

EMISSION FACTOR DOCUMENTATION FOR
AP-42 SECTION 1.11
WASTE OIL COMBUSTION

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1. INTRODUCTION

The document "Compilation of Air Pollutant Emission Factors" (AP-42) has been published by the U.S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. The AP-42 is routinely updated by EPA to respond to new emission factor needs of EPA, State, and local air pollution control programs and industry.

An emission factor relates the quantity (weight) of pollutants emitted to a unit of activity of the source. The uses for the emission factors reported in AP-42 include:

1. Estimates of area-wide emissions;
2. Emission estimates for a specific facility; and
3. Evaluation of emissions relative to ambient air quality.

The purpose of this report is to provide background information from over 12 test reports to support revision of emission factors for waste oil combustion.

Including the introduction (Chapter 1), this report contains five chapters. Chapter 2 gives a description of the use of waste oil for combustion in boilers and space heaters. It includes a characterization of the industry, an overview of the different boiler and space heater types, a description of emissions, and a description of the technology used to control emissions resulting from waste oil combustion. Chapter 3 is a review of emissions data collection and analysis procedures. It describes the literature search, the screening of emission data reports, and the quality rating system for both emission data and emission factors. It also describes particle size determination and particle size data analysis methodology. Chapter 4 details pollutant emission factor development. It includes the review of specific data sets, the results of data analysis, and the data base protocol. Chapter 5 presents the AP-42 Section 1.11.

2. INDUSTRY DESCRIPTION

The purpose of this report is to amass and document information about the combustion of waste oils - information to use in updating Section 1.11 of the latest supplement to AP-42 (1988). Waste oil includes used crankcase oil from automobiles and trucks, used industrial lubricating oils (such as metal working oils), and other used industrial oils (such as heat transfer fluids). In addition to updated emission factors for the criteria pollutants, the new supplement will report, depending on availability of data, emission factors for certain non-criteria pollutants: speciated total organic compounds (TOC), speciated toxic metals, ozone depleting gases, and global warming gases.

2.1 CHARACTERIZATION OF THE INDUSTRY^{1,2}

In 1983, about 8.7 billion liters (2.3 billion gallons) of crankcase oils/industrial lubricating oils/other industrial oils were sold. These are the precursors for the "waste oil" that was defined above. Of the 8.7 billion liters (2.3 billion gallons), about one half, or 4.5 billion liters (1.2 billion gallons), were recovered as waste oil and subsequently reused or disposed of. Of the 4.5 billion liters (1.2 billion gallons), 56 percent was sold to collectors, reclaimers, or fuel oil dealers, with the rest managed by the generators.

Burning was the single largest category of used oil utilization. It accounted for almost 2.2 billion liters (590 million gallons) in 1983.

2.2 PROCESS DESCRIPTION³

Used oil can be burned in a variety of combustion systems including industrial boilers, commercial/institutional boilers, space heaters, asphalt plants, cement and lime kilns, other types of dryers and calciners, and steel production blast furnaces. Boilers and space heaters consume the bulk of the waste oil burned. Space heaters are small combustion units [generally less than 70 kW (250,000 Btu/hr) heat input that are common in automobile service stations and automotive repair shops where supplies of waste crankcase oil are available. Unless otherwise indicated, kw and MW refer to combustor heat input in this report.

Boilers designed to burn No. 6 (residual) fuel oils or one of the distillate fuel oils can be used to burn waste oil, with or without modifications for optimizing combustion. As an

alternative to combustion modification, the properties of the waste oil can be modified by blending with the fuel oil, to the extent required to accomplish a clean burning fuel mixture.

2.3 EMISSIONS

The emissions from waste oil burning reflect the compositional variations of the waste oils. A partial list of the inorganic species found in a representative waste oil are compared with those same species found in distillate and residual oil (see Table 2-1).

2.3.1 Particulate Matter Emissions³

Ash in the waste oil was much higher than ash in the distillate oils and was also higher than the ash in the residual oils. The waste oil had substantially higher concentrations of most of the trace elements reported than those concentrations found in the virgin oils. However, because of the shift to unleaded gasoline, waste crankcase oils contain lower concentrations of lead now than was the case when the representative waste oil was analyzed in 1983.

Without controls, higher concentrations of ash and trace metals in the waste fuel extrapolate to higher emission levels of total particulate matter (PM) and trace metals in the flue gas emissions.

Low efficiency pretreatment steps, such as large particle removal with screens or coarse filters, are common prefeed procedures at oil-fired boilers. Reductions in total PM emissions are expected from these techniques but little or no effect will be noticed on the level of small particles below the size of 10 micrometers (PM-10). Pretreatment steps were usually not well defined in the references containing emissions data for waste oil combustion.

2.3.2 Sulfur Dioxide Emissions³

Average sulfur concentrations of waste oil, distillate oil, and residual oil were reported in Table 2-1 as follows:

- Waste oil: 5,000 micrograms per gram
- Distillate oil: 2,400 micrograms per gram
- Residual oil: 10,000 micrograms per gram

These results suggest that uncontrolled SO₂ emissions will increase when waste oil is substituted for a distillate oil but will decrease when residual oil is replaced. As stated above,

combustors which already burn distillate or residual oils are those most amenable for fuel substitution with waste oils or with waste oil added to the virgin fuel.

