Polychlorinated dibenzo-p-dioxin and dibenzofurans (PCDD/Fs), polybrominated diphenyl ethers (PBDEs), and polychlorinated biphenyls (PCBs) monitored by tree bark in an E-waste recycling area

Sheng Wen, F. Yang, J.G. Li, Yan Gong, X.L. Zhang, Y. Hui, Y.N. Wu, Y.F. Zhao, Ying Xu

1. Introduction

It is estimated that there were 3000 tons of waste electrical and electronic equipment (WEEE or E-waste) produced every day in the world, and nearly 70% of them are exported to China for recycling (UNEP, 2005). E-waste recycling has already become an industry in developing countries in recent years (Zhao et al., 2006a, 2007a,b; Chan et al., 2007; Leung et al., 2007; Wong et al., 2007; Liu et al., 2008). Unfortunately, due to the crude E-waste recycling activities, such as open burning of E-waste and dumping of processed materials in those places, a lot of contaminants are released into the environment, including polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), polybrominated diphenyl ethers (PBDEs), and polychlorinated biphenyls (PCBs) (Leung et al., 2007; Wong et al., 2007). E-waste is becoming a major environmental concern particularly in developing countries in recent years (Zhao et al., 2006a, 2007a,b; Chan et al., 2007; Leung et al., 2007; Wong et al., 2007; Liu et al., 2008).

PCDD/Fs and PCBs are known as Stockholm Convention persistent organic pollutants (POPs), while commercial pentabromodiphenyl ether (Penta-BDE) and octabromodiphenyl ether (Octa-BDE) are chemicals under consideration for inclusion in the Convention (UNEP, 2006). PBDEs are used as brominated flame retardants which have been widely applied to circuit board, computers, televisions, textiles, furniture, and other building materials (Birnbaum and Staskal, 2004). PCDD/Fs are the combustion products when electrical wire is burnt in the open, and when the electronic components are removed from circuit boards by heating over a grill using honeycombed coal blocks (coal mixed with river sediment) as fuel (Fig. S1, Supplementary material) (Yu et al., 2006). PCBs are used in capacitors and transformers. Then, their possible emission can occur during the recycling procedure of E-waste (Wang et al., 2005). PCDD/Fs, PBDEs, and PCBs are ubiquitous, persistent, and have been implicated in causing a range of health problems in the immune, endocrine, nervous, and reproductive system of humans and animals (Safe, 1994; Vallack et al., 1998; Chen et al., 2001). These contaminants can be bioaccumulated and biomagnified. Fish, birds, bird eggs, and other biota have been used to study the distribution of these contaminants in the environment, but sometimes it is difficult or expensive to sample these materials. On the other hand, tree bark is easy and inexpensive to sample. And it has been used to monitor different inorganic and organic pollutants, such as ammonia, cadmium, and copper (Rosamilla et al.,...
2004), PAHs (Sturaro et al., 1993; Zhao et al., 2006b), PCDD/Fs (Clars- 
son et al., 2002; Lella et al., 2006), PCBs (Hermanson and Johnson,
2007), and PBDEs (Zhu and Hites, 2006; Qiu and Hites, 2007). As a re-
result of high lipid content and large surface area, bark is a good passive
sampler for those persistent organic compounds with high K_{ow} val-
ues, even when presented at low atmospheric concentrations (Her-
manson and Hites, 1990). Furthermore, tree bark usually stays on the
tree for 3–5 years; thus, bark acts as an integrating sampler during this
period. Therefore tree bark was used in this study as a biomonitor to
discuss the levels and profiles of PCDD/Fs, PBDEs, and PCBs at
Luqiao area in Zhejiang Province, east China, which is one of the big-
gest sites for recycling of E-waste in China (Zhao et al., 2006a).

