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# Comparison of Air Pollutant Emissions from Vaporizing and Air-Atomizing Waste Oil Heaters

Robert E. Hall
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

and

W. Marcus Cooke and Rachael L. Barbour
Battelle Columbus Laboratories
Columbus, OH 43201

Robert E. Hall, M.S.M.E., is a Research Mechanical Engineer for the Industrial Environmental Research Laboratory, U.S. EPA, Research Triangle Park, NC 27711.
W. Marcus Cooke, Ph.D., is a Projects Manager, and Rachael L. Barbour is a Researcher, Battelle Columbus Laboratories, 505 King Avenue, Columbus, OH 43201.

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## Introduction

The sharp rise in the price of heating oil during the past decade has resulted in increased usage of lower cost fuels, where available. One such fuel is waste crankcase oil which is only 20 to 25 percent of the cost of distillate heating oil of equivalent heating value. It is being used by businesses with an abundant supply of waste oil to heat large areas, such as garages.

The use of waste crankcase oil as a heating fuel has caused concern among environmental agencies. As a result of requests received from a number of state and federal agencies, the U.S. Environmental Protection Agency's Industrial Environmental Research Laboratory located in Research Triangle Park, NC, has conducted a series of tests to determine the level of emissions from two types of waste oil heaters. Emissions were measured from two popular designs of waste oil heaters, vaporizing pot and air atomizing. Also, two different types of waste crankcase oils were used. One was an automotive crankcase oil that came from a service station, and the other was a truck waste crankcase oil that came from a diesel truck fleet.

The major concern about using these oils as fuel is related to the inorganic emissions. The tests were designed to quantify criteria pollutant emissions such as $NO_x$, $SO_x$, CO, and particulate, as well as organic and inorganic emission levels.

## Test Equipment and Fuels

Two types of waste oil heaters were tested while firing filtered, but otherwise untreated, waste crankcase oils. One was a Kroll, Model W400L, waste oil heater rated at 35.2 kW (120,000 Btu/hr heat input). It uses a vaporizing pot burner in which only the heated vaporized fuel is combusted. With this type of burner the residue of unburned material, which accumulates in the bottom of the fuel pot, must be physically removed. This residue was also analyzed for organic and inorganic content.

The other unit tested, a Dravo Hastings Thermoflo, Model 20-WO, waste oil heater rated at 73.3 kW (250, 000 Btu/hr heat input), uses a low pressure air atomizing burner. With this type of burner most of the fuel is burned and discharged as stack effluent. During the tests a light coating of material was noticed on the combustion chamber and heat exchanger walls. Sampling and analyzing this material for each run was not feasible due to its small quantity and difficulty in obtaining the sample. Cleaning the heater between tests was not practical either.

Two different types of waste crankcase oils were tested in each heater. One was an automotive waste crankcase oil that was obtained from a service station.

The other was a truck crankcase oil that came from a diesel truck fleet. Results of the fuel ultimate and proximate analyses are given in Table I. Heating values for both truck and automotive waste crankcase oils are similar to those expected for No. 2 fuel oil. Both oils are quite viscous compared to No. 2 oil and have relatively high values for water, ash, and sulfur, as expected in waste oils. The automotive oil had a low carbon value. Comparison with literature for density, heating value, and hydrogen/carbon ratios suggests that these two waste oils are similar to No. 4 fuel oil in their combustion properties. Both waste oils were analyzed by inductively coupled argon plasma (ICAP) and atomic absorption spectrometry (AAS) to determine fuel elemental mass values. The automotive waste oil contained much higher concentrations of metals than did the truck crankcase oil.

## Test Measurements

During each test run, data were manually recorded for the following physical parameters: fuel flow rate, stack temperature, ambient air temperature, barometric pressure, relative humidity, and pressure differences.

Gaseous emissions were measured with the following continuous analyzers:

| Gas | Analyzer |
|---|---|
| Oxygen ($O_2$) | Paramagnetic |
| Carbon Dioxide ($CO_2$) | Nondispersive Infrared (NDIR) |
| Carbon Monoxide (CO) | Nondispersive Infrared (NDIR) |
| Nitric Oxide (NO) | Chemiluminescence |
| Nitrogen Dioxide ($NO_2$) | Chemiluminescence |
| Sulfur Dioxide ($SO_2$) | Ultraviolet |
| Hydrocarbon (HC) | Flame Ionization Detector |

It should be noted that a heated sampling line was used for $NO_x$ and hydrocarbon analyses.

Smoke number was measured under steady-state operating conditions, and a Bacharach smoke spot number was obtained by averaging five consecutive smoke spots taken at 1 minute intervals.[1]

Total particulate emissions were determined for selected test conditions using the EPA Method 5 sampling procedure modified with a sorbent (XAD-2) module cartridge to collect organics. A minimum of two samples were collected at each test condition.

