work Book of Atmospheric Dispersion Estimates." Office of Air Programs Publications No. AP-26, U.S. Government Printing Office, Stock Number 5503-0015, 1970.

4. Federal Register, "Standards of Performance for New Stationary Sources." 42FR41755, Volume 42, Number 160, August 18, 1977.

5. L. Manson and S. Unger, "Hazardous Material Incinerator Design Criteria." EPA-600/2-79-198, October 1979.

6. E. E. Berry, et. al., "Experimental Burning of Waste Oil as a Fuel in Cement Manufacture." Technology Development Report, EPA-4-WP-75-1, Environment Canada, June 1975.

7. U.S. EPA, "Control Techniques for Lead Air Emissions." Volume 1, Chapter 1-3, EPA-450/2-77-012, December 1977.

8. B. Fuller, et. al., "Environmental Assessment of PCB's in the Atmosphere." EPA-450/3-77-045, November 1977.

9. R. J. Bidga, et. al., "Review of All Lubricants Used in the U.S. and Their Re-refining Potential." DOE/BC/30227-1, June 1980.

10. E. V. Anderson, "Phasing Lead Out of Gasoline." Chemical and Engineering News, pps. 12-16, February 1978.

11. G. J. Mascetti and H. M. White, "Utilization of Used Oil." Aerospace Report No. ATR-78 (7834)-1, DOE, August 1978.

12. N. J. Weinstein, "N. J. Waste Oil Recycling and Disposal." EPA-670-2-74-052, August 1974.

13. S. P. Maltezou, "Waste Oil Recycling: The New York Metropolitan Area Case." Council on the Environment of New York City, March 1978.

14. S. Chansky, et. al., "Waste Automotive Lubricating Oil as a Municipal Incinerator Fuel." EPA-R2-73-293, September 1973.

Table I. Experimentally determined Stack Test standards and lead and particulate emission levels during waste automotive oil combustion.

Standards	Unit	Jan. 80 Test Avg. Values[a]		June 80 Test Avg. Values[a]	
Fuel Flow Rate	g.p.h.	39.20	78.00	40.00	80.00
Wet Stack Gas Mol. Wt.	lb/lb-mole	28.37	28.62	28.73	28.61
Stack Temperature	^{o}F	294.00	296.00	286.00	317.00
Stack Velocity	SFPS	9.64	18.27	11.28	17.39
Absolute Stack Pressure	In. Hgt.	30.00	29.97	29.47	29.72
Total Sample Vol.	SCF	62.56	61.90	58.41	38.00
% Moisture	%	10.02	10.90	10.50	11.45
Stack Flow Rate	SCFM	1817.00	3442.00	2125.00	3277.00
Lead and Particulates					
Fuel Flow Rate	g.p.h.	39.20	78.00	40.00	80.00
Pb in Waste Oil	p.p.m.	660.00	710.00	1000.00	1060.00
Pb Input[b]	lb/hr.	0.25	0.47	0.35	.71
Total Pb Sampled	mg	35.13	41.73	31.60	27.17
Pb Emission Rate	lb/hr.	0.13	0.32	0.15	0.31
Pb (Output/Input)	%	54.59	67.53	43.83	43.83
Particulate Sampled on Filter	mg	377.70	324.70	—	—
Particulate Emission Rate	lb/hr.	1.44	2.38	—	—
Pb In Particulate	%	8.10	11.47	—	—

[a] All values represent average data from 3 experimental trials.

[b] mg/l assumed to approximate p.p.m. and (mg/l) x 3.785 (l/gal.) x (gal./hr.) x (lb/453.59 mg) = lb/hr.

Table II. Experimentally determined levels of metals in waste automotive oil during stack and analytical testing at Skidmore College, January 1980.

Element	Unit	Laboratory Oil Analysis[a]	Field Test Filter Analysis[a]	
Fuel Flow Rate	g.p.h.		39.200	78.000
Pb	mg/l	660.000	33.470	35.930
	lb/hr.[b]	0.254	0.128	0.270
Cr	mg/l	3.470	0.700	0.630
	lb/hr.	0.001	0.330	0.005
Ni	mg/l	< 2.000	0.300	0.650
	lb/hr.	< 0.010	0.001	0.004
Mg	mg/l	10.400	6.410	4.390
	lb/hr.	0.004	0.024	0.033
Fe	mg/l	42.300	9.360	8.190
	lb/hr.	0.016	0.036	0.060
V	mg/l	< 20.000	0.320	2.700
	lb/hr.	< 0.020	0.001	0.020

[a] All values represent average data from 3 experimental trials.

[b] mg/l assumed to approximate p.p.m. and (mg/l) x 3.785 (l/gal.) x (gal./hr.) x (lb/453.59 mg) = lb/hr.

NOTE TO EDITORS

Table III. Physical Characteristics and metal concentrations for waste automotive oils tested at Skidmore College, compared to waste oils tested during Environmental Protection Agency studies.