2.3.3 Chlorinated Organic Emissions^{2,3}

Constituent chlorine in the waste oils exceeded the concentration of chlorine in the two types of virgin oil. High levels of halogenated solvents are often found in waste oil as a result of inadvertent or deliberate additions of the contaminant solvents with the waste oils. Many efficient combustors can destroy more than 99.99 percent of the chlorinated solvents present in the fuel. However, given the wide array of combustor types that burn waste oils, the presence of these compounds in the emission stream cannot be ruled out. Also, they raise the level of hydrochloric acid (HCl) in the emission stream.

2.3.4 Other Organic Emissions^{2,4,5}

The flue gases from waste oil combustion need to be monitored for organic compounds other than chlorinated solvents. At parts per million by weight (ppmw) levels, some of the 170 organic compounds and organic classifications listed as hazardous under Title III of the Clean Air Act have been found in waste oils. Benzene and toluene were reported at concentrations over 5 percent. Polychlorinated biphenyls (PCBs) and polychlorinated dibenzo dioxins (dioxins) have been detected in waste oil samples. Additionally, these hazardous compounds may be formed in the combustion process as products of incomplete combustion (PICs).

2.4 CONTROL TECHNOLOGIES

Emissions can be controlled by the pretreatment of the waste oil to remove the pollutant precursors or with emission controls to remove the air pollutants.

2.4.1 Pretreatment³

Reduction of emission levels is not the only purpose of pretreatment of the waste oil. Improvement in combustion efficiency and reduction of erosion and corrosion of the combustor internal surfaces are important considerations. The most common pretreatment scheme uses sedimentation followed by filtration. Water and large particles are removed without having much effect on sulfur, nitrogen, or chlorine contents. Other methods of pretreatment involve clay contacting; demetallization by acid, solvent, or chemical contacting; and thermal processing to remove residual water and light ends. These latter processes might be attractive as waste reduction schemes or to recycle the waste oil, but the added costs probably hinder their use as part of a combustion process.

Blending of waste oil with a virgin fuel oil is practiced frequently and has the same effect as some of the other pretreatment processes. However, for the purpose of developing emission factors, blending by itself was assumed to be in the uncontrolled category.

2.4.2 Emission Controls^{3,6}

Waste oil serves as a substitute fuel for combustors designed to burn distillate or residual oils. Therefore, the emission controls are usually those in place when waste oil is first burned.

For small boilers and space heaters, all of the sources having acceptable test data for determining emission factors were uncontrolled.

For an asphalt plant, PM emissions, which included the dust from drying of the aggregate, were controlled with a fabric filter.

TABLE 2-1. TYPICAL CONCENTRATIONS OF SELECTED CONTAMINANTS IN WASTE OIL AND IN DISTILLATE AND RESIDUAL FUEL OILS
(All Concentrations in ug/g)

Contaminant	Waste oil		Distillate oil		Residual oil	
	Average concentration	Concentration range	Average concentration	Concentration range	Average concentration	Concentration range
Ash	6500	1000-12000	25	--	2500	--
Chlorine	2200	1000-6700	100	--	12	3-380
Nitrogen	1000	100-2800	300	100-600	3500	1500-5000
Sulfur	5000	2700-7500	2400	500-6000	10000	2000-28000
Trace elements						
Aluminum	45	2-640	8	0.3-33	3.8	0.3-19
Arsenic	12	1-100	0.8	0.1-0.2	0.8	0.02-2.0
Barium	66	9-160	0.5	0.4-14	1.3	0.3-3.4
Cadmium	1	0.6-2.8	0.3	0.1-0.9	2.3	0.01-0.9
Chromium	6	1-37	1.3	0.5-2.8	1.3	0.1-1.7
Iron	240	58-1300	12	4-79	18	2-2200
Lead	1100 ^a	170-2100	1.8	0.5-4.4	3.5	0.1-8.0
Magnesium	260	5-590	6.3	0.8-6.5	13	0.8-760
Vanadium	3	0.1-13	1.6	0.05-17	160	1-110
Zinc	800	90-1550	3.6	0.6-6.4	1.3	0.6-35

^a Lead levels have decreased since these values were determined in 1982 and 1983.

REFERENCES FOR CHAPTER 2

1. Composition and Management of Used Oil Generated in the United States, PB85-18029, Franklin Associates Ltd. for U.S. Environmental Protection Agency, Washington, DC, November 1985.
2. Waste Oil: Technology, Economics, and Environmental Health and Safety Considerations, Mueller Associates, Inc. for U.S. Department of Energy, Office of Environmental Analysis, January 1987.
3. Emission Factor Documentation for AP-42: Section 1.11. Waste Oil Combustion, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1987.
4. The Fate of Hazardous and Nonhazardous Wastes in Used Oil Disposal and Recycling, DOE/BC/10375-6, U.S. Department of Energy, Bartlesville, OK, October 1983.
5. The Clean Air Act: Title III, Public Law 101-549, November 15, 1990.
6. "Waste Oil Combustion at a Batch Asphalt Plant: Trial Burn Sampling and Analysis", Arthur D. Little, Inc, Cambridge, MA, For Presentation at the 76th Annual Meeting of the Air Pollution Control Association, June 19-24, 1983.

3. GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

The first step of this investigation involved a search of available literature relating to criteria and noncriteria pollutant emissions associated with the combustion of waste oil. This search included the following sources:

- AP-42 background files;
- Files and dockets maintained by the Emission Standards Division of Office of Air Quality, Planning and Standards (OAQPS) for relevant New Source Performance Standards (NSPSs) and National Emission Standards on Hazardous Air Pollutants (NESHAPs);
- "Locating and Estimating" reports available through EPA's Clearinghouse for Inventories and Emission Factors (CHIEF) web site;
- Particulate matter less than ten microns in diameter (PM-10) "gap filling" documents in the OAQPS library;
- Publications available through EPA's Control Technology Center;
- Reports and project summaries from EPA's Office of Research and Development;
- Control Techniques Guideline documents generated by the Emission Standards Division of OAQPS;
- Information in the Air Facility System (AFS) of EPA's Aerometric Information Retrieval System (AIRS);
- Handbook of Emission Factors, Parts I and II, Ministry of Health and Environmental Protection, The Netherlands;
- EPA's CHIEF and National Air Toxics Information Clearinghouse (NATICH);
- EPA databases, including SPECIATE, XATEF, and TSAR;
- Various EPA contractor reports; and
- In-house files maintained by EPA contractors.

To reduce the large amount of literature collected to a final group of reference pertinent to this report, the following general criteria were used:

1. Emissions data must be from a primary reference:
 - a. Source testing must be from a referenced study that does not reiterate information from previous studies.
 - b. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was contained in the previous document. If the exact source of the data could not be determined, the document was eliminated.
2. The referenced study must contain test results based on more than one test run.
3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions (e.g., one-page reports were generally rejected).

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria.

3.2 EMISSION DATA QUALITY RATING SYSTEM¹

As part of the analysis of the emission data, the quantity and quality of the information contained in the final set of reference documents were evaluated. The following data were always excluded from consideration.

1. Test series averages reported in units that cannot be converted to the selected reporting units;
2. Test series representing incompatible test methods (i.e., comparison of EPA method 5 front-half with EPA method 5 front- and back-half);
3. Test series of controlled emissions for which the control device is not specified;
4. Test series in which the source process is not clearly identified and described; and
5. Test series in which it is not clear whether the emissions were measured before or after the control device.

Data sets that were not excluded were assigned a quality rating. The rating system used that specified by the OAQPS for the preparation of AP-42 sections. The data were rated as follows:

A--Multiple tests performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily conform to the methodology specified in either the inhalable particulate (IP) protocol documents or the EPA reference test methods, although these documents and methods were certainly used as a guide for the methodology actually used.

B--Tests that were performed by a generally sound methodology but lack enough detail for adequate validation.

C--Tests that were based on an untested or new methodology or that lacked a significant amount of background data.

D--Tests that were based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following criteria were used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurred, an evaluation was made of the extent such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data are documented in this report. Many variations can occur unnoticed and without warning during testing. Such variations can include wide deviations in sampling results. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and were given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those (if any) specified by EPA to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

3.3 PARTICLE SIZE DETERMINATION

There is no one method which is universally accepted for the determination of particle size. A number of different techniques can be used which measure the size of particles according to their basic physical properties. Since there is no "standard" method for particle size analysis, a certain degree of subjective evaluation was used to determine if a test series was performed using a sound methodology for particle sizing.

For pollution studies, the most common types of particle sizing instruments are cyclones and cascade impactors. Traditionally, cyclones have been used as a preseparator ahead of a cascade impactor to remove the larger particles. These cyclones are of the standard reverse-flow design whereby the flue gas enters the cyclone through a tangential inlet and forms a vortex flow pattern. Particles move outward toward the cyclone wall with a velocity that is determined by the geometry and flow rate in the cyclone and by their size. Large particles reach the wall and are collected. A series of cyclones with progressively decreasing cut-points can be used to obtain particle size distributions.

Cascade impactors used for the determination of particle size in process streams consist of a series of plates or stages containing either small holes or slits with the size of the openings decreasing from one plate to the next. In each stage of an impactor, the gas stream passes through the orifice or slit to form a jet that is directed toward an impaction plate. For each stage, there is a characteristic particle diameter that has a 50 percent probability of impaction. This characteristic diameter is called the cut-point (D_{50}) of the stage. Typically, commercial instruments have six to eight impaction stages with a backup filter to collect those particles which are either too small to be collected by the last stage or which are re-entrained off the various impaction surfaces by the moving gas stream.

3.4 EMISSION FACTOR QUALITY RATING SYSTEM

The quality of the emission factors developed from analysis of the test data was rated utilizing the following criteria:

A--Excellent: Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough so that variability within the source category population may be minimized.

B--Above average: Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As in the A-rating, the source category is specific enough so that variability within the source category population may be minimized.

C--Average: Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A-rating, the source category is specific enough so that variability within the source category population may be minimized.

D--Below average: The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are noted in the emission factor table.

E--Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always noted.

The use of these criteria is somewhat subjective and depends to an extent on the individual reviewer. Details of the rating of each candidate emission factor are provided in Chapter 4 of this report.

REFERENCES FOR CHAPTER 3

1. Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections (Draft), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1992.

4. POLLUTANT EMISSION FACTOR DEVELOPMENT

This chapter describes the test data and methodology used to develop pollutant emission factors for external combustion processes using waste oil as the fuel.

4.1 REVIEW OF SPECIFIC DATA SETS

A total of 12 references reporting emissions data were documented and reviewed during the literature search. Reports of waste oil emissions published since the last AP-42 revision (1988) were, in large part, not applicable to emission factor determinations. The references used to determine the emission factors for the criteria pollutants in the earlier AP-42 also contained data applicable to the development of non-criteria emission factors which are to be incorporated in this updated AP-42. Non-criteria pollutant data are available for several organic species, for toxic metal species, and for carbon dioxide (CO₂).