Particulate size distributions were determined by using the Mark III Andersen Stack Sampler. A minimum of two Andersen samples were taken at each selected test condition. However, these results are not included in this paper.

In addition, data were obtained for an EPA Level 1 assessment.[2] This required the use of a Source Assessment Sampling System (SASS) train with subsequent data reduction by Battelle-Columbus Laboratories.[3] The analysis included: spark source mass spectroscopy (SSMS) using an AEI Model MS-702R instrument to screen elemental constituents; inductively coupled argon plasma (ICAP) spectrometry using a Jarrell-Ash Model 975 instrument to analyze elemental species; and atomic absorption spectroscopy (AAS) using a Perkin-Elmer Model 5000 instrument to provide mercury (Hg), arsenic (As), and antimony (Sb) emissions data. Total chromatographable organic (TCO) analyses, gravimetric (GRAV) analyses, infrared (IR) analyses, and low resolution mass spectroscopic (LRMS) analyses were performed to obtain information about organic emissions.

A slipstream of the stack effluent was ducted into a dilution tunnel where a flow of filtered dilution air was allowed to mix with the heater discharge at a ratio of 10:1. The entire dilution tunnel effluent was collected on a Teflon coated Fiberglas filter. The dilution tunnel simulates the dilution and mixing that would occur if the flue gas were discharged directly into the environment.

The sampling conditions for the two stack effluent samplers (SASS train and dilution tunnel) are given in Table II for both types of waste oil heaters firing both waste crankcase oil fuels (automotive and truck).

## Results

### Gaseous and Particulate Emissions

Continuous monitors were used to measure oxygen and emissions of carbon monoxide (CO), unburned hydrocarbons (HC), nitric oxide (NO), nitrogen dioxide ($NO_2$), and sulfur dioxide ($SO_2$). The data shown in Table III compare emissions from the vaporizing burner and air atomizing burner while firing No. 2 fuel oil, automotive waste crankcase oil, and truck waste crankcase oil. In general, CO and HC emissions are similar to those of a conventional oil burner. NO and $SO_x$ emissions are significantly higher from the waste oil combustion than from No. 2 fuel oil combustion because the fuel nitrogen and sulfur content is higher, as shown in Table I. The air atomizing burner was capable of operating at a lower excess air level, and thus provided more efficient combustion. Nitrogen dioxide ($NO_2$) was also measured, but was not detected while firing the automotive crankcase oil and was only detected in 25 percent of the tests while firing the truck crankcase oil. In those cases $NO_2$ only averaged 6 ppm.

Smoke number was measured under steady-state operating conditions. For each number reported in Table III, five consecutive smoke numbers taken at 1 minute intervals were averaged.

Particulate loading data are also shown in Table III. The data show that the air atomizing burner emitted particulate at levels an order of magnitude higher than did the vaporizing burner, while firing waste crankcase oils. This was due to the difference in firing type between the two burners. The vaporizing pot burner retained much of the inorganic material in the pot residue, whereas the air atomizing burner permits more of the inorganic material to be carried by the flue gas into the stack. It is also of interest to note the difference in particulate loading for the air atomizing burner while firing No. 2 oil (10 $mg/m^3$) vs. waste crankcase oils (224 $mg/m^3$). This difference is due to the high inorganic content of the waste oils.

## Organic Emissions

Organic loading, as indicated by the SASS train samples in Figure 1, was similar for all four test runs with the concentrations being slightly lower when burning automotive crankcase oil than with truck crankcase oil. For all tests, excluding the air atomizing/automotive crankcase oil test, dilution tunnel sampling collected 20 to 30 percent less organic material than did the SASS train. Both sampling methods indicated essentially the same concentration of organics in the air atomizing/automotive crankcase oil test. These analyses revealed that the total organic material collected by the dilution filter averaged slightly lower than, but compared favorably with, the total organics collected by the SASS train. Some highly volatile organic constituents would not be retained on either sample collection system; e.g., methanol, benzene.

The chemical composition of the organic portion of the samples from all four effluents, sampled by both SASS train and dilution tunnel, was generally similar. The two major types of constituents were hydrocarbons (mainly aliphatic, some olefinic, and aromatic), and oxidized species such as ketones, esters, aldehydes, acids, and (to a lesser extent) ethers, anhydrides, alcohols, and lactones. In tests with the vaporizing pot heater, significant quantities of polynulcear aromatic hydrocarbons (PAH)) were found in the gaseous discharges while burning automotive crankcase oil, and a similar result was observed in the vaporizing pot residue after combusting truck crankcase oil. Infrared analysis did indicate the presence of aromatic ring compounds in many of the samples, including liquid chromatography (LC) fractions of most of the liquid chromatographed samples. This finding indicates that PAHs and related compounds could be present, although a compound specific technique such as capillary gas chromatography/mass spectrometry (GC/MS) would be necessary to determine levels of individual compounds, and this analysis was not performed.

