

Fate of Metals in the Combustion of Industrial Waste Oils



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This study aims to establish criteria under which to use industrial waste oils as alternative fuels for combustion under conditions of maximum environmental safety. Waste oils as well as the particulate matter emitted from their combustion were analysed and characterized. The size, morphology and composition of metals in the particulate matter contained in the oils as well as chlorine content were analysed by electron microscopy and X-ray microanalysis. Heavy metals were determined in the oil by ETAAS. All the oil samples characterized were burnt in an experimental combustor where the conditions of combustion were modified. The emitted particulate matter was chemically digested and Cr, V, Cd, Cu, Pb and Fe were determined in each final solution by ETAAS. The results obtained, the accumulation factors for metals and the relationship between combustion conditions and emission of particulate matter and metals, are discussed.

Keywords: *Combustion; waste oil; electron microscopy; particulate matter; metals*

Introduction

A potential use of mineral waste oil is as an alternative fuel owing to its energy content.¹ However, such combustion should not be done indiscriminately. The mineral waste oils contain heavy metals, chlorine and chlorine derivatives and other toxic chemicals.^{2,3} Their combustion could produce more toxic compounds which would then be emitted into the atmosphere.⁴ To avoid this source of air pollution, the current legislation establishes a maximum limit of concentration for some of the mentioned substances, such as heavy metals and organochlorine compounds (PCBs), in both the oil and the emitted particulate matter.^{5,6}

The emission of toxic metals from combustion sources is a potential threat to human health.⁷ The emitted metals are often concentrated on particulate matter with diameters of less than 1 μm .⁸ The concentration of metals on small particles increases the risk of their adverse effects on human health. Once in the environment, these particles can penetrate deep into the lungs where the toxic metals would be in close contact with the blood supply.⁹

However, depending on the combustion conditions, the total amount and the size of particulate matter can be modified, as well as the metals emitted to the atmosphere.

On the other hand, the physical form into which the metals are converted in the combustion device, may influence their volatility. Some metals originally present in the industrial oil could exit the waste combustion system as a vapour phase together with the gaseous emissions. Consequently, two principal classes of escape pathways can be identified. One class of pathway is characterized by the vaporization of the metals at some point in the combustion system. The second class is characterized by the particulate matter containing nonvolatile metals.

Most of the studies carried out in this subject deal with only one fraction involved in the combustion, either the waste oil or the particulate matter. To study the whole process is a difficult task, since a very controlled combustion device as well as powerful analytical techniques are needed. However, considering only the total process, and after characterizing both the waste oils and the particulate matter emitted, the distribution and fate of metals in the combustion can be found.

The present paper describes a study carried out in a pilot combustion plant in which some industrial waste oil was burnt. The size and morphology of the particulate matter both in the oil and in that emitted when the oil was burnt were also evaluated. The combustion conditions were modified and the determination of several metals in the oil and in the emitted particulate matter from the combustion was accomplished.

Experimental

Apparatus

Electron microscopy (EM) and X-ray microanalysis (XRMA) were performed on a JEOL (Palo Alto, CA, USA) JSM 6400 type microscope equipped with an X-ray spectrometer energy dispersive system (EDS) and with a primary micro-X-ray source and collimating attachment for microanalysis, with a Link Analytical (Redwood City, CA, USA) e-XL, with Si (Li) MK6/6 b VTW detector.

Measurements were made with a 20 kV and 0.6 nA electron current. A Balzers MED 10 unit was used to prepare the samples at high vacuum. Imaging and sizing were performed using the same equipment.

The peak profiles for each metal were obtained from the ZAF-4/VSP library supplied with the equipment.

A Thermo-Jarrel Ash video 11 Atomic Absorption Spectrometer equipped with both a graphite furnace and flame and hydride generators was used for the analysis of metals.

A pilot combustion plant was used to burn the oil, under the following operating conditions: flow rate of oil: 20 kg h^{-1} , maximum pressure 22 bar; flow rate of air: 500 kg h^{-1} .

The experimental combustor used was of 610 mm diameter and 3.2 m length with a maximum power of 500 kW. Rosemund automatic monitors for NO_x , SO_2 , CO_2 , CO , O_2 and total hydrocarbons were coupled directly in the exit of the combustor.