The original group of 12 documents was reduced to a final set of 8 documents containing useful data for calculating emission factors. For the four documents not used, the reasons for rejection were:

- Reference 1: Not a primary reference;
- Reference 2: Not a primary reference;
- Reference 3: Summary report, and no primary reference was listed; and
- Reference 4: Used spiked diesel fuel for simulation of a waste fuel.

In the subsections to follow, emission measurements qualifying for emission factor determinations are described for each reference.

4.1.1 Reference 5

The sampling and analysis program was designed to characterize the organic and inorganic emissions from six small boilers firing waste oil. The tested units represented a cross-section of small boiler types, firing techniques, and capacities (Table 4-1).

Emissions were not controlled. A 15,000 liter (4,000 gallon) supply of waste oil was obtained from a licensed vendor and used as a base stock. The base stock was spiked with four volatile organic compounds and four semi-volatile compounds. Five of the six boilers burned only waste oil. The cast iron boiler burned a 50:50 mixture of waste oil and No. 2 oil.

Metals and total PM emissions were collected by EPA Method 5, with an impinger train modified to collect hydrochloric acid (HCl). Particle size fractions were collected with a Andersen high capacity impactor at four of the six sites. Oxygen, CO₂, and carbon monoxide (CO) were analyzed.

The 1988 AP-42 Section 1.11 used these results to determine emission factors for particulate matter, particulate matter less than ten microns in diameter (PM-10), lead, carbon monoxide, and HCl. The same results are incorporated into the emission factor determinations for the updated AP-42 section. The data resulting from this test program were of good quality and were well documented. A rating of A was assigned to the data.

4.1.2 Reference 6

Seven sampling and analysis test runs were made to evaluate emissions as functions of different types of waste oil when blended with base stocks of No. 2 fuel oil or of No. 6 fuel oil. Blends were as follows:

- 15-25 percent industrial waste oil in No. 2 oil;
- 8 percent crankcase oil in No. 2 oil;
- 9.72 percent crankcase oil in No. 6 oil;
- 60.4 percent crankcase oil in No. 6 oil;
- 20.8 percent reprocessed oil in No. 6 oil;
- 100 percent reprocessed oil; and
- 20.6 percent industrial waste oil in No. 6 oil.

Tests were conducted on three source categories, but no design details were available. For seven sets of tests, heat input was in the range of 0.5 - 5.7 MW (1.8 - 19.5 million Btu/hr). No emission controls were used.

Pollutants of interest were lead, filterable PM, SO₂, and nitrogen oxides (NO_x). Data were sufficient to determine emission factors for PM, SO₂, NO_x, and CO₂.

The investigators used EPA methods to determine PM, SO₂, and NO_x, and CO₂. Details are lacking, but based on the statements that EPA methods were used, a data quality rating of B was assigned.

4.1.3 Reference 7

The boiler tested was rated at 5.9 MW (20 million Btu/hr). Waste crankcase oil was heated to lower the viscosity and thus facilitate particle settling. The waste oil was fed through basket-type filters with magnetic inserts for the removal of iron.

The test program consisted of two test series to measure emissions at 150 liters/hr (40 gallons/hr) feed rate (about 25 percent of rated capacity) and 300 liters/hr (80 gallons/hr). Each test series included sets of three trials. Measurement goals were the determination of PM and lead emissions. PM was measured using EPA Method 5, using 0.05 N nitric acid in the impingers for the collection of the lead. Lead was analyzed by atomic absorption. Carbon dioxide and the other fixed gases were determined by Orsat analysis. Waste oil was sampled just ahead of the burner. The oil samples were composited to obtain one sample.

Since EPA methods were employed, a rating of A was assigned to these data.

4.1.4 Reference 8, 9

The test program characterized emissions from two small space heaters, one rated at 35 kW (120,000 Btu/hr) and the other rated at 75 kW (250,000 Btu/hr). The smaller heater vaporized the waste oil in a pot burner, which accumulated much of the ash in the residue of the pot burner. The larger heater utilized air atomization as a firing technique, which entrained the ash particles in the flue gas stream. Filtered, but otherwise untreated, waste crankcase oil was fired at both heaters.

Two types of waste oil were tested in each heater. An automobile waste crankcase oil (automotive) was obtained from a service station. The other waste crankcase oil (truck) came from a diesel truck fleet. Ultimate and proximate analyses were obtained for the two oils.

Emissions data included concentrations of PM, selected metal species, and effluent gases (SO₂, NO_x, CO, and unburned hydrocarbons). PM was collected with a Modified EPA Method 5 sampling train (modified to collect volatile organic compounds with a XAD-2 resin trap). Metal species were collected in a Source Assessment Sampling System (SASS) and analyzed by

inductively coupled argon plasma (ICAP). Gases were analyzed with continuous analyzers as follows:

<u>Gas</u>	<u>Method</u>
Oxygen	Paramagnetic
Carbon dioxide	Nondispersive infrared
Carbon monoxide	Nondispersive infrared
Nitric oxide	Chemiluminescence
Nitrogen dioxide	Chemiluminescence
Hydrocarbons	Flame ionization

Although the SASS method is not an EPA reference method, all others are, and are presented in considerable detail. An A data quality rating was assigned.

4.1.5 Reference 10

Combustion equipment for this test program included a small institutional boiler described in subsection 4.1.3. and two space heating units described in subsection 4.1.4.