Infrared analyses indicated that the truck crankcase oil tended to generate more oxidized organic species than did automotive crankcase oil combustion. This was evidenced by higher levels of acids and lactones in the gaseous discharges.

The organic composition of SASS and dilution tunnel samples were significantly different. The dilution tunnel extracts had lower levels of aliphatic hydrocarbons and esters than the parallel SASS samples. The differences in organic chemical composition, observed between the two techniques when sampling the same source, indicate that transformations may be occurring in the dilution process or on the filters themselves.

## Inorganic Emissions

The inorganic composition of discharges from these space heaters showed very high levels of a number of elemental species. As with organic discharges, speciation would be required to characterize adverse health impacts which might be expected from using these waste fuels for space heating. In the case of metallic species, the combustion emissions of several toxic or carcinogenic metals were found at elevated levels, especially in the flue gas stream from the air atomization burner and in the vaporizing pot residues. For example, 16 metallic species including boron are compared in Figure 2 for the vaporizing pot test using automotive crankcase oil. The metallic content of the fuel and pot residue is compared on a weight of fuel burned basis where it is observed that most of the fuel metal content is retained in the pot residue.

The flue gas concentration of elemental species was generally much higher for the air atomizing burner than for the vaporizing pot burner. Typical concentrations are shown in Figures 3a and 3b for the air atomizing heater using automotive crankcase oil. Fuel levels and flue gas levels are shown for both SASS and dilution tunnel samples. For most elements, the SASS train collected a significantly higher amount of the element of interest than the dilution tunnel, indicating that metallic species may be passing through the dilution tunnel sampler uncollected. An anomalously high value for chromium is seen in the SASS sample in Figure 3a. This may be due to contamination from stainless steel parts in the SASS train. Nickel is seen to also show anomalous behavior with a high measured level in the SASS sample but low fuel concentrations.

An interesting comparison can be made between the truck and automotive crankcase oils. The high metallic content of crankcase oil is attributed to wear of metal engine parts or, in the case of lead, exposure of residues from lead-containing gasoline to lubricated surfaces. Thus, automotive crankcase oil would be expected to yield higher lead levels than the corresponding recycled oil from truck lubrication. As shown in Figure 4, which illustrates elements emitted at higher levels, this trend is observed in the tests with the air atomization burner, showing much higher lead levels with automotive crankcase oil. In Figure 5 a similar comparison is made of the total mass of elements for waste oils and pot residues from the vaporizing burner firing truck and automotive crankcase oils. As in Figure 2, this figure also shows that a significant percentage of the elements are retained in the pot residue of the vaporizing burner.

## Comparison with TLVs

Although speciation is necessary to evaluate specific health impacts, it is significant to note that several elements exceeded the threshold limit values established for chemical substances.[4] Nine elemental species which showed elevated discharges as measured by their flue gas concentrations are shown in Table IV. A comparison of sampling systems, burner types, and fuels tested is also included. The magnitude of several of these discharges is very high. Consider lead, where the air atomizing burner produced concentrations at 1,000 times the 8-hour average TLV when burning automotive crankcase oil. A leaky flue or direct exposure to the flue gas could produce an elevated exposure to lead from this source. Iron is also a source of concern because the combination of iron oxides and certain PAH compounds has been shown to produce an elevated risk of cancer in laboratory animals.[5] Ni, P, Cr, Cu, and Fe all had high metal discharge concentrations, especially for the case of air atomization burners.

## Conclusions

This study provides information about emissions from waste crankcase oil heaters. The data provided should be useful to heater manufacturers and to regulators. Burner design and fuel composition both have an obvious effect on the level of inorganic elements emitted. The vaporizing pot burner retained a significant amount of the trace elements in the pot residue, whereas the air atomizing burner allowed more of the trace elements to be carried by the flue gas into the stack, and had particulate emission levels that were an order of magnitude higher.

The study also showed that total organic emissions from the two burner designs are similar. However, higher levels of polynuclear aromatic hydrocarbons (PAH) were found in discharges of the vaporizing pot burner.

Emissions of carbon monoxide and unburned hydrocarbons are similar to those of a conventional oil burner. However nitric oxide (NO) and sulfur dioxide ($SO_2$) were significantly higher due to higher nitrogen and sulfur contents in the fuel.