An isokinetic probe equipped with a bronze tubular filter was used to collect the particulate matter. The probe was placed in the exit of combustor before the cyclone or other separation system.

Combustion

The experimental conditions of the combustion are shown in Table 1.

A schematic of the experimental combustor used is shown in Fig. 1. Two identical isokinetic probes were used to collect the particulate matter. One of the probes was placed in the axis of

the combustion chamber and the other one in a diameter at a distance of $R/2$ from the axis being R the radius of the combustion chamber. This situation was selected in order to obtain the maximum information about both the particulate matter production and their morphology and composition. The isokinetic ratio was continuously checked to assure the representativity of the particulate matter sampling. The flow pumped through the probes was adjusted to the average velocity of gases in the corresponding section of the combustor.

As the probes were placed inside the combustion chamber, the concentration of particulate matter sampled represents the maximum concentration since there were no filters or trapping devices before the sampling site. Each probe contained a conical filter placed in the tube.

Sample Preparation

To study the size and composition of particulate matter contained in the oil, 1 l of oil was filtered through a 45 μm glass fibre filter. The filter was dried in an oven at 105 $^{\circ}\text{C}$. A small part of this filter containing the particulate matter was covered with gold to make it a conductor of electricity and it was analysed by EM and XRMA.

To prepare the sample of particulate matter emitted in the combustion of the oil, a slurry of particulate matter in acetone was prepared. Several drops of this slurry were placed on the sampler of the EM, and it was dried. The sample was covered with carbon to increase its conductivity.

The waste oil was filtered through a 100 μm filter to remove particulate matter before injection into the combustor.

Determination of Metals in the Oil

Several solutions of oil were prepared in xylene by diluting directly the waste oil with xylene. These solutions were analysed by ETAAS. Ten microliter samples were directly injected into the graphite furnace. Both Smith-Hieftje and deuterium were used as background correctors. Coated graphite tubes were used for all metals except Cd for which non-coated tubes were used.

A blank of xylene was measured in each case to check the absence of atomic signal at the corresponding wavelength. The experimental conditions used in each case to measure the concentration of metals by ETAAS are shown in Tables 2 and 3.

Determination of Metals in Particulate Matter

All the particulate matter sampled in the isokinetic probe was accurately weighed and placed in a glass beaker with 5 ml of

HCl (37.5%) and 5 ml of HNO_3 (60%). The mixture was heated until total elimination of nitrous vapours. The yellow solution obtained was cooled to room temperature and 10 ml of HClO_4 (70%) were added. Once all of the sample was digested, the final colourless solution was made up to 100 ml with distilled water. Appropriate dilutions of the sample solutions were made when necessary. These solutions were directly injected into the graphite furnace of an atomic absorption spectrometer. The experimental conditions used are shown in Tables 3 and 4.

Determination of Chlorine

The determination of chlorine in the waste oils was carried out in a total organic halogen analyser (TOX-10 E) Mitsubishi Kasei (Tokyo, Japan) equipped with an adsorption module with activated charcoal columns. An analyser module with calcination oven, a control system and a titration cell, where the electrolytic analysis was carried out were coupled to this system. The procedure consisted of the adsorption of the oil on a microcolumn of activated charcoal, after which the adsorbent was burnt. Chlorine compounds were transformed into hydro-

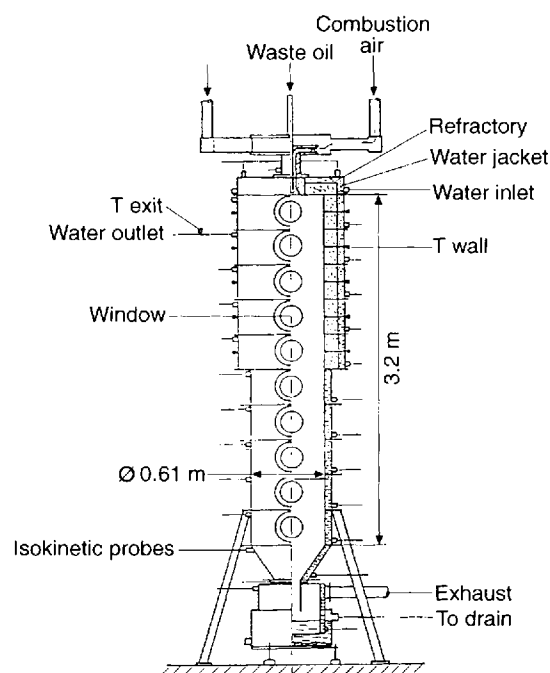


Fig. 1 Combustor.

