

## **PCBs and PCDD/DFs in waste oil illegally-dumped and neglected for more than 20 years**

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### **ABSTRACT**

Quantification of polychlorinated biphenyls (PCBs), polychlorinated-dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) in waste oil by high resolution gas chromatography-high resolution mass spectrometry (HRGC-HRMS), and profiling of their congeners and homologues were described. Waste oil packed in drums which were estimated to have been exposed to the weather for more than 20 years were found by the illegal dumping patrol in 2006.

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PCBs were detected in all of 12 waste oil samples examined, with concentrations in the range of 0.0032-22 µg/g. The main pollution sources of the waste oil samples were presumed to be KC300, KC400 and/or KC500 by principal component analysis (PCA) and a chemical mass balance (CMB) method. The concentrations of PCDDs and PCDFs (PCDD/DFs) in the illegally-dumped waste oil ranged from 1.1 to 360 pg/g and 1.3 to 110 pg/g, respectively. The ratios of toxicity equivalency quantity (TEQ) of PCDDs and PCDFs to Co-PCBs were lower than those of Yusho rice oil. Consequently, it was determined that even after 20 years of exposure to the weather, no PCB denaturation occurred. However, it was confirmed that low-chlorinated biphenyls in corroded drums would have evaporated into the atmosphere.

**Keywords:** Illegally-dumped waste oil, PCBs, denaturation of PCB, PCDDs, PCDFs.

## **INTRODUCTION**

Approximately 59,000 tons of polychlorinated biphenyls (PCBs) were manufactured between 1954-1972 in Japan, and about 54,000 tons were consumed within the country.<sup>[1]</sup> PCBs have been widely used in heat exchange fluid, electric insulating oil for transformers and condensers, plasticizers, paint and carbonless copying paper. Such wide-ranging use of PCBs is due to their

remarkable characteristics such as chemical and thermal stability, acid-, alkali- and hydrolysis-resistance, water-insolubility, high electrical insulation, high boiling-point, and non-flammability. In Japan, the Yusho incident in 1968, which severely impaired human health, was caused by contamination of PCBs in cooking oil. <sup>[2-6]</sup> Exposure to PCBs, like in the Yusho incident, has occurred throughout the world. Consequently, PCBs have been detected in various living organisms, including humans, and from environmental mediums. PCB pollution has become one of the most serious environmental problems. <sup>[7-11]</sup>

As a result, production and distribution of PCBs was restricted by administrative agencies in 1972. In 1974, the "Law Concerning the Examination and Regulation of Manufacture, etc., of Chemical Substances (Class I) (Law No. 117 of 1973)" was enacted, and the manufacturing, import and use of PCBs was prohibited. Moreover, with evidence of long-range transport of PCBs to regions where they had never been used before, and the global expansion of PCB pollution, the United Nations Environmental Program (UNEP) adopted the "Stockholm Convention on Persistent Organic Pollutants (POPs)" in 2001 to reduce the release of POPs, including PCBs, into the environment. In Japan, the "Law Concerning Special Measures for Promotion of Proper Treatment of PCB Waste (PCB Special Measures Law) (Law No.65 of 2001)" was set up by the central government to establish a framework for the prompt, secure and appropriate treatment of PCB waste. The law defines the obligations of PCB waste holders, former PCB manufactures, central government and

local governments, sets deadlines for treatment of PCB waste, and obliges the registration and public reporting of stored PCB waste. The Japan Environmental Safety Corporation (JESCO) will establish and operate five regional plants nationwide, according to the PCB Waste Treatment Basic Plan, which was established by the Ministry of the Environment (MOE). PCB waste holders must treat or entrust waste to JESCO until the year 2016.

The main sources of PCBs detected in the environment are PCB formulations such as Kanechlor (Japan), Aroclor (USA and UK), Clophen (Germany), Chlorofen (Poland) and Pyralene (France) and byproducts formed in thermal combustion processes.<sup>[12]</sup> The PCB formulation is caused by leakage, volatilization or misplacement of PCB waste.<sup>[1]</sup> Presence of PCB in the environment is also a result of illegal dumping of PCB wastes. If illegally dumped waste oil is found, it should be examined for contamination with PCBs, so as to determine the most appropriate method of treatment. Additionally, formation of polychlorinated dibenzofurans (PCDFs) and coplanar polychlorinated biphenyls (Co-PCBs), caused by the denaturation of PCBs, should be tested for as these might be harmful to the operator's health.

