

THERMAL DECOMPOSITION OF MOBILE PHONES

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Introduction

Mobile phones are used for a variety of purposes, including keeping in touch with family members, conducting business, and having access to a telephone in the event of an emergency. Some people carry more than one cell phone for different purposes. In 2006 more than one billion mobile phones were shipped worldwide, 22.5 % more than the quantity shipped in 2005. By 2008 the number of mobile phone users around the world was predicted to reach two billion¹.

One important characteristic of these electronic devices is that they become outdated very fast and the number of unused or retired phones will keep growing year after year, posing an ever increasing problem for the environment due to the fact that most of them are discarded with the household garbage.

These wastes present a growing disposal problem because of the substances involved that may cause serious damage to the environment and have adverse effects on human health. Therefore, the management of these wastes must be done properly. To this regard, the latest Electrical and Electronic Equipment Waste Directive² promotes the re-use, recycling and recovery of these wastes as well as the collection of electrical and electronic wastes as a separate waste stream, which enhances the prospects for economic recycling.

There are interesting contributions in literature considering pyrolysis and/or combustion of electronic wastes, mainly focused in the treatment of printed circuit boards and plastics recovered from e-wastes²⁻⁴.

This study complements a previous work⁵ with the aim of achieving a better understanding of the most important pollutants evolved in the thermal decomposition of mobile phones as a representative domestic e-waste.

Materials and methods

Three types of waste obtained from a mobile phone were employed in pyrolysis and combustion runs in order to analyze the pollutants emitted. The first sample was the printed circuit board alone, including metals (named as EC = Electronic Circuit). The second sample was the case of the mobile phone (named as MC = Mobile Case) and the last sample was obtained by crushing together a mixture of the circuit board (11 g) and the mobile case (17 g) (named as EW = Electronic Waste). Table 1 shows some characteristics of each material.

Table 1. Ultimate analysis of the wastes used on dry basis and net calorific value.

Wt%	EW	EC	MC
C	63.0	19.0	78.9
H	5.7	1.5	6.9
S	0.0	0.0	0.0
N	1.7	0.0	2.6
O and ash	29.6	79.5	11.6
Net calorific value (kJ/kg)	16663	7650	30634

A laboratory scale horizontal tubular reactor was used for the combustion and pyrolysis runs of each sample under fuel-rich conditions. Figure 1 shows a scheme of the system used. Different quantities of each waste were placed on a holder and introduced into the reactor at constant speed. Table 3 shows the operation conditions for

every run. Nitrogen and synthetic air were used for the pyrolysis and combustion runs respectively and a quartz package located at the end of the reactor was used to obtain a good mixing.

Table 2. Experimental conditions for pyrolysis and combustion runs.

Waste	Feed speed (mm/s)	Flow (mL/min)	Feed mass (mg)	Temperature (°C)	Atmosphere
EC	1	300	350	850	Air/Nitrogen
MC	1	300	130	500, 850	Air/Nitrogen
EW	1	300	130	850	Air/Nitrogen

For the pyrolysis and combustion of each material, the outlet gas stream was sampled to analyze carbon oxides, gases, volatile compounds and semivolatile compounds as polycyclic aromatic hydrocarbons (PAHs), polychlorodibenzo-p-dioxin and polychlorodibenzofurans (PCDD/Fs), and dioxin-like PCBs.

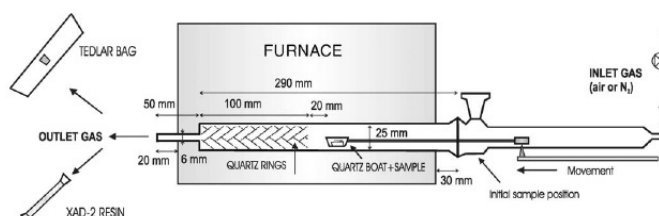


Figure 1. Scheme of the batch laboratory scale tubular reactor.

Carbon oxides, gases and volatile compounds were collected in a Tedlar[®] bag (Supelco, Bellefonte, USA). Carbon oxides were analyzed by GC-TCD (Shimadzu GC-122 14A) with an Alltech CTR I column, and the other non-condensable compounds were analyzed by HRGC-FID (Shimadzu GC-17A) using a capillary column Alumina KCl Plot.

Semivolatile compounds, including PAHs, PCDD/Fs and dioxin-like PCBs, were collected using a polyaromatic Amberlite[®] XAD-2 resin as sorbent (Supelco, Bellefonte, USA) placed at the outlet of the furnace during the entire experiment. Before the decomposition runs, a control containing no sample was carried out using the same experimental conditions.

After extraction in dichloromethane in accordance with the U.S. EPA 3540C method⁶, PAHs were analyzed by HRGC-MS (Agilent GC 6890N/Agilent MS 5973N) using the isotope dilution method. PCDD/Fs and dioxin-like PCBs were analyzed according to US-EPA 1613 and 1668A methods. After extraction with toluene, cleanup was performed using the Power Prep system (FMS, Inc., Boston, MA) with three different columns: silica, alumina, and activated carbon (FMS, Inc., Boston, MA). The analysis was completed by HRGC/HRMS. For HRGC, an Agilent HP5890 gas chromatograph equipped with programmable temperature vaporization (PTV) inlet with a septumless head was used. For HRMS, Micromass Autospec Ultima-NT mass spectrometer (Micromass, Waters, U.K.) with a positive electron impact (EI+) source was employed.