Table 1 Experimental conditions used in the combustion of the waste oil

Experiments	Oil temp./ $^{\circ}\text{C}$	Air temp./ $^{\circ}\text{C}$	Oil flow/ kg h^{-1}	Air flow/ mbar	Sampling temp./ $^{\circ}\text{C}$	Oil injection pressure/ kg cm^{-2}	Time/min	Oil con- sumption/ kg	Total volume of gases/ m^3	Conc. of particu- lates/ mg m^{-3}
E2	40	180	20.1	6.1	660	12.5	146	48.91	1132	513.7
E3	40	85	20.2	6.4	653	12.9	144	48.48	1116	389.6
E4	40	135	19.9	6.2	672	12	139	46.10	1077	512.6
E5	60	85	20	6.3	672	14.5	126	42	977	803.6
E6	60	135	20.7	5.9	684	17.5	157	52.52	1217	812.1
E7	60	180	20	6.05	638	16	145	48.33	1124	646.5
E8	80	180	20	6.0	668	17.5	87	29	674	862.1
E9	80	135	20.1	6.0	665	20	50	16.75	388	975.6
E10	80	85	20	6.0	662	22	54	18	418	1110
E11	40	85	20.1	6.5	717	14	181	60.63	1403	372.9
E12	40	85	20	5.9	695	21	183	61	1418	286.9

chloric acid which was titrated by redox titration with an electrolytically generated silver ion.

Results and Discussion

Combustion of Waste Oil

The combustion of waste oil involves many variables which can affect both the amount and characteristics of the effluents, such as gases and particulate matter, and the temperature and energy production. In order to study the influence of these variables, the combustion conditions such as the temperature of both the oil and the combustion air were modified as well as the presence of a water oil emulsion.

The waste oil burnt was industrial oil collected in Aragón Community (Spain) which was mainly a mixture of industrial and automotive oil. The waste oil was supplied in 200 l containers. Six different oils, all of them from actual mixtures of waste oils, were burnt and in each case the oil was well characterized before burning. Eleven different experiments named from E2 to E12, were carried out under different combustion conditions, as shown in Table 1. Previous experiments demonstrated that when the oil was colder than 37 °C, the flame was extinguished. In the same way, when the temperature of the combustion air was lower than 80 °C, a poor combustion with flame variations and a high production of fumes was observed. In order to compare the results obtained, the temperature of both oil and air was held at 40 and 85 °C, respectively, in several experiments. These conditions could be

considered as 'basic' conditions. The last experiment, E12 was performed with an emulsion of oil and water (7.5% m/m of water in oil) and under the 'basic' conditions.

In each case the particulate matter produced in the combustion were collected on the isokinetic probes and analysed. Taking into account the mass of particulate matter and the gas flow pumped through the probe in each case, the total concentration of particulate matter was calculated. The results obtained are included in Table 1.

As can be seen, a higher concentration of particulate matter was obtained when the temperature of oil was increased. This fact could be attributed to two different phenomena. One of them is the decrease in the dynamic viscosity of the oil when the temperature increases, making a poorer atomization of the oil in the combustion chamber. Under such conditions the efficiency of the combustion process would be lower. The second reason is the influence of the oil temperature on the quality of the emulsion of oil itself. It is well known that colloid dispersions such as waste oil are modified against temperature, and one of the main effects is the agglomeration of particulate matter to produce bigger agglomerates. These large particulate matter would produce a decrease in the efficiency of the combustion and, consequently, a higher production of the emitted particulate matter.

On the other hand, according to the literature,¹⁰ the use of a water emulsion with the oil instead of the pure liquid combustible should reduce the emission of particulate matter. In our case, an experiment was carried out adding 7.5% of water to the oil previously to be burnt. As can be seen in Table 1, the reduction of the total amount of particulate matter emitted in the experiment number E12 is about 26% with respect to that obtained just with the oil under the same combustion conditions.