A composite waste oil was prepared using 4 waste oils in a combination that would be representative of 14 waste oils obtained from 14 collectors/recyclers. The composite was spiked with three organic compounds at levels of about 90 ppm each and polychlorinated biphenyls (PCBs) at a level of 40 ppm. An automobile waste crankcase oil (No. 14) was the other oil used in the test program.

Emissions data were collected for metal and organic species. The EPA Modified Method 5 train, modified to collect organics with a XAD-2 resin trap, was used to collect the metal species. A SASS train was also employed for collection of the metals and for obtaining PM-10 data. The metals were analyzed by ICAP. Semivolatile organic compounds were extracted from the combined particulate fractions of the SASS train and analyzed by gas chromatography/mass spectrometry (GC/MS) Method 625 for semivolatile organic compounds.

The data amenable to emission factor determination were PM and metal species by EPA Modified Method 5 and organic species collected by the SASS train. A data quality rating of A

was assigned for the small boiler and the atomizing burner space heater categories and a rating of B was assigned to the vaporizing burner space heater.

4.1.6 Reference 11

The waste oil, 100 percent of the fuel used, was burned to dry and heat aggregate in a rotary kiln prior to mixing the aggregate with asphalt in a batch asphalt plant. The off gas from the kiln contained entrained aggregate and moisture combined with the products of combustion of the waste oil and its impurities. A fabric filter was used to control particulate emissions.

A reprocessed waste oil was used that had been spiked with enough trichloroethylene for a waste oil chlorine content of about one percent. The investigators of Reference 3 report an average of only 0.3 percent chlorine for the 24 waste oils analyzed for that study. Therefore, HCl emissions exceeded normal expectations. Three sampling runs were completed and the results averaged. EPA Method 5 was used to sample for PM, metals species and HCl. Chlorinated organic species were trapped on Tenax adsorbent. Metals were analyzed by ICAP or atomic absorption and the trichloroethylene was determined by gas chromatography/mass spectrometry (GC/MS).

Emission factors were determined for total PM, a limited number of metals including lead, the spiked organic compound, and HCl. Sound methodology was used in this test program but description of methods and documentation of test results was limited in the report. Results of the three sampling runs were reported as averages. A rating of B was assigned to the data.

4.2 RESULTS OF DATA ANALYSIS

Data analysis had as its objectives the calculation of emission factors for criteria and non-criteria air emissions from burning a waste oil in external combustion devices. The emission factors were reported as kilograms of pollutant per cubic meter of waste oil (or pounds of pollutant per 1000 gallons of waste oil).

Two major factors contributed to the variability of the data: (1) end uses for the combustion of the waste oil, and (2) characteristics of the waste oil used in the tests. Possible external combustion end uses for waste oil include industrial boilers, commercial/institutional boilers, space heaters, asphalt plants, cement and lime kilns, other types of dryers and calciners, and steel production blast furnaces.

Useful data were found for small boilers, space heaters, and a batch asphalt plant. These end users vary a great deal in heat input and type of firing. The heat input rate varied from 30

kW (100,000 Btu/hour) for the space heaters to 15 MW (50 million Btu/hour) for the asphalt plant. Waste automotive oils (crankcase oil) dominate the total supply of waste oil, but industrial oils add a host of different physical properties and contaminants to the various mixtures that are burned. Thus, waste oil may vary substantially in its composition despite efforts by suppliers to blend away the variations. In some cases the waste oil is mixed with distillate oil.

4.3 PROTOCOL FOR DATA BASE

Using the criteria discussed in Section 3.2, four reports were rejected. The remaining 8 reports having A or B data quality ratings and representing 28 source tests were thoroughly reviewed to establish a data base for the following classes of pollutants: PM and lead, speciated metals, total and speciated organic carbon, gaseous products of combustion - CO, CO₂, SO₂, NO_x), and other gases (HCl).

Excepting the batch asphalt plant, all sources were classified as uncontrolled. The sources usually employed some pretreatment to remove large particles, along with magnetizing to remove iron particles. Reference 9 reported that one of the waste oils that was burned was a reprocessed oil.

Generally, the analysis took one of five forms:

1. Acceptance of reported emission factor.
2. Calculation, using reported time-based rates for pollutant and waste oil.
3. Calculation, using reported concentrations of pollutant in flue gas of volume percent, ppmv, or weight per volume ratio, and using reported time-based rates for flue gas and waste oil.
4. Use F-factor and heating value of waste oil to determine stoichiometric volume of flue gas per volume of waste oil. Convert stoichiometric volume to total volume by adding reported excess air. Use reported concentrations of pollutant as in method 3 above.
5. Accept emission factors reported in preceding AP-42.

One of the five methods described above was chosen, based on the data available in a particular reference, and an emission factor was calculated or chosen for a given sampling run. The procedure was repeated for each sampling run, or for averaged sets of replicate sampling runs, until a data base is amassed for each source category.

In addition to unit conversions, Methods 3 and 4 above required some preprocessing to:

- Convert from volume to weight of pollutant, using molecular weight,
- Correct flue gas from stoichiometric amounts to total amounts by adding excess air:

$$\text{Total dscf} = \frac{\text{dscf}(\text{stoichiometric}) \times \%O_2}{1 - 4.79 \times \%O_2}$$

where %O₂ is percent excess oxygen in flue gas.