Results and discussion

Table 3 shows the main results obtained in the analysis of gases, volatile and semivolatile compounds (including the sixteen polyaromatic compounds established by US EPA as priority PAHs) for each experiment. The total yields are also shown.

As can be seen, methane is the most abundant light hydrocarbon in all runs, although other important compounds were found, such as benzene, ethylene and toluene.

In accordance with the nature of the materials, phenol and styrene present the most important yields for semivolatile compounds. Phenol is present in the printed circuit board from epoxy resin, and styrene is present in the copolymer ABS/PC from the mobile case. On the other hand, naphthalene, acenaphthylene and phenanthrene are the main PAHs obtained in all the runs. Pyrolysis and combustion of the mixture of printed circuit board and mobile case produced the highest yields for the 16 PAHs.

Table 3. Emissions of gases, volatile and semivolatile compounds.

	Pyrolysis (mg/kg _{sample})				Combustion (mg/kg _{sample})			
	EC 850°C	MC 500°C	MC 850°C	EW 850°C	EC 850°C	MC 500°C	MC 850°C	EW 850°C
Gases and volatile compounds								
<i>Carbon oxides:</i>								
CO ₂	19225	49503	47879	35606	250499	316725	754072	743999
CO	29235	14336	56646	45965	35053	77569	99815	105794
%R _{CO} = ppm CO/ (ppm CO+ ppm CO ₂)	60	22	54	56	12	20	12	12
<i>Main light hydrocarbons:</i>								
methane	3504	1700	19055	15187	1996	952	12611	13563
ethylene	725	1582	14855	7528	444	1796	9820	6553
propylene	258	1202	3793	3091	120	1096	2256	1942
benzene	2143	1202	30308	11070	1295	2199	23845	15887
toluene	426	14774	19161	1575	227	3500	14934	5996
xilene (o-,m-,p-)	81	12372	3305	160	2	2974	2343	634
TOTAL light Hydrocarbons	7521	39191	96436	43093	4332	15676	69481	47403
Semivolatile and PAHs								
<i>Main 16 priority PAHs:</i>								
naphthalene	5548	188	16669	22922	2684	183	12802	16306
acenaphthylene	331	nd	10398	15577	224	nd	9632	17453
fenanthrene	1253	9	5254	9695	863	nd	4834	8495
fluorene	286	15	5713	4152	446	nd	6366	3687
TOTAL 16 PAHs	5288	243	44711	62402	8632	224	41654	55340
<i>Other abundant compounds:</i>								
styrene	nd	nd	13986	28926	nd	nd	22352	28800
phenol	94115	359556	45634	45920	13056	104434	33373	32277
TOTAL semivolatile compounds	125391	407172	154880	184635	30718	208745	141379	140442

The highest content of total PCDD/Fs in the combustion runs was found for the combustion of MC at 500 °C (867 pg I-TEQ/g). As can be seen in Figure 2a, similar 2,3,7,8-Cl substituted PCDD/Fs congener patterns were obtained for the combustion of the different samples. In all cases, OCDD was the compound with the highest yield, although due to its low toxic equivalence factor it only contributes around 1-3 % of the total pg WHO-TEQ/g (Figure 2b).

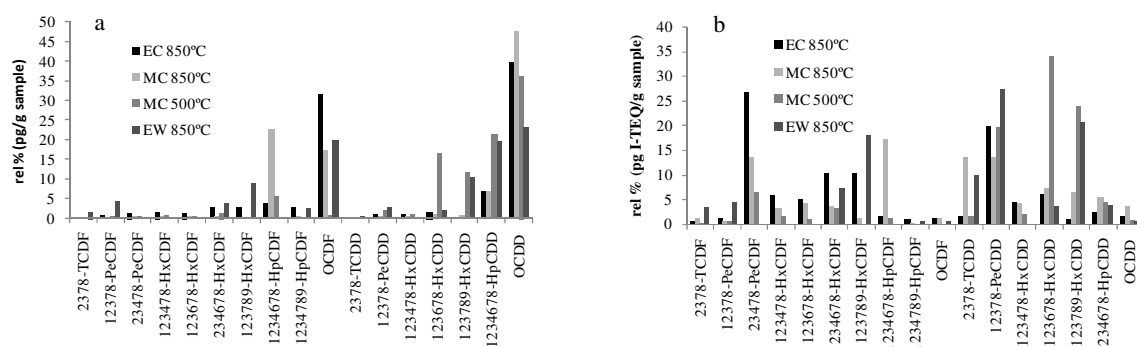


Figure 2. 2,3,7,8-Cl-Substituted PCDD/F congener patterns for emissions from EC, MC and EW combustion in the laboratory reactor: a) Relative pg/g; b) Relative pg I-TEQ/g.

The results obtained in this work show the importance of avoiding the open burning of these kinds of wastes, usually carried out in some countries to recover the valuable parts of the mobile phones.

Acknowledgements

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