Table 2 Experimental conditions used in the analysis of some metals by ETAAS in waste oils

	Temperature/°C					
	Pb	Fe	Cr	Cu	Cd	V
<i>Drying</i> —	150	150	150	150	150	150
Ramp/s	2	2	2	2	2	2
Hold/s	0	0	0	0	0	0
Purge/s	1	1	1	1	1	1
<i>Pyrolysis 1</i>	350	750	550	350	350	500
Ramp/s	15	30	30	25	25	15
Hold/s	0	0	0	0	0	0
Purge/s	2	2	2	2	2	2
<i>Pyrolysis 2</i> —	600	950	900	750	400	750
Ramp/s	20	30	30	25	10	15
Hold/s	0	0	0	0	0	0
Purge/s	1	2	2	1	1	2
<i>Atomization</i> —	1800	2100	2100	1800	1600	2400
Ramp/s	1	0	0	0	1	0
Hold/s	4	4	4	4	4	1
Purge/s	0	0	0	0	0	0
<i>Cleaning</i> —	2100	2300	2400	2200	2000	2400
Ramp/s	0	0	0	0	0	0
Hold/s	2	2	2	2	2	4
Purge/s	3	3	3	3	3	1

Table 3 Operating parameters of AAS

	λ /nm	Slit/nm	Lamp intensity/A	Background corrector
Pb	217.0	1.0	4	Deuterium
Cu	324.7	1.0	4	Smith-Hieftje
V	318.5	0.5	18	Smith-Hieftje
Cr	357.9	0.5	6	Smith-Hieftje
Cd	228.8	1.0	3	Smith-Hieftje
Fe	248.3	0.3	6	Smith-Hieftje

Qualitative Analysis of Particulate Matter

As the waste oils come from different industrial uses, they may contain a wide range of metals. Most of these metals are linked with particulate matter and consequently, they should be analysed on such solid matter. One of the available procedures for qualitative analysis of solids is the use of an electron

Table 4 Experimental conditions used in the analysis of some metals by ETAAS in particulate matter

	Temperature/°C					
	Pb	Fe	Cr	Cu	Cd	V
<i>Drying</i> —	150	150	150	150	150	150
Ramp/s	2	2	2	2	2	2
Hold/s	0	0	0	0	0	0
Purge/s	1	1	1	1	1	1
<i>Pyrolysis</i> —	350	650	900	550	350	500
Ramp/s	15	15	30	25	25	15
Hold/s	0	0	0	0	0	0
Purge/s	2	2	2	2	2	2
<i>Pyrolysis 2</i> —	550	900	1000	750	400	750
Ramp/s	20	15	30	25	10	15
Hold/s	0	0	0	0	0	0
Purge/s	1	2	2	1	1	2
<i>Atomization</i> —	1600	2100	2000	1800	1600	2400
Ramp/s	1	15	0	0	1	0
Hold/s	4	4	4	4	4	1
Purge/s	0	0	0	0	0	0
<i>Cleaning</i> —	2000	2300	2200	2000	2000	2400
Ramp/s	0	0	0	0	0	0
Hold/s	2	2	2	2	2	3
Purge/s	3	3	3	3	3	1

microprobe equipped with an X-ray scan, and this technique was used in this case, to study both the characteristics of particulate matter and for the identification of the metals.

The size and morphology of the formed particulate matter were studied and compared to those corresponding to the particulate matter contained in the oil. Fig. 2 shows several EM micrographs of both types of particulate matter. Fig. 2(a) represents a fine distribution of particulate matter emitted from the combustion of waste oil, in which the disperse-type particles ($< 10 \mu\text{m}$) form a prominent part. These particles are mainly spherical opaque and non-opaque or rounded angular forms as well as cenospheres as shown in Fig. 2(b). The particles from the waste oil are predominantly visualized as agglomerated vesiculars and angulars as shown in Fig. 2(c) and (d). These differences in morphology between the particulate matter before and after the combustion process are similar to those obtained in the combustion of fuel oil.¹¹

The qualitative analysis by X-ray showed the presence of P, S, Cl, Ca, Cr, Fe, Cu, Zn and Pb (Fig. 3). No differences were observed in the qualitative composition of metals between both type of particulate matter from the oil and from the combustion. Other elements such as V and Cd also present in the particulate matter, were not detected by X-ray owing to their low concentration in the sample.