2. Materials and methods

2.1. Sampling

The prevailing wind in Luqiao area is from the southeast except
in the winter. Thus, two sampling sites were chosen in northwest-
ern hills of Luqiao area in July 8–13, 2006 (Fig. 1). The distances of
site A and B from the E-waste recycling area are nearly 5 and
10 km, respectively. Bark samples of pine tree (Cedrus deodara)
were collected in both sites. A piece of tree bark with
\( C_{24} \)\(^{10} \) cm\(^2\) was chiseled from each tree at a height of 1.5 m above the ground
level. Eleven trees were sampled for bark in each site. And the dis-
tance between each sampled tree was over 100 m. The bark sam-
ples were then wrapped in aluminum foils and carried to the lab.
All of the samples were stored at \( 0 \)–\( 20 \)\(^{\circ}\)C until chemical analysis.

2.2. Chemical reagents and standard solutions

All solvents were pesticide residue grade and were purchased
from J.T. Baker (J.T. Baker, Inc., NJ, USA). Silica gel (ICN silican 100–
200 mesh) and basic aluminum (ICN 04574 Alumina B Super I) were
purchased from ICN (Eschwege, Germany). Florisil was obtained
from LGC Promochem (Hadfield, UK). Bio-Beams SX-3 was pur-
chased from Bio-Rad (Richmond, USA). Standard solutions of
PCDD/Fs (1613-LCS, 1613-IS) (USEPA, 1997), PBDEs (1614-LCS, 1668A-IS) (USEPA,
2007), and PCBs (1668a-LCS, 1668a-IS) (USEPA,
1999) were obtained from Cambridge Isotope Laboratories Inc., USA.

2.3. Sample preparation

Before the pretreatment, the thin green layer of lower plants
(lichens, mosses, etc.), if present, was removed from the bark. The out-
er layer of approximately 2 mm thick was isolated and freeze-dried.

Tree bark was then cut into pieces (<2 mm) before chemical
extraction.

2.4. Measurement of PCDD/Fs, PBDEs, and PCBs

The detailed pretreatment procedure for PCDD/Fs, PBDEs, and
PCBs has been described in our previous work (Wen et al., 2008).
Briefly, approximately 5 g of tree bark was spiked with \( ^{13} \)C-labeled
surrogate standards, and then extracted in a Soxhlet apparatus for
48 h with 250 mL of 50% n-hexane in acetone. The lipid concentra-
tion was determined gravimetrically after evaporation of solvent.
Then, the extract was adjusted to 100 mL with n-hexane. 20 g of
acid silica (44%, w/w) was added and stirred for 20 min in water
bath at 70 \(^{\circ}\)C to remove the lipid. After that, the concentrated ex-
tract was sequentially subjected to multilayer silica gel, florisil,
AgNO\(_3\)–silica, basic alumina chromatography columns and gel per-
meation chromatography (GPC) for further cleanup and being sep-
arated into the three chemical groups (Fig. S2, Supplementary
material). Each fraction was concentrated to 10 \( \mu \)L under gentle
nitrogen gas flow. \( ^{13} \)C-labeled internal standards (1668A-IS for
PCBs and PBDEs, 1613-IS for PCDD/Fs) were added into the extracts
prior to the GC injection. The quantification was performed on a
high resolution gas chromatography (HRGC) coupled with high
resolution mass spectrometer (HRMS) (Finnigan MAT 95xp, Thermo
Electron) with an electron impact (EI) ion source. Exactly
1 \( \mu \)L of sample solution was injected by an autosampler (AS2000,
Thermo Electron) in splitless mode.

2.5. Quality assurance and quality control

To ensure the quality of analysis, a blank sample was analyzed
in a batch of nine samples. The average values of blank samples
were subtracted from those of the samples. Recoveries of all
\(^{13} \)C\(_{12}\)-labeled surrogates were between 35% and 110% for all sam-
ple, which is in the acceptable range established by the USEPA
1613B, 1614, and 1668A. The Laboratory has successfully partici-
pated in an inter-laboratory comparison study of PCDD/Fs, PBDEs,
and PCBs in different matrices organized by the Norway Institute
of Public Health (Norwegian Institute of Public Health, 2005) (Li et al.,
2007; Wen et al., 2008).