If the fuel was a mixture of a waste oil and a virgin fuel oil, such as No. 2 or No. 6 oil, the emission factor was based on the blended oil.

Emission factors for some of the pollutants were corrected to a feed pollutant concentration basis. The calculated emission factor was divided by the weight percent of pollutant precursor in the feed, for example weight percent sulfur for the pollutant SO₂; the reported emission factor includes the pollutant precursor as a multiplier. For example, if the measured emissions were 21 lbs SO₂/1000 gallons of oil and sulfur in the oil was 0.17 weight percent:

$$\text{Reported EF} = (21.3/0.17) = 125S,$$

where S is weight percent sulfur in fuel, and EF has units of pounds of SO₂/1000 gallons of oil per weight percent of sulfur.

Quality control and quality assurance procedures were used to assure that the data base accurately reflected the reported test data. Each data rating form was checked by a second reviewer to assure accurate documentation of reference exclusion or emission data rating criteria. In addition, manual and spreadsheet calculations were spot checked by a second reviewer to assure accurate documentation of reported emission and process data prior to calculation of overall average emission factors. After emission tables were generated, a final comparison was made between randomly selected test reports, their associated data rating forms, and the produced emission table to assure the quality of the data acquisition and associated calculations.

TABLE 4-1. CHARACTERISTICS OF SMALL BOILERS TESTED IN REFERENCE 5 TESTS

Boiler type	Method of atomization	Rated heat input capacity, kW (10 ⁶ Btu/hr)	Heat input during test, kW (10 ⁶ Btu/hr)
Cast iron ^a	Mechanical	145 (0.5)	125 (0.43)
Horizontal return tube	Rotary cup	700 (2.4)	850 (2.9)
Scotch firetube, 3 pass	Air	790 (2.7)	500 (1.7)
Scotch firetube, 4 pass	Rotary cup	1,000 (3.4)	560 (1.9)
Scotch firetube, 3 pass	Air	1,200 (4.2)	760 (2.6)
Scotch firetube, 4 pass	Air	3,600 (12.5)	910 (3.1)

^aBurned 50:50 mixture of waste oil and No. 2 oil; all others burned 100 percent waste oil.

TABLE 4-2. SUMMARY OF EMISSION FACTORS FOR SPECIATED METALS FROM WASTE OIL COMBUSTION^a
(kg pollutant/cubic meter oil)

Source category/ reference/rating	Sb	As	Be	Cd	Cr	Co	Mn	Ni	Se	P
<u>Small boilers</u>										
10,a	BDL	1.3E-02	BDL	1.1E-03	2.4E-03	2.5E-05	8.2E-03	1.3E-03	BDL	
<u>Batch asphalt plant</u>										
11,b		7.4E-05		2.6E-05	9.8E-04					
<u>Space heaters:</u>										
<u>Vaporizing burner</u>										
8,a				BDL	4.3E-04	4.3E-04		2.3E-02		4.2E-03
8,a				2.2E-05	9.1E-02	1.2E-03		4.6E-04		4.3E-03
10,a	4.8E-05	4.8E-05	BDL	BDL	9.6E-05	BDL	4.8E-05	8.0E-05	BDL	
10,a	3.2E-05	5.6E-04	BDL	4.8E-05	8.3E-04	1.1E-03	4.8E-04	4.0E-04	BDL	
<u>Atomizing burner</u>										
10,b	5.3E-04	9.2E-03	1.7E-04	8.6E-04	3.4E-03	6.6E-05	1.1E-02	7.9E-04	BDL	
10,b	5.4E-04	5.2E-03	2.5E-04	8.0E-04	6.0E-03	1.0E-03	1.3E-03	3.6E-03	BDL	
8,a				2.3E-03	4.6E-03	3.4E-04		2.3E-02		
8,a				1.6E-03	7.3E-02	1.1E-03		5.2E-02		

BDL = Below detection limit

^aAll sources were uncontrolled except batch asphalt plant, which was controlled by a fabric filter.

TABLE 4-3. SUMMARY OF EMISSION FACTORS FOR Pb AND PM FROM WASTE OIL-FIRED COMBUSTORS^a

Source category/ reference/rating	Pb _i		PM _i	
	kg/m ³	lb/1000 gal	kg/m ³	lb/1000 gal
<u>Small boilers</u>				
5,a			7.9A	66A
5,a			8.6A	72A
5,a			8.4A	70A
5,a			6.7A	56A
5,a			7.9A	66A
5,a			8.7A	73A
10,a	1.6E+00	1.3E+01	4.8A	40A
6,a			8.0A	67A
5,a				
7,b	4.6E-01	3.8E+00		
<u>Space heaters:</u>				
<u>Atomizing burner</u>				
10,a			9.4A	78A
10,a			7.4A	62A
8,a	8.5E-01	7.05E+00	6.8A	57A
10,b	1.3E+00	1.1E+01		
10,b	6.8E-01	5.7E+00		
10,a				
10,a				
10,a				
10,a				
8,a	2.1E+00	1.76E+01		
<u>Vaporizing burner</u>				
10,a	4.6E-03	3.8E-02	0.53A	4.4A
10,a	9.2E-03	7.7E-02	0.14A	1.2A
8,a	4.0E-03	3.37E-02	0.34A	2.8A
8,a	3.5E-02	2.89E-01		
<u>Batch asphalt plant</u>				
11,a			0.03A	0.27A
11,b	1.1E-03	9.4E-03		

A = Ash content of fuel, weight percent.