Quantitative Analysis of Particulate Matter

The quantitative analysis of metals were carried out by ETAAS. Table 3 shows the experimental conditions used in each case.

Table 5 summarizes the analytical results of metals in the waste oil. As can be seen, among the elements studied, Pb, with a concentration ranging from 177 to 408 $\mu\text{g g}^{-1}$, is the major

component. The content of Cd and V is quite low, as could be expected. It is worth emphasizing that all the results are expressed as total content of metal. No speciation analysis was carried out to distinguish for instance, Cr^{III} and Cr^{VI} in this case. From a general point of view these results agree with those obtained in other studies.¹²

One interesting aspect is the content of chlorine. It is well known that waste oils contain a variable amount of chlorine. As result of its presence, both the combustion process and the composition of the exhausts are strongly affected.

The chlorine could be transformed during the combustion process into both metal chlorides and hydrochloric acid. In both cases, such compounds would exit the combustion chamber, either as particulate matter or in the vapour phase.

Table 6 shows the concentration of metals found in the particulate matter emitted from the combustion of the oil in each case. All the experiments included in the same line of the table correspond to the same oil. As can be seen, the conditions at which the combustion is carried out affect greatly not only the concentration of the particulate matter in the exhaust gases, but also their composition.

Examining the values, several aspects can be emphasized. First is the apparent accumulation of some metals on the particulate matter. After each combustion test, the combustor device was cleaned. The particulate matter found in the conduits as well as in the combustion chamber was negligible compared with the mass fraction obtained in the exit.

If the balance of each metal is considered as follows:

In oil: Mass of metal = Mass in oil as particulate + Mass dissolved in oil

Out of oil: Mass of metal out = Mass collected by high temp. probe + Mass remaining on combustor walls + Mass exiting in flue gas stream