2.6. Data analysis

Data are presented as means ± SEM (standard error of the
mean). When calculating the toxic equivalent (TEQs) of samples,
the concentrations of undetected congeners were set to their limits of detection (LOD, S/N = 3).

3. Results and discussion

3.1. Concentrations of PCDD/Fs, PBDEs and PCBs

Almost all targeted congeners of PCDD/Fs, PBDEs, and PCBs were found in the samples except that PCB 104, 169, and 188 were not detected in several samples. The average concentrations were 0.1 ± 0.0 µg g⁻¹ lipid weight for PCDD/Fs, 1.4 ± 0.2 µg g⁻¹ lipid weight for PBDEs, and 6.5 ± 0.8 µg g⁻¹ lipid weight for PCBs (Table 1). In addition, PCDD/F-HQ-TEQs (Van den Berg et al., 1998, 2006), PBDE-HQ-TEQs and total dioxin-like TEQs were calculated to be 1.3, 0.5, and 1.8 ng TEQ g⁻¹ lipid weight on the basis of WHO-1998-TEF, respectively. The concentrations and TEQs of these contaminants and their special congeners were expressed on a dry-weight or lipid-weight basis and shown in Table 1. The

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Tree bark (n = 22)a</th>
<th>TEQsd</th>
<th>Tree bark (n = 22)b</th>
<th>TEQse</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PCDD/Fs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2378-TCDD</td>
<td>212.1 ± 24.4</td>
<td>212.10</td>
<td>3.6 ± 0.3</td>
<td>3.59</td>
</tr>
<tr>
<td>12378-PeCDD</td>
<td>142.2 ± 15.8</td>
<td>142.20</td>
<td>2.5 ± 0.2</td>
<td>2.46</td>
</tr>
<tr>
<td>123478-HxCDD</td>
<td>67.9 ± 7.7</td>
<td>67.79</td>
<td>1.2 ± 0.1</td>
<td>1.12</td>
</tr>
<tr>
<td>123678-HxCDD</td>
<td>133.9 ± 14.3</td>
<td>133.9</td>
<td>2.3 ± 0.3</td>
<td>0.23</td>
</tr>
<tr>
<td>123789-HxCDD</td>
<td>73.9 ± 9.5</td>
<td>73.9</td>
<td>1.3 ± 0.1</td>
<td>1.13</td>
</tr>
<tr>
<td>1234678-HpCDD</td>
<td>440.2 ± 45.1</td>
<td>440.2</td>
<td>7.7 ± 0.6</td>
<td>0.08</td>
</tr>
<tr>
<td>OCDD</td>
<td>(1.5 ± 0.2) x 10³</td>
<td>1.5</td>
<td>24.9 ± 2.4</td>
<td>0.00</td>
</tr>
<tr>
<td>2378-TCDF</td>
<td>(2.2 ± 0.2) x 10³</td>
<td>2.2</td>
<td>37.7 ± 2.7</td>
<td>2.77</td>
</tr>
<tr>
<td>12378-PeCDD</td>
<td>(1.0 ± 0.1) x 10³</td>
<td>1.0</td>
<td>17.8 ± 1.4</td>
<td>0.89</td>
</tr>
<tr>
<td>23478-TeCDD</td>
<td>945.8 ± 109.1</td>
<td>94.5</td>
<td>16.3 ± 1.4</td>
<td>8.16</td>
</tr>
<tr>
<td>123478-HxCDD</td>
<td>582.4 ± 65.9</td>
<td>58.2</td>
<td>10.1 ± 0.8</td>
<td>1.01</td>
</tr>
<tr>
<td>123678-HxCDD</td>
<td>625.9 ± 70.9</td>
<td>62.6</td>
<td>10.8 ± 0.9</td>
<td>1.09</td>
</tr>
<tr>
<td>234678-HxCDD</td>
<td>540.4 ± 63.0</td>
<td>54.0</td>
<td>9.4 ± 0.8</td>
<td>0.94</td>
</tr>
<tr>
<td>123789-HxCDD</td>
<td>370.4 ± 46.4</td>
<td>37.0</td>
<td>0.6 ± 0.1</td>
<td>0.06</td>
</tr>
<tr>
<td>1234678-HpCDD</td>
<td>(1.3 ± 0.1) x 10³</td>
<td>1.3</td>
<td>22.4 ± 1.9</td>
<td>0.22</td>
</tr>
<tr>
<td>1234789-HpCDD</td>
<td>133.0 ± 15.3</td>
<td>13.3</td>
<td>2.3 ± 0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>OCDF</td>
<td>764.8 ± 58.3</td>
<td>0.08</td>
<td>12.9 ± 1.2</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Table 1**