## Acknowledgments

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## References

1. "Standard Method of Test for Smoke Density in Flue Gases from Distillate Fuels," ASTM Designation: D2156-65 (Reapproved 1970), 1970. Annual Book of ASTM Standards, Part 17, pp. 728-731.

2. Lentzen, D.E., Wagoner, D.E., Estes, E.D., and Gutknecht, W.F., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," U.S. Environmental Protection Agency, IERL, Research Triangle Park, NC, EPA-600/7-78-201 (NTIS No. PB 293 795), October 1978.

3. Barbour, R.L., McGinnis, K.M., and Cooke, W.M., "Chemical Analysis of Waste Crankcase Oil Combustion Samples," Draft Report, U.S. Environmental Protection Agency, IERL, Research Triangle Park, NC (Contract No. 68-02-2686, Task 133), 1982.

4. "TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1980," ACGIH, Cincinnati, OH, 1980.

5. Saffiotti, U., Montesano, R., Sellakumar, A.R., and Kaufman, D.G., "Respiratory Tract Carcinogenesis Induced in Hamsters by Different Dose Levels of Benzo(a)Pyrene and Ferric Oxide," J. Natl. Cancer Inst., Vol. 49: 1199-1208, 1972.

Table I. Analytical results of truck and automotive crankcase oil and No. 2 fuel oil samples.

| Analysis Performed | Truck Crankcase Oil | Automotive Crankcase Oil | No. 2 Fuel Oil |
|---|---|---|---|
| Heating Value, Gross | | | |
| MJ/kg (Btu/lb) | 44.30 ( 19,040) | 43.61 ( 18,750) | 45.04 ( 19,360) |
| GJ/m³ (Btu/gal) | 39.54 (141,850) | 39.09 (140,250) | 38.02 (138,180) |
| Heating Value, Net | | | |
| MJ/kg (Btu/lb) | 41.54 ( 17,860) | 40.76 ( 17,520) | - |
| GJ/m³ (Btu/gal) | 37.07 (133,000) | 36.54 (131,090) | - |
| API Gravity @ 15°C | 26.7 | 26.0 | 33.6 |
| Density @ 15°C, g/ml | 0.894 | 0.898 | - |
| Viscosity @ 40°C, mm²/s or cs | 65.4 | 67.7 | 2.75 |
| Viscosity @ 40°C, kPa.s or cp | 57.4 | 59.8 | - |
| Density @ 40°C by pycnometer, g/ml | 0.876 | 0.882 | 0.844 |
| Karl Fisher Water, % | 0.94 | 1.15 | - |
| Ash, % | 0.63 | 1.17 | <0.01 |
| Carbon, % | 86.5 | 81.3 | 87.0 |
| Hydrogen, % | 13.0 | 13.4 | 12.5 |
| Nitrogen, % | 0.07 | 0.12 | <0.1 |
| Sulfur, % | 0.86 | 0.46 | 0.22 |
| | | 97.6 | |

Table II. Sampling data.

| Sampling Condition | Vaporizing Burner |  | Air Atomizing Burner |  |
|---|---|---|---|---|
|  | Automotive | Truck | Automotive | Truck |
| Average Stack Temperature, °C | 414 | 416 | 339 | 332 |
| Alnor Reading, m/min (ft/min) at stack conditions | 129<br>(424) | 126<br>(412) | 84<br>(275) | 88<br>(288) |
| Stack Diameter, cm | 15.2 | 15.2 | 22.9 | 22.9 |
| Total Volume Sampled (SASS), $m^3$ | 30 | 32 | 15 | 29 |
| Total Volume Sampled (Dilution Tunnel), $m^3$ | 238 | 83 | 122 | 90 |
| Volumetric Flow Rate (Q) at STP (20°C, 0.1 MPa (1 atm)), $m^3$/sec | 0.015 | 0.014 | 0.024 | 0.024 |
| Fuel Feed Rate, l/hr (gal/hr) | 2.51<br>(0.662) | 2.46<br>(0.65) | 5.91<br>(1.56) | 5.91<br>(1.56) |

Table III. Gaseous and particulate data from waste oil heaters.