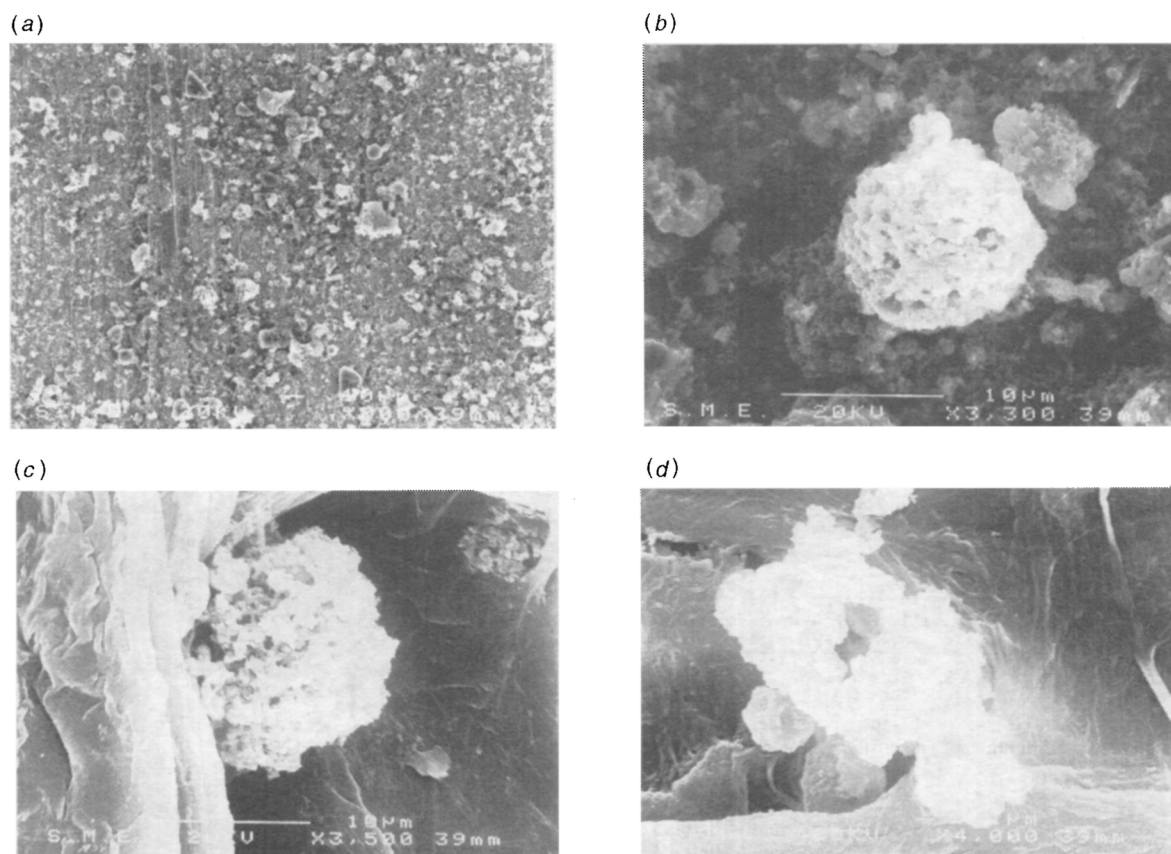


Fig. 2 Electron micrographs of: (a) fine distribution of particulate matter emitted from the combustion of waste oil; (b) cenospheres emitted from the combustion of waste oil; (c) particulate matter contained in waste oil; and (d) agglomerated particulate matter contained in waste oil.

and assuming that the mass remaining on the combustor walls was very low, a new parameter called the 'accumulation factor' (AF) could be defined as follows:

$$AF = [M]_p/[M]_o$$

where $[M]_p$ is the concentration of each metal in the particulate matter and $[M]_o$ concentration in the oil burnt. When these accumulation factors are plotted as a three dimensional graph versus both the temperature of oil and the temperature of air, Fig. 4 is obtained. As can be seen, the influence of the combustion conditions and particularly that of oil temperature, are clear. With the only exception of Cd and perhaps Cu, the maximum AF is reached when the oil temperature is 60 °C and the air temperature 180 °C. These conditions are also those at which the temperature of the sample collection was the minimum, 638 °C.

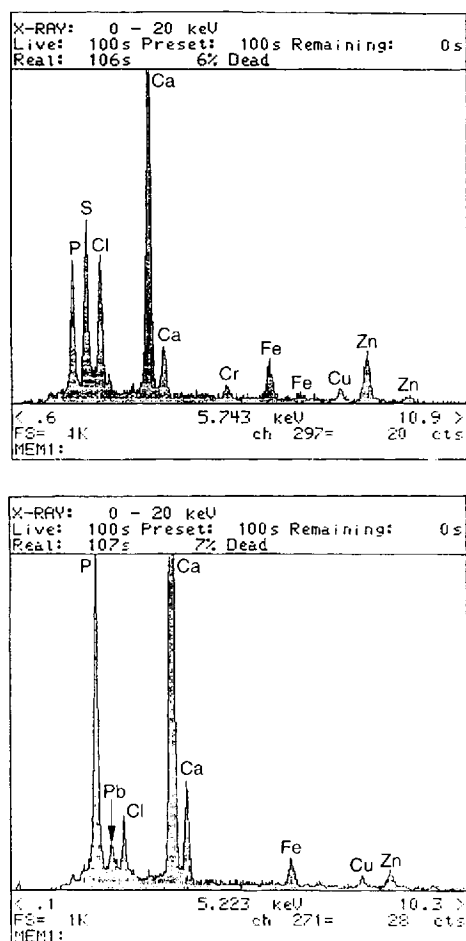


Fig. 3 X-ray spectrum of particulate matter.

Comparing the results of the metals, it can be seen that lead is less accumulated in the particulate matter than Cd and V.

As it was assumed that all the metals in the oil were distributed in the particulate matter and in the gas exhaust, the fraction of each metal which is not present in the particles should appear in the gas fraction. Table 7 shows the results obtained expressed as a percentage of the metal escaping as vapour phase in the gas exhaust. These values were calculated as follows:

$$[M]_g = \frac{[M]_o F_o - [M]_p F_p F_g}{[M]_o F_o} \times 100 = \% [M]_g$$

where $\% [M]_g$ is the amount of each metal in the gaseous fraction expressed as percentage of the total amount of metal; $[M]_o$ is the concentration of each metal in the oils; F_o is the total flow of oil burnt in each experiment; $[M]_p$ is the concentration of each in the particles; F_p is the concentration of particulate matter in the gaseous fraction in each experiment; and F_g is the total volume of gas which exits the combustion chamber in each experiment.