^aAll sources were uncontrolled except batch asphalt plant, which was controlled by a fabric filter.

TABLE 4-4. SUMMARY OF EMISSION FACTORS FOR SPECIATED ORGANIC COMPOUNDS FROM SPACE HEATERS^a
(kg pollutant/cubic meter oil)

Pollutant	Source category/reference/rating			
	Vaporizing burner 10,b	Atomizing burner 10,a	Vaporizing burner 10,b	Atomizing burner 10,a
Phenol	2.9E-04	3.3E-06		
Dichlorobenzene	1.0E-07			
Naphthalene	3.0E-03	9.2E-06	2.3E-06	1.3E-05
Phenanthrene/ anthracene	2.5E-03	2.2E-05	3.3E-06	2.0E-06
Dibutylphthalate		4.9E-06		3.1E-06
Butylbenzylphthalate	6.1E-05			
Bis-2-ethylhexyl-phthalate	3.2E-04		1.9E-04	
Pyrene	1.7E-03	1.2E-06	5.3E-06	8.0E-07
Benz(a)anthracene/ chrysene	4.8E-04			
Benzo(a)pyrene	4.8E-04			

^aSpace heaters were uncontrolled.

TABLE 4-5. SUMMARY OF CO₂ AND CO EMISSION DATA FROM WASTE OIL COMBUSTORS^a

Source category/reference/rating	CO ₂		CO	
	kg/m ³	lb/1000 gal	kg/m ³	lb/1000 gal
<u>Small boilers</u>				
6,b	3,800	31,400	0.6	5
6,b	3,200	26,400		
6,b	3,100	25,500		
6,b	3,050	25,200		
6,b	2,900	24,200		
6,b	2,750	22,900		
6,b	2,200	18,600		
6,b	2,400	20,100		
6,b	2,680	22,340		
6,b	2,600	21,800		
6,b	1,700	14,000		
6,b	2,100	17,300		
6,b	2,350	19,600		
6,b	2,870	23,900		
6,b	1,710	14,200		
10,a	2,150	17,900		
5,a			0.6	5
<u>Space heaters:</u>				
<u>Vaporizing burner</u>				
10,a	2,950	24,500		
10,a	2,500	20,800		
10,a	2,700	22,700		
8,a			0.19	1.6
8,a			0.22	1.8
8,a			0.20	1.7
<u>Atomizing burner</u>				
10,a	2,920	24,300		
10,a	2,950	24,600		
10,a	2,925	24,400		
8,a			0.28	2.3
8,a			0.23	1.9
8,a			0.25	2.1

^aAll sources were uncontrolled.

TABLE 4-6. SUMMARY OF EMISSION FACTORS FOR NO_x AND SO₂ FROM WASTE OIL COMBUSTORS^a

Source category/reference/rating	NO _x		SO ₂	
	kg/m ³	lb/1000 gal	kg/m ³	lb/1000 gal
<u>Small boilers</u>				
9,b ^b	1.48	12.3	15.0S ^d	125S
9,b	2.38	19.8	15.7S	131S
9,b	3.28	27.3	15.1S	126S
9,b	2.15	17.9	16.1S	134S
9,b	1.99	16.6	20.5S	171S
9,b	2.27	18.9	21.7S	181S
9,b	2.51	20.9	19.7S	164S
<u>Space heaters:</u>				
<u>Vaporizing burner</u>				
10,a ^c	1.47	12.2	12.8S	106.4S
10,a	1.28	10.7	11.3S	93.7S
<u>Atomizing burner</u>				
10,a	2.22	18.5	14.0S	116.4S
10,a	1.56	13.0	11.8S	98S

^aAll sources were uncontrolled.

^bData in this reference reported as NO. NO₂ not detected, or detected in negligible amounts.

^cData in this reference reported as NO_x.

^dS = weight percent sulfur in fuel.

REFERENCES FOR CHAPTER 4

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9. Chemical Analysis of Waste Crankcase Oil Combustion Samples, EPA-600/7-83-026, U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1983.
10. The Fate of Hazardous and Nonhazardous Wastes in Used Oil Disposal and Recycling, DOE/BC/10375-6, U.S. Department of Energy, Bartlesville, OK, October 1983.
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5. AP-42 SECTION 1.11: WASTE OIL COMBUSTION

The revision to Section 1.11 of AP-42 is presented in the following pages as it would appear in the document. A marked-up copy of the 1988 version of this section is included in Appendix B.

APPENDIX A
EMISSION SOURCE DATA RATING FORMS

REPORT ON REVISIONS TO

5th EDITION AP-42

Section 1.11

Waste Oil Combustion

Prepared for:

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1.0 INTRODUCTION

This report supplements the Emission Factor (EMF) Documentation for AP-42 Section 1.11, Waste Oil Combustion, dated April 1993. The EMF describes the source and rationale for the material in the most recent updates to the 4th Edition, while this report provides documentation for the updates written in both Supplements A and B to the 5th Edition.

Section 1.11 of AP-42 was reviewed by internal peer reviewers to identify technical inadequacies and areas where state-of-the-art technological advances need to be incorporated. Based on this review, text has been updated or modified to address any technical inadequacies or provide clarification. Additionally, emission factors were checked for accuracy with information in the EMF Document and new emission factors generated if recent test data were available.

If discrepancies were found when checking the factors with the information in the EMF Document, the appropriate reference materials were then checked. In some cases, the factors could not be verified with the information in the EMF Document or from the reference materials, in which case the factors were not changed.