| | Oxygen | Excess Air | Carbon Monoxide | | Unburned Hydrocarbons | | Nitric Oxide | | Sulfur Dioxide | | Steady-State Smoke No. | Particulate Loading |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | ppm @ 3% $O_2$ | g/kg | ppm @ 3% $O_2$ | g/kg | ppm @ 3% $O_2$ | g/kg | ppm @ 3% $O_2$ | g/kg | Bacharach | mg/m$^3$ |
| Vaporizing Burner | | | | | | | | | | | | |
| No. 2 Oil | 9.45 | 76.9 | 31.2 | 0.48 | 2.5 | 0.06 | 51.2 | 0.84 | 20.1 | 0.7 | 4.1 | 24.15 |
| Automotive Waste Oil | 9.98 | 84.6 | 14.7 | 0.23 | 3.3 | 0.08 | 104.4 | 1.72 | 195.6 | 6.9 | 1.0 | 18.20 |
| Truck Waste Oil | 10.08 | 86.7 | 16.5 | 0.25 | 1.8 | 0.04 | 90.3 | 1.47 | 318.6 | 11.1 | 1.0 | 26.70 |
| Air Atomizing Burner | | | | | | | | | | | | |
| No. 2 Oil | 4.20 | 23.5 | 12.9 | 0.20 | 1.7 | 0.04 | 59.4 | 0.97 | 55.9 | 1.9 | 0.0 | 10.28 |
| Automotive Waste Oil | 4.83 | 27.9 | 25.0 | 0.38 | 3.1 | 0.08 | 158.1 | 2.61 | 214.0 | 7.5 | 2.2 | 224.45 |
| Truck Waste Oil | 4.83 | 28.0 | 16.7 | 0.25 | 2.1 | 0.05 | 109.6 | 1.79 | 333.0 | 11.6 | 1.1 | 223.40 |

Table IV. Comparison of discharge concentrations of some elements determined by ICAP and the American Conference of Governmental Industrial Hygienists Threshold Limit Values (all values are reported in μg/m$^3$).

| Element | Pb | P | Cr | Ni | Cu | Zn | Cd | Fe | Co |
|---|---|---|---|---|---|---|---|---|---|
| Threshold Limit Values (Time Weighted Averages) | 150 | 1000 | 500 | 100 | 1000 | 5000 | 50 | 1000 | 50 |
| SASS Trains | | | | | | | | | |
| Vaporizing Burner-Truck | 197 | 205 | 1547 | 1104 | 16 | 450 | -- | 5,641 | 21 |
| Vaporizing Burner-Automotive | 1,604 | 199 | 4198 | 21 | 16 | 194 | 1 | 15,180 | 54 |
| Air Atomizing Burner-Automotive | 143,900 | 19,440 | 4954 | 3548 | 2377 | 66,210 | 109 | 22,280 | 72 |
| Air Atomizing Burner-Truck | 57,740 | 68,710 | 313 | 1560 | 2377 | 117,400 | 155 | 15,510 | 23 |
| Dilution Filters | | | | | | | | | |
| Vaporizing Burner-Truck | 124 | 522 | 0.9 | 4 | 11 | 341 | 0.3 | 48 | 2 |
| Vaporizing Burner-Automotive | 549 | 170 | 0.6 | - | 6 | 89 | 0.4 | 37 | 1 |
| Air Atomizing Burner-Automotive | 85,800 | 40,460 | 295 | 54 | 1764 | 45,650 | 86 | 9,041 | 218 |
| Air Atomizing Burner-Truck | 23,770 | 50,760 | 79 | 32 | 1019 | 44,630 | 86 | 4,374 | 9 |