More than 90% of lead is in the gas, confirming the suggestion of Linak and Wendt.⁴ This behaviour agrees with the idea of the influence of volatility of the different chemical compounds formed during the combustion. In fact, some metals such as Pb, are able to produce volatile species which, at high temperature, exit the combustion chamber in the vapour phase.

On the other hand, the temperature of the oil strongly influences the behaviour of chromium, which increases in the gaseous fraction when the oil temperature increases too.

Concerning environmental safety, the concentration of Pb, Cu and Fe are much higher than the maximum values permitted by the legislation^{5,6} as shown in Table 7. The legislation sets a maximum value of 5 mg m⁻³ of each of Pb, Cu and Cr each and with a maximum value of 5 mg m⁻³ of total emission from the combustion of waste oil. It is obvious that the results of the oil burnt.¹⁰ For this reason, it is not surprising that the results obtained in the combustion study carried out by EPA¹² were slightly different, with lower values of Pb and Cu than those obtained in our case.

Conclusions

The combustion of waste oil produces two main phases containing heavy metals. One phase is the solid particulate matter emitted in which the metals are condensed and accumulated on their surface. The second important phase is the gaseous one, which contains a variable amount of heavy metals, probably as volatile chlorides.¹³ Such volatile compounds could exit the combustion chamber as well as their conduits and they could produce a dangerous emission of heavy metals into the atmosphere. The emission will depend on the chemical composition of the waste oil as well as on the experimental

Table 5 Concentration of metals found in waste oils*

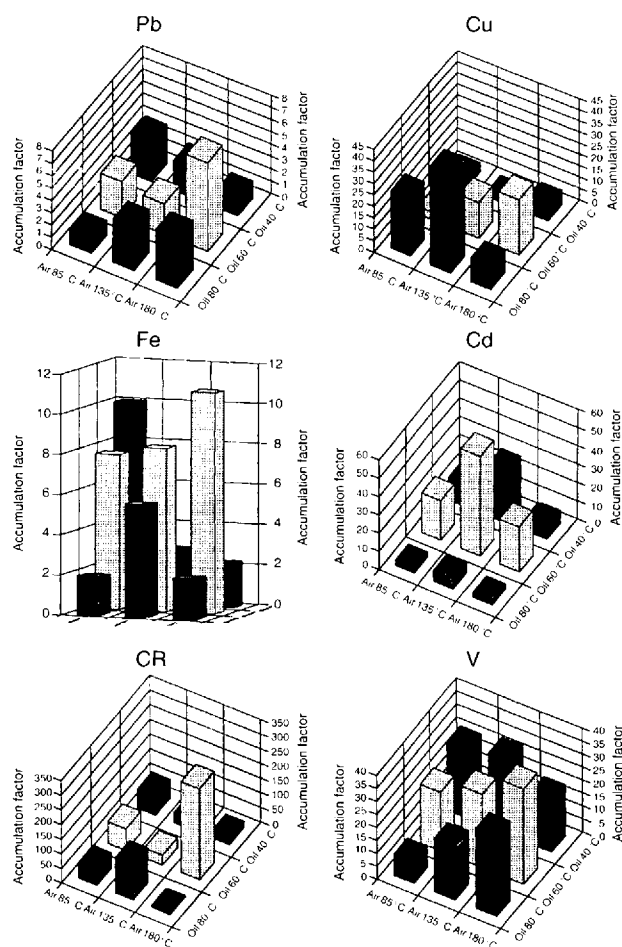
Experiments	Pb/ $\mu\text{g g}^{-1}$	Fe/ $\mu\text{g g}^{-1}$	Cr/ $\mu\text{g g}^{-1}$	Cu/ $\mu\text{g g}^{-1}$	Cd/ng g ⁻¹	V/ng g ⁻¹	Total chlorine/ $\mu\text{g g}^{-1}$
E2	280 ± 12	185 ± 9	2 ± 0.1	97 ± 6	32.7 ± 3	254 ± 34	254
E3/E3	329 ± 24	151 ± 7	3 ± 0.1	135 ± 6	36.8 ± 3	197 ± 27	273
E5/E6	408 ± 12	188 ± 2	3 ± 0.2	135 ± 6	28 ± 4	177 ± 21	1084
E7/E8	177 ± 8	202 ± 14	2 ± 0.2	84 ± 3	31.7 ± 4	163 ± 16	287
E9/E10	205 ± 12	173 ± 9	1 ± 0.1	47 ± 3	29.1 ± 2	244 ± 4	216
E11/E12	299 ± 14	127 ± 7	1 ± 0.1	90 ± 6	28.1 ± 2	176 ± 2	237

* Average of five independent analyses.