Three sections follow this introduction. Section 2 of this report documents the revisions and the basis for the changes. Section 3 presents the revised AP-42 Section 1.11, and Section 4 contains the EMF documentation dated April 1993.

2.0 REVISIONS

This section documents the revisions made to Section 1.11 of AP-42. At the request of EPA, the metric units were removed.

2.1 Particulate Matter, PM

The PM emission factors were checked against information in Table 4-3 of the EMF Document and the following mathematical errors were corrected:

Source Category	Previous PM Emission Factor lb/1000 gal	Revised PM Emission Factor lb/1000 gal
Small Boilers	61A	64A
Space Heaters, Atomizing burners	64A	66A

2.2 Particulate Matter Less Than 10 Microns, PM-10

The PM-10 factors remain the same as in the 9/88 version of AP-42.

2.3 Lead, Pb

The Pb emission factors could not be confirmed from information in Table 4-3 of the EMF Document or from the references. Table 4-3 does not show the factors as a function of Pb content, nor is the assumed Pb content documented in the EMF Document or in the references. Footnote "e" in Table 1.11-1 (dated 9/88) states that 0.04 percent Pb in waste oil was assumed. (This footnote was deleted from the 7/93 version of AP-42.) However, when 0.04 percent is used, the Pb factors still cannot be confirmed from information in Table 4-3 of

the EMF Document. Therefore, since it was not possible to determine if these factors were incorrect, they have not been changed.

2.4 Nitrogen Oxides, NO_x

The NO_x factors were found to be in the wrong columns; therefore, all the factors in the metric unit columns were switched to the English unit columns as shown in the following table:

Source Category	Previous NO_x Emission Factor lb/1000 gal	Revised NO_x Emission Factor lb/1000 gal
Small Boilers	2.3	19
Space Heaters, Vaporizing Burners	1.3	11
Space Heaters, Atomizing Burners	1.9	16

2.5 Sulfur Oxides, SO_x

The SO_x factors were found to be in the wrong columns; therefore, all the factors in the metric unit columns were switched to the English unit columns as shown in the following table:

Source Category	Previous SO_x Emission Factor lb/1000 gal	Revised SO_x Emission Factor lb/1000 gal
Small Boilers	17.6S	147S
Space Heaters, Vaporizing Burners	12.0S	100S
Space Heaters, Atomizing Burners	12.9S	107S

2.6 Carbon Monoxide, CO

The CO factors were found to be in the wrong columns; therefore, all the factors in the metric unit columns were switched to the English unit columns as shown in the following table:

Source Category	Previous CO Emission Factor lb/1000 gal	Revised CO Emission Factor lb/1000 gal
Small Boilers	0.60	5
Space Heaters, Vaporizing Burners	0.20	1.7
Space Heaters, Atomizing Burners	0.25	2.1

2.7 Total Organic Compounds (TOC)

The TOC factors could not be verified as there was no information in the EMF Document concerning these factors. Additionally, the TOC factors are different from the 9/88 version. These factors have not been changed as we have no basis to make changes.

2.8 Hydrogen Chloride, HCl

The HCl factors remain the same as the 9/88 version of AP-42.

2.9 Speciated Metals

Factors for speciated metals were checked against Table 4-2 of the EMF Document and the following corrections were made:

Compound	Source Category	Previous Emission Factor lb/1000 gal	Revised Emission Factor lb/1000 gal
Arsenic—	Space Heaters: Vaporizing Burners	1.1E-03	2.5E-03
Beryllium—	Space Heaters: Atomizing Burners	3.9E-07	1.8E-03
Cadmium-	Space Heaters: Vaporizing Burners	1.5E-04	2.9E-04
Chromium-	Space Heaters: Vaporizing Burners	2.6E-01	1.9E-01
Cobalt-	Space Heaters: Vaporizing Burners	5.7E-03	7.6E-03

2.10 Speciated Organic Compounds

Factors for speciated organic compounds were checked against Table 4-4 of the EMF Document and the following mathematical errors and typographical errors were corrected:

Compound	Source Category	Previous Emission Factor lb/1000 gal	Revised Emission Factor lb/1000 gal
Dichlorobenze—	Space Heaters: Vaporizing Burners	6.7E-06	8.3E-07
Naphthalene—	Space Heaters: Vaporizing Burners	1.3E-02	1.2E-02
Naphthalene—	Space Heaters: Atomizing Burners	9.4E-05	9.2E-04
Phenanthrene/Anthracene	Space Heaters: Vaporizing Burners	9.9E-05	1.0E-04
Pyrene—	Small Boilers	7.0E-03	7.1E-03
Pyrene—	Space Heaters: Atomizing Burners	5.1E-05	8.3E-06

3.0 REVISED SECTION 1.11

This section contains the revised Section 1.11 of AP-42, 5th Edition. The electronic version can be located on the EPA TTN at <http://134.67.104.12/html/chief/fsnpub.htm>.

4.0 EMISSION FACTOR DOCUMENTATION, APRIL 1993

This section contains the complete Emission Factor Documentation for AP-42 Section 1.11, Waste Oil Combustion, dated April 1993. The electronic version can be located on the EPA TTN at <http://134.67.104.12/html/chief/fbgdocs.htm>. The zipped file on the TTN contains this (1996) background report as well as the 1993 Emission Factor Documentation.

APPENDIX B

MARKED-UP 1988 AP-42 SECTION 1.11