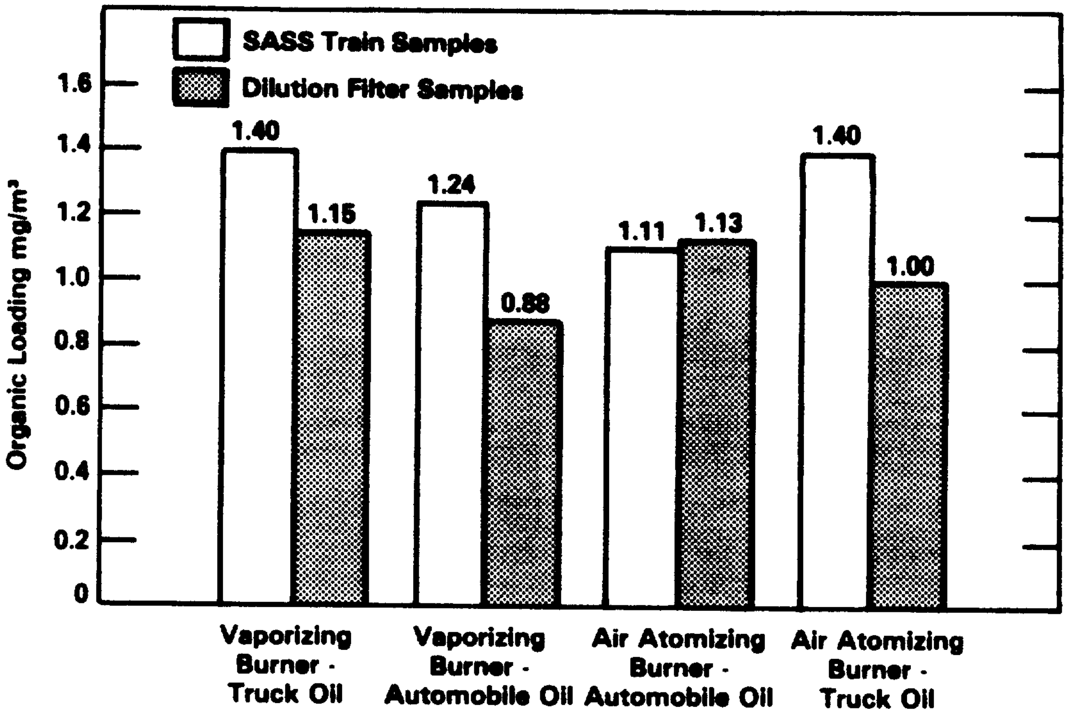

Figure 1. Comparison of total organics for each test run sampled by SASS train and dilution tunnel.

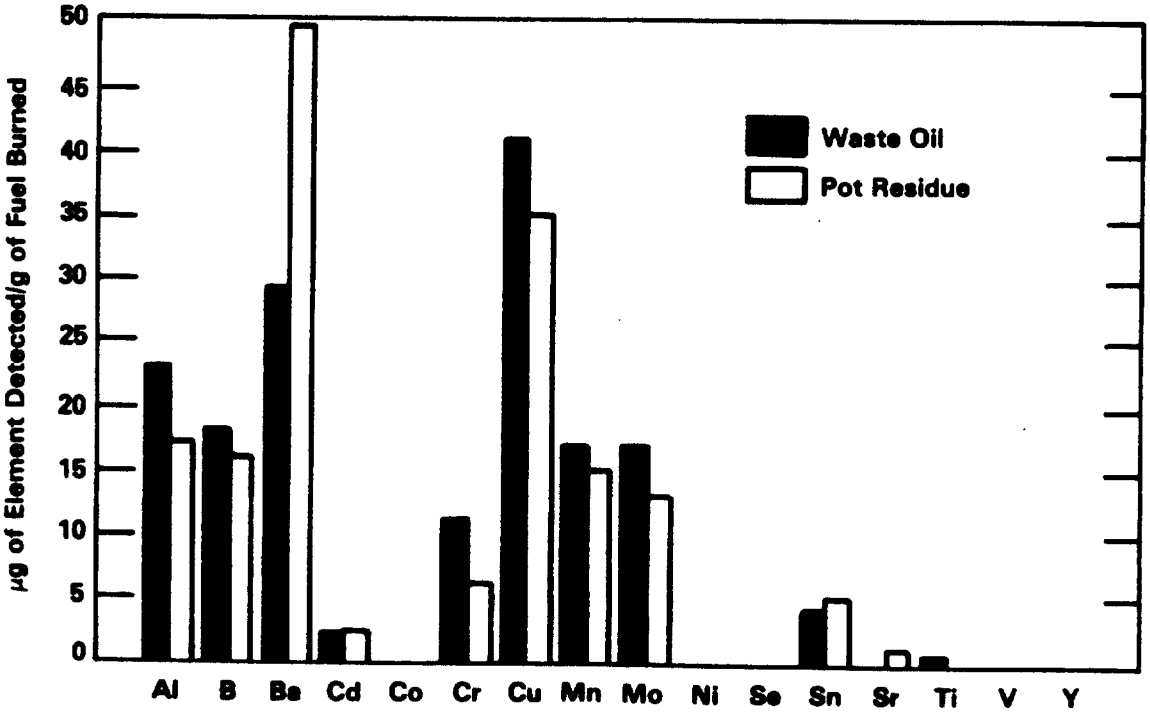

Figure 2. Comparison of total mass of elements determined by ICAP for the fuel and pot residue in the vaporizing pot heater burning automotive crankcase oil.