Table 6 Concentration found of metals in particulates emitted from the combustion of industrial waste oils^d

Experiments	Pb/ $\mu\text{g g}^{-1}$	Fe/ $\mu\text{g g}^{-1}$	Cr/ $\mu\text{g g}^{-1}$	Cu/ $\mu\text{g g}^{-1}$	Cd/ mg g^{-1}	V/ $\mu\text{g g}^{-1}$
E2	394 \pm 14	407 \pm 14	41 \pm 1	575 \pm 21	227 \pm 3	5 \pm 0.01
E3	1035 \pm 40	1574 \pm 22	189 \pm 1.5	508 \pm 29	445 \pm 17	5.2 \pm 0.2
E4	794 \pm 39	938 \pm 9	104 \pm 5	254 \pm 21	1002 \pm 42	56 \pm 0.2
E5	1187 \pm 54	1458 \pm 29	223 \pm 17	450 \pm 36	611 \pm 13	4 \pm 0.2
E6	1040 \pm 40	1514 \pm 12	102 \pm 8	2092 \pm 118	1527 \pm 54	5 \pm 0.2
E7	1280 \pm 90	2155 \pm 41	621 \pm 19	2008 \pm 69	794 \pm 18	6 \pm 0.2
E8	715 \pm 78	413 \pm 14	14 \pm 0.5	825 \pm 12	85 \pm 7	5 \pm 0.3
E9	720 \pm 26	966 \pm 16	120 \pm 8	2008 \pm 44	168 \pm 8	5 \pm 0.3
E10	247 \pm 15	324 \pm 11	53 \pm 0.6	1175 \pm 40	78 \pm 4	2 \pm 0.1
E11	489 \pm 50	963 \pm 8	247 \pm 5	765 \pm 10	315 \pm 8	5 \pm 0.8
E12	1312 \pm 102	1582 \pm 13	18 \pm 4	1833 \pm 70	378 \pm 18	5 \pm 0.2

^d Average of five independent analyses.

**Fig. 4** Accumulation factors.**Table 7** Percentage of metal as vapour phase contained in the exhaust gases

Experiments	Pb (%)	Fe (%)	Cr (%)	Cu (%)	Cd (%)	V (%)
E2	98.31	97.35	22.69	92.91	91.47	65.83
E3	96.82	89.16	12.51	95.89	86.56	70.81
E4	96.98	87.51	32.16	97.63	66.02	62.94
E5	95.17	87.28	23.01	97.23	63.75	58.33
E6	98.12	93.83	36.26	88.18	57.59	79.76
E7	89.58	83.91	45.39	65.58	64.18	50.75
E8	93.61	96.02	86.94	82.32	95.21	48.55
E9	93.84	90.05	83.53	27.58	89.93	64.70
E10	97.26	95.72	79.65	43.70	94.09	78.63
E11	98.59	94.39	11.60	93.33	91.50	78.22
E12	96.65	89.08	13.94	84.55	96.65	75.90

conditions used in the combustion process. The accumulation factor, *i.e.*, the ratio between the concentration of each metal in the emitted particles and in the oil, is highly dependent on the metal as well.

Here this accumulation factor, ranges from 310 for chromium to 1.4 for lead. In the present paper a combustor especially designed for research and development was used without a filter or separation of particulate matter before the sampling point. However, an efficient system of trapping particulate matter should be used if the industrial oil waste were to be used as alternative fuel.

Industrial waste oil could be used as alternative fuel only if an efficient trap of particulate matter were installed. The study carried out confirms such attempts. A further study of the gaseous fraction emitted should be focused on the composition of volatile metal derivatives in order to assure that the combustion is sufficiently safe from an environmental point of view.

This is a challenge from an analytical point of view, and new methodology should probably be developed in order to assess the representativity of such gaseous sampling of volatile metals.

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