Description	Unit	Skidmore Composite Values[a]	E.P.A. Composite Values[b]
Gravity	°API @ 60°F	25.000	20.0-27.9
Specific Gravity	@ 60°F	0.904	0.887-0.934
Density	lbs/gal	7.529	7.40-7.78
Viscosity	sus @ 100°F	332.000	87-837
Viscosity	Centistokes @ 100°F	71.600	17.3-180.6
Pour Point	°F	-25.000	(-40)-(-30)
Flash Point	°F	335.000	175-415
Heating Value	BTU/gal	132,812.000	105,555-143,360
Heating Value	BTU/lb	17,640.000	13,571-19,000
Neutralization No.	mg KOH/g	5.140	4.0-14.3
Water	wt. %	7.500	0.1-22.0
Sulfur	wt. %	0.460	0.21-0.65
Ash	wt. %	1.340	0.03-3.78
Silicon	ppm Si	120.000	10-875
Calcium	ppm Ca	1040.000	700-3,000
Sodium	ppm Na	155.000	16-300
Iron	ppb Fe	42.3-226.000	50-2,000
Magnesium	ppm Mg	10.4-300.000	10-1,108
Lead	ppm Pb	600-2000.000	800-5,500
Vanadium	ppm V	6.35-20.000	3-39
Copper	ppm Cu	30.000	5-348
Barium	ppm Ba	1.500	10-2,000
Zinc	ppm Zn	971.000	300-3,000
Phosphorus	ppm P	265.000	500-2,000
Tin	ppm Sn	13.600	5-112
Chromium	ppm Cr	3.47-11.300	8.50
Nickel	ppm Ni	2.0-2.120	3-30
Manganese	ppm Mn	29.100	5-10
Cadmium	ppm Cd	2.200	4
Silver	ppm Ag	0.224	1
Aluminum	ppm Al	10.700	10-800
Titanium	ppm Ti	7.470	5-30

[a] Values from 2 tests completed by Capital Material Testing and N.Y. State Department of Environmental Conservation.

[b] Values taken from E.P.A. - 600/5-74-032 (Sept. 1974)'

Table IV. Experimentally determined levels of gas emissions recorded during evaluation of waste automotive oil combustion.

Description	Unit	Jan. 80 Test[a]		June 80 Test[a]	
Fuel Flow Rate	g.p.h.	39.20	78.00	40.00	80.00
CO_2	%	6.80	10.73	10.87	11.07
O_2	%	10.67	6.27	6.40	5.73
CO	%	0.00	0.20	0.13	0.13
N_2	%	82.37	82.80	82.60	83.20
SO_2 Emission[b]					
Fuel Flow Rate	g.p.h.	39.20	78.00	—	—
S	%	0.33	0.33	—	—
S x CO_2	10^{-4}	2.22	3.58	—	—
F/2.67C		0.42	0.42	—	—
SO_2	10^{-4}	0.93	1.50	—	—
SO_2	p.p.m.	93.00	150.00	—	—

[a] All values represent average data from 3 experimental trials.

[b] Empirical Formula: $SO_2 = \frac{F}{2.67} \frac{S}{C} CO_2$ (on dry basis), where F = 0.9 and C = 80%

Source: J. APCA, Vol. 25, No. 8, pp. 851-855, August 1975.