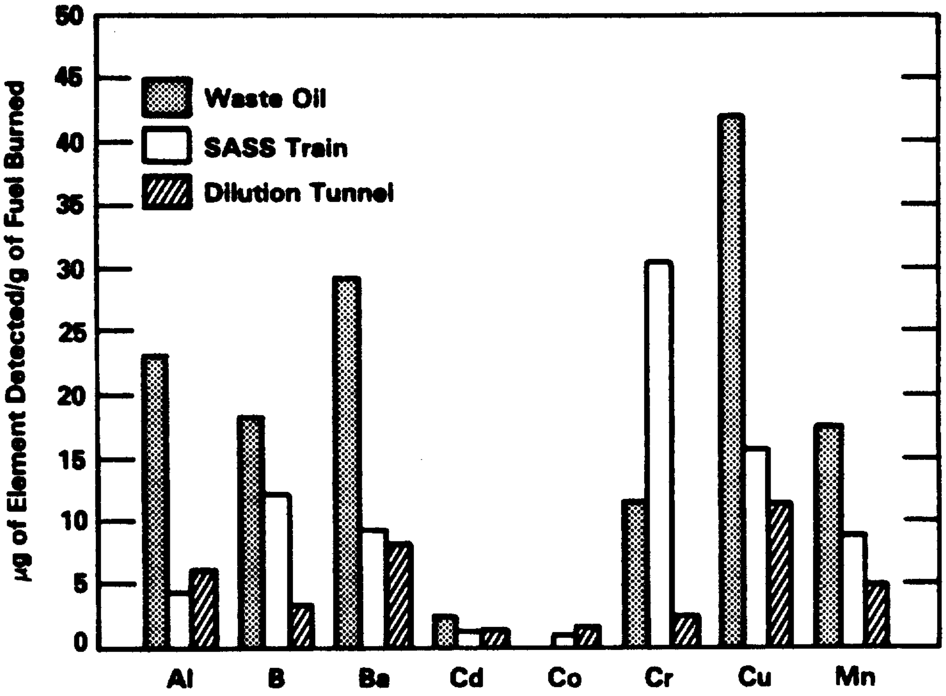

Figure 3a. Comparison of total mass of elements determined by ICAP for the air atomizing heater burning automotive crankcase oil.

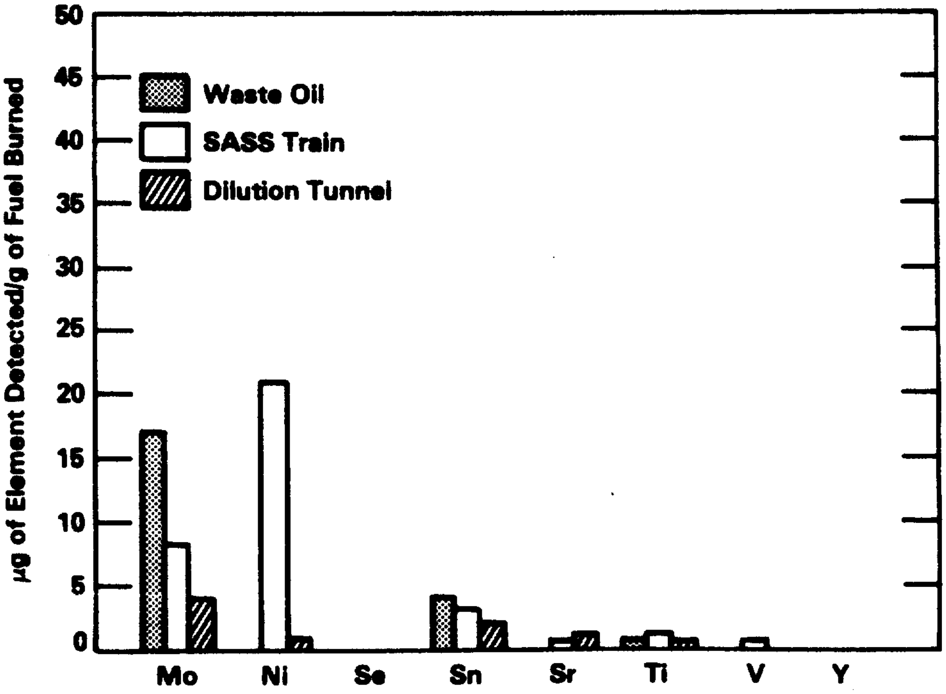

Figure 3b. Comparison of total mass of elements determined by ICAP for the air atomizing heater burning automotive crankcase oil.