Summary of PCDD/Fs, PBDEs, and PCBs and their special congeners’ concentrations in tree bark samples collected from Luqiao area (Mean ± SEM or mean).

---

a phosphorus g⁻¹ lipid weight or pg TEQ g⁻¹ lipid weight.
b phosphorus g⁻¹ dry weight or pg TEQ g⁻¹ dry weight.
c sum of total PCDD/Fs (Tetra- to octa-CDD/Fs).
d TEQ was calculated by WHO-TEQ 1998 (Van den Berg et al., 1998).
e TEQ was calculated by WHO-TEQ 2005 (Van den Berg et al., 2006).
f sum of total PCBs (Tri- to deca-CBs).
g sum of total indicator PCBs (PCB28, 52, 101, 118, 153, 180).
h sum of total PBDEs (Tri- to hepta-BDEs and deca-BDE).
measured levels of congeners and homologues of PCDD/Fs, PBDEs, and PCBs in tree bark were summarized in Table S1–S3 (Supplementary Material), respectively.

The levels of PCDD/Fs, PBDEs, and PCBs in tree bark have been reported by previous studies and shown in Table 2 (Hermanson and Hites, 1990; Wagrowski and Hites, 2000; Lella et al., 2006; Zhu and Hites, 2006; Hermanson and Johnson, 2007; Qi and Hites, 2007). The concentrations of PCDD/Fs, PBDEs, and PCBs found in this study were of the same magnitude as their respective highest concentration. For instance, the PBDE level in tree bark of our study was close to the highest concentration found near the largest PBDE manufacturing facilities (Zhu and Hites, 2006), but much higher than others (Qi and Hites, 2007).

Tree bark is an excellent scavenger and sink of semivolatile organic compounds due to its high lipid content and large surface area (Simonich and Hites, 1995). Therefore, tree bark was suggested to be a biomonitor of semivolatile organic compounds (Hermanson and Hites, 1990). High accumulations of PCDD/Fs, PBDEs, and PCBs detected in tree bark indicated the heavy contaminations of these pollutants in Luqiao area (Zhao et al., 2006a, 2007a, b; Chan et al., 2007; Liu et al., 2008).

3.2. Homologue and congener profiles of PCDD/Fs, PBDEs, and PCBs

To indicate the fingerprint characters of contaminations from recycling of E-waste, relative abundances of homologues and congeners of PCDD/Fs, PBDEs, and PCBs in tree bark samples (n = 22) were calculated and shown in Fig. 2. The data were all normalized to the summation mass of congeners and total homologues.

3.2.1. PCDD/Fs

Generally, the concentrations of PCDD homologues in tree bark samples were higher than those of PCDD homologues with the same degree of chlorination, except for OCDD and OCDF (Fig. 2). TCDFs contributed to nearly 47% of total PCDD/Fs in the samples, and PCDFs (21.1%) and TCDDs (11.5%) were the other main homologues. Among seventeen 2,3,7,8-PeCDFs congener profiles (Fig. 2), the main contribution to PCDD/Fs followed this trend: 2,3,7,8-TCDF > OCDD > 1,2,3,4,6,7,8-HpCDF > 1,2,3,7,8-PeCDF > 2,3,4,7,8-PeCDF. According to the PCDD/F-TEQs in tree bark, 2,3,4,7,8-PCDF, 1,2,3,7,8-PeCDD, and 2,3,7,8-TCDD contributed to about 70% of the total WHO-TEQs-1998. Among them, 2,3,4,7,8-PCDF was predominant congener and contributed to nearly 36% of the total WHO-TEQs-1998 (Fig. S3, Supplementary material).