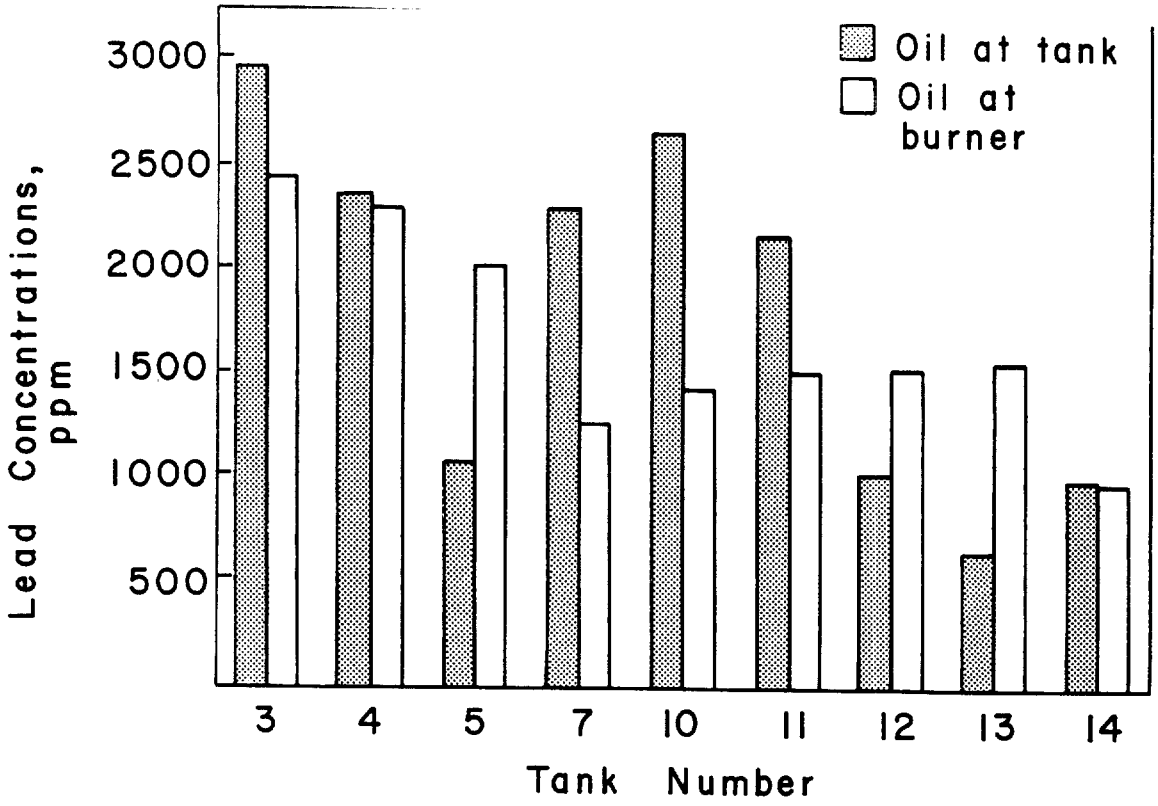

Figure 1. Lead concentrations of tested waste automotive oils as delivered to tank and prior to burner.

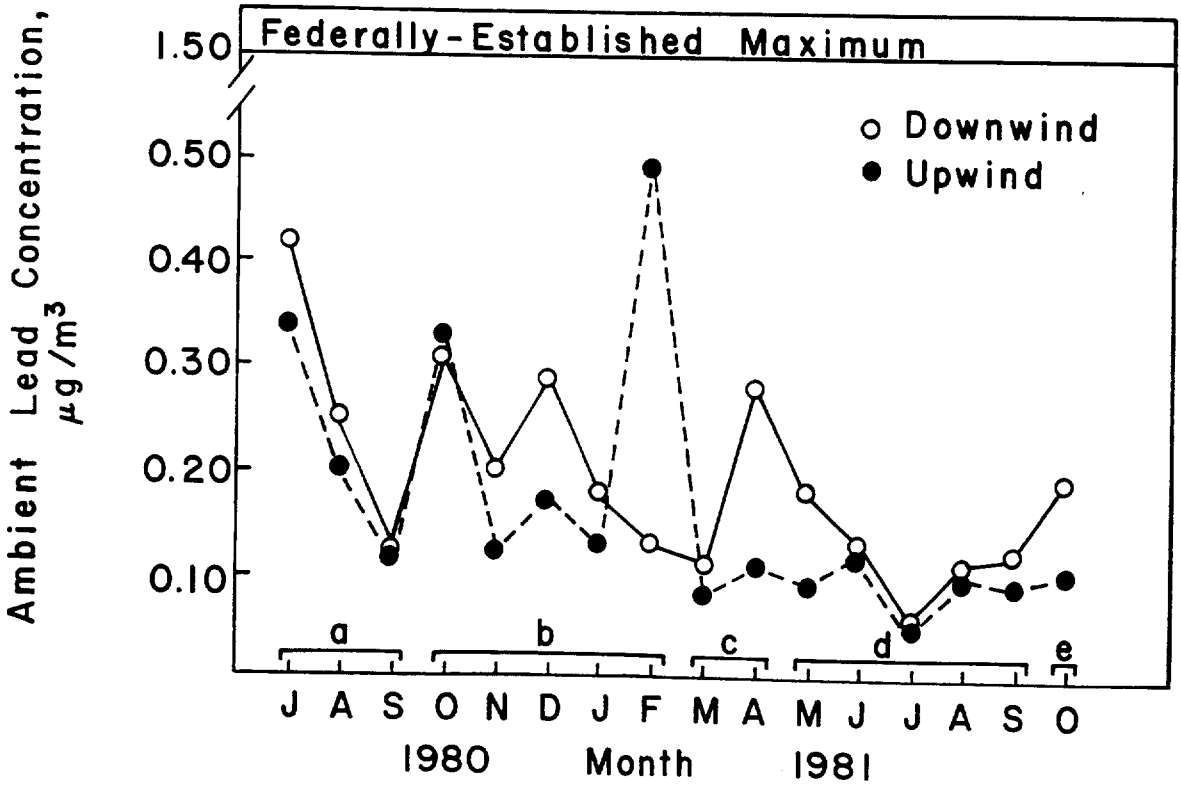

Figure 2. Ambient ground-dispersion lead concentrations at downwind and upward sites.
Key: (a) and (d) no waste oil (W.O.); (b) W.O. at 40 G.P.H.; (c) and (e) W.O. at 80 G.P.H.