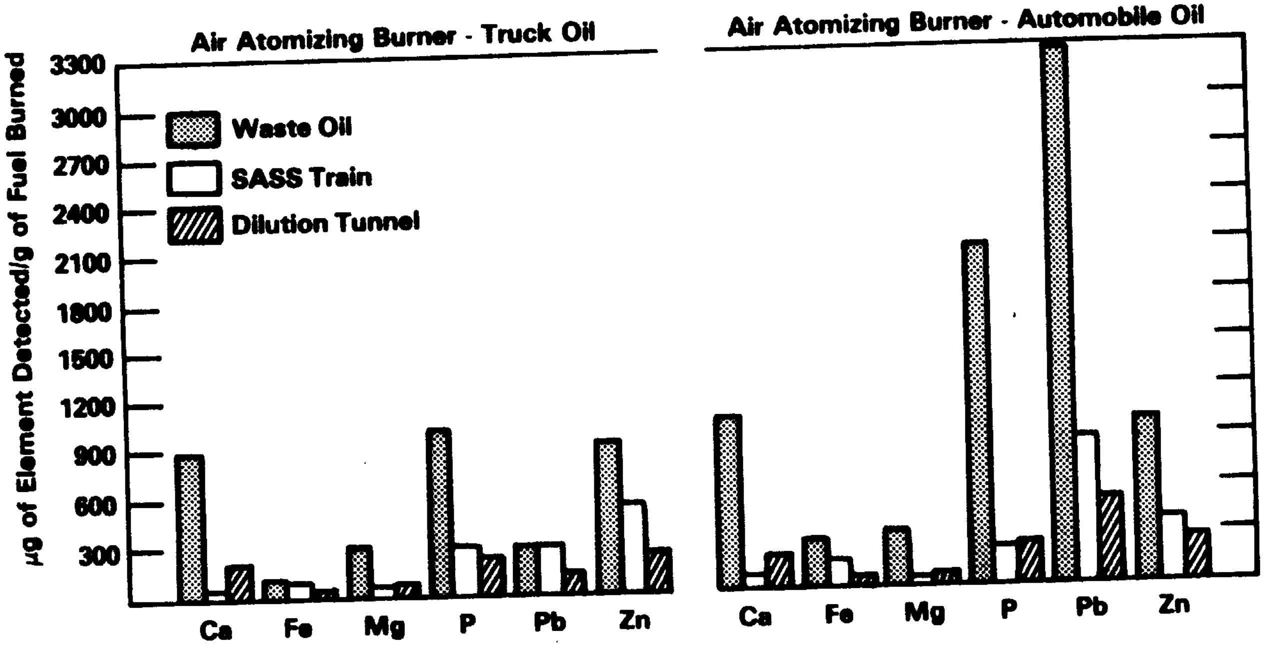

Figure 4. Comparison of total mass of elements determined by ICAP for the air atomizing heater burning automotive and truck crankcase oil.

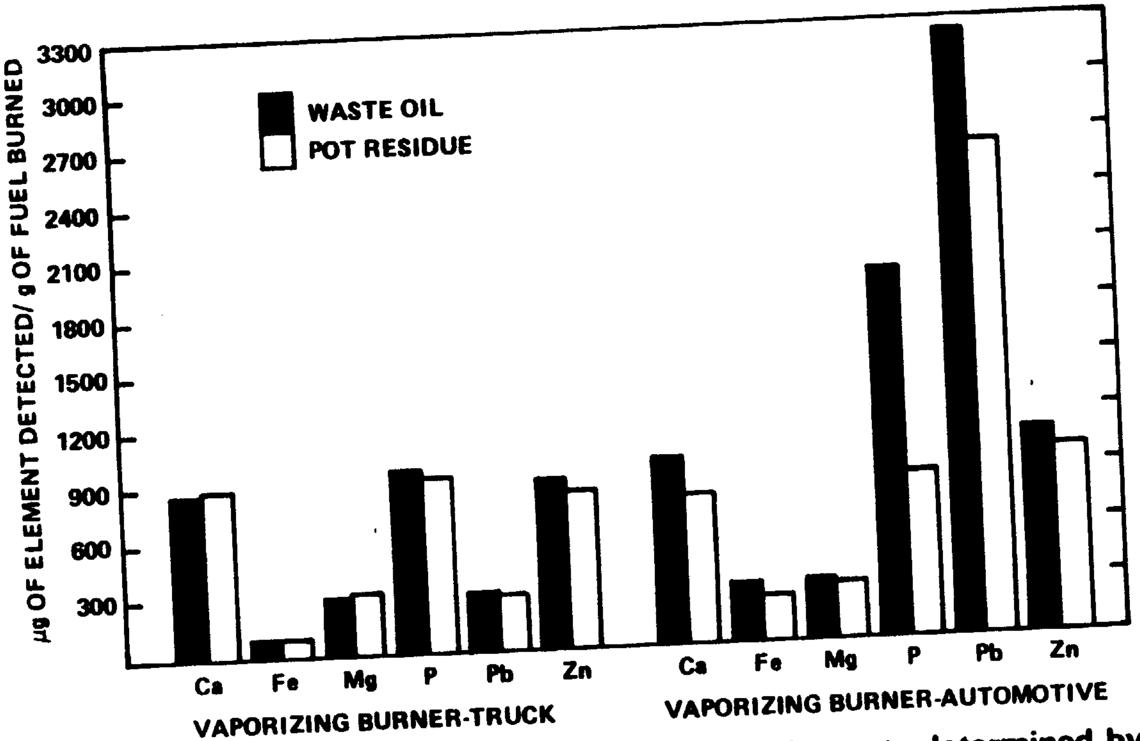

Figure 5. Comparison of total mass of elements determined by ICAP for waste oil and pot residue in the vaporizing pot heater burning truck or automotive crankcase oils.