3.2.2. PBDEs

Of PBDE homologues, deca-BDE accounted for 56.9–87.2% and was the most abundant homologue in tree bark (Fig. 2). As for congeners, an order of abundance was detected in the samples as follows: PBDE209 > 47 > 99 > 183 > 153 (Fig. 2). Given that the congener composition of three commercial products is well known (La Guardia et al., 2006), it is possible to fit the observed congener profile to a linear combination of the profiles of these commercial products. A least squares procedure was employed to calculate the minimum of $\sum c_i^2$ according to the below function (Zhu and Hites, 2006).

$$
\sum c_i = \frac{1}{d} \left( f_p c_{i,p} + f_o c_{i,o} + f_d c_{i,d} + c_{i,obs} \right)^2
$$

where $f_p$ is the fraction of the penta product in the samples, $c_{i,p}$ is the percent of congener in the penta product, $f_o$ is the fraction of the octa product in the samples, $c_{i,o}$ is the percent of congener i in the octa product, $f_d$ is the fraction of the deca product in the samples, $c_{i,d}$ is the percent of congener i in the deca product; and $c_{i,obs}$ is the average observed percent of congener i in the samples. The parameters of $J$ were determined as $f_p = 0.151$, $f_o = 0.100$, and $f_d = 0.749$ in the tree bark. The analytical results indicated that deca-BDE commercial mixtures were the main source of PBDEs in tree bark. The similar pattern of PBDEs was also observed in some other environmental matrices in the same area such as soil and sediment (Liu et al., 2008). PBDEs can be released from plastics containing brominated flame retardants when heating (e.g., melting of polymers) (de Wit, 2002). Therefore, open burning of E-waste is supposed to be one of the most important processes to release PBDEs into the environment in Luqiao area.

3.2.3. PCBs

The contamination pattern of the selected PCBs homologues in tree bark was in the order: 3-PCBs > 5-PCBs > 4-PCBs > 6-PCBs > 7-PCBs > 8-PCBs > 9-PCBs ≈ 10-PCBs. $\sum_3$–$5$CBs averagely contributed to 79.3% (65.9–87.4%) of total PCBs. As for congeners, indicator PCBs (PCB28, 101, 118, 138, 153, 52, and 180) were determined.

### Table 2

<table>
<thead>
<tr>
<th>Site, Country</th>
<th>PCDD/Fs Total&lt;sup&gt;a&lt;/sup&gt;</th>
<th>TEQ&lt;sup&gt;a&lt;/sup&gt;</th>
<th>PCBs Total&lt;sup&gt;b&lt;/sup&gt;</th>
<th>TEQ</th>
<th>PBDEs Total&lt;sup&gt;d&lt;/sup&gt;</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luqiao District, China&lt;sup&gt;a&lt;/sup&gt;</td>
<td>107.8 × 10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>1.3 × 10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>6.5 × 10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>509.6</td>
<td>1.4 × 10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>Present study</td>
</tr>
<tr>
<td>Park Ridge, Illinois, USA&lt;sup&gt;a&lt;/sup&gt;</td>
<td>232.0 × 10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>&lt;100 × 10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>171.9 × 10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>112.0 × 10&lt;sup&gt;6&lt;/sup&gt;</td>
<td>6.3 × 10&lt;sup&gt;5&lt;/sup&gt;</td>
<td>(Hermanson and Hites, 2006)</td>
</tr>
<tr>
<td>Arkansas, USA&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.8 × 10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.9 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anniston, Ala, USA&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.8 × 10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kubal, Afghanistan&lt;sup&gt;a&lt;/sup&gt;</td>
<td>&lt;2</td>
<td>22.8</td>
<td>1.9 × 10&lt;sup&gt;2&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bloomington, IN, USA&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.1 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Lakes region, USA&lt;sup&gt;a&lt;/sup&gt;</td>
<td>48.0 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halle, Germany&lt;sup&gt;f&lt;/sup&gt;</td>
<td>21.0 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trieste, Italy&lt;sup&gt;f&lt;/sup&gt;</td>
<td>15.0 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hanam, South Korea&lt;sup&gt;f&lt;/sup&gt;</td>
<td>8.1 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shenzhen, China&lt;sup&gt;f&lt;/sup&gt;</td>
<td>107.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hangzhou, China&lt;sup&gt;f&lt;/sup&gt;</td>
<td>1.8 × 10&lt;sup&gt;7&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tianjin, China&lt;sup&gt;f&lt;/sup&gt;</td>
<td>8.1 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>22.8</td>
<td>1.8 × 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>As above</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Sum of total PCDD/Fs (Tetra- to octa-CDD/Fs).
<sup>b</sup> TEQ was calculated by WHO-TEQ (Van den Berg et al., 1998).
<sup>c</sup> Sum of total PCBs (Tri- to deca-CBs).
<sup>d</sup> Sum of total PBDEs (Tri- to hepta-BDEs and deca-BDE).
<sup>e</sup> pg g<sup>-1</sup> lipid weight or pg TEQ g<sup>-1</sup> lipid weight.
<sup>f</sup> pg g<sup>-1</sup> dry weight or pg TEQ g<sup>-1</sup> dry weight.
Fig. 2. Relative abundances of selected congeners and homologues of PCDD/F, PBDEs, and PCBs in tree bark samples (n = 22) collected from Luqiao area. The data were all normalized to the summation mass of congeners and total native compounds homologues.

Fig. 3. PCB homologue profiles in tree bark samples collected from Luqiao area. Data for Aroclors 1242, 1254 and 1260 are from Schulz et al., 1989.
as the major congeners (Fig. 2). As for TEQs, PCB126 was the main contributor and accounted for about 81.2% of total PCB-TEQs (Fig. S3, Supplementary material). In addition, the PCB homologue profile in tree bark was similar to that of the commercial mixtures (Aroclors 1242:1254:1260 = 3:1:1) (Fig. 3). Therefore, the low chlorinated Aroclors mixtures should be the main source of PCBs contamination in Luqiao area. In fact, approximately $10 \times 10^4$ tons of PCBs were produced in China from 1965 to 1974. Ninety percent of them was trichlorobiphenyl and applied in transformers and capacitors. These abandoned transformers and capacitors were dismantled which lead to the possible release of PCBs in Luqiao area.

3.3. Comparison of pollutants levels between two sites

As described in the sampling of materials and methods, the distances between sampling places and E-waste recycling area are nearly 5 and 10 km. Meanwhile, no significant difference was found between the levels of pollutants in tree bark collected from the two sites. Then, it can be concluded that the environment in Luqiao is highly contaminated by these pollutants through atmospheric dispersion.

4. Conclusion

High concentrations of PCDD/Fs, PBDEs, and PCBs were detected in tree bark collected in Luqiao an E-waste recycling area. The results indicated heavy contaminations of these pollutants in local environment. The homologue and congener profiles of PCDD/Fs, PBDEs, and PCBs suggested that these pollutants originated from crude E-waste recycling activities such as open burning of E-waste and obsolete transformer dismantling. The E-waste recycling affecting local environment is so serious that safe and scientific recycling operations of E-waste should be anticipated to avoid health damaging of the workers and local inhabitants.

Acknowledgements

We appreciate the CDC employee in Luqiao area for their help in sampling. This research is supported by National High-Tech Research Program of China (2006AAA06Z424 and 2006AA06Z403) and National Natural Scientific Foundation of China (Nos. 200607030, 30771812, and 20837003).

Appendix A. Supplementary data


References