In this study, determination of PCBs, polychlorinated dibenzo-*p*-dioxins (PCDDs) and PCDFs in illegally-dumped waste oil exposed to weather for more than 20 years was performed. The pollution sources of PCBs in the waste oil were evaluated by principal component analysis (PCA) and chemical mass balance (CMB) methods. The resultant data might indicate the extent of harm

inflicted on the atmosphere due to leakage of PCBs from illegally-dumped waste oil. Moreover, the denaturation of PCBs in waste oil neglected in atomosphilic condition for more than 20 years was examined by an analysis of PCDDs and PCDFs (PCDD/DFs). The result obtained was compared to the heating medium reported in the Yusho incident. [6]

## **MATERIALS AND METHODS**

### **The Illegally-dumped Waste Oil Sample**

Drums containing waste oil were found by the illegal dumping patrol. It was confirmed that oil was leaking from some of the corroded drums. The waste oil was packed in drums, neglected and exposed to the elements for more than 20 years. Twelve waste oil samples (A-L) were tested in this study. Waste oil sample B from the corroded drum was thought to be mixed with rainwater. As for the color of the waste oils, sample A and G were pale yellow, sample J and L were brown and others (sample B, C, D, E, F, H, I and K) were black. Sample D and K were less-viscid and appeared to be engine oil. The viscosity of sample L was low, and the others were viscid.

## PCBs Analysis

Sample extraction and purification were performed according to the Japanese standard method<sup>[13]</sup> as follows; Twenty five grams of the waste oil sample were initially dissolved in 50 mL of *n*-hexane. Fifty milligram of the waste oil in *n*-hexane was extracted with *n*-hexane-saturated dimethyl sulfoxide (DMSO) after addition of a cleanup spike that consisted of twenty-four [<sup>13</sup>C]-labeled congeners of PCBs (Kanto Chemical Co., Tokyo, Japan). Then, this step was repeated three times. The DMSO phase was back extracted with *n*-hexane and *n*-hexane-extracted water. This back extraction was performed in triplicate. The *n*-hexane phase was treated with 30 mL of 2 M potassium hydroxide, and washed with *n*-hexane-extracted water. The *n*-hexane phase was treated with concentrated sulfuric acid, and washed with *n*-hexane-extracted water. The concentrated *n*-hexane phase was cleaned up using a multi-layer silica gel column (Na<sub>2</sub>SO<sub>4</sub>, silica gel, 10% AgNO<sub>3</sub>-silica gel, silica gel, 22% H<sub>2</sub>SO<sub>4</sub>-silica gel, 44% H<sub>2</sub>SO<sub>4</sub>-silica gel, silica gel, 2% KOH-silica gel, silica gel) chromatography. This column was eluted with 100 mL of *n*-hexane containing 10% dichloromethane. The eluate was concentrated to 50 µL after addition of recovery standards consisting of seven [<sup>13</sup>C]-labeled congeners of PCBs (Kanto Chemical Co.) for high resolution gas-chromatography-high resolution mass spectrometry (HRGC-HRMS) analysis.

## PCDD/DFs Analysis

After addition of a cleanup spike consisting of seventeen [ $^{13}\text{C}$ ]-labeled 2,3,7,8-chlorine substituted PCDD/DFs (Kanto Chemical Co.) into 2.5 g of the waste oil in *n*-hexane, the sample was extracted with *n*-hexane-saturated DMSO. Then, this step was repeated three times. The DMSO phase was back extracted with *n*-hexane and *n*-hexane-extracted water. This back extraction was performed triplicate. The *n*-hexane phase was treated with 30 mL of 2 M potassium hydroxide, and washed with *n*-hexane-extracted water. Thereafter, the sample purification was performed according to the Japanese standard method <sup>[14]</sup> as follows; the *n*-hexane phase was treated with concentrated sulfuric acid, and washed with *n*-hexane-extracted water. The concentrated *n*-hexane phase was cleaned up using the multi-layer silica gel column chromatography. This column was eluted with 200 mL of *n*-hexane. The eluate was loaded onto the activated carbon-dispersed silica gel reversible column (Kanto Chemical Co.), and successively eluted with 50 mL of *n*-hexane and 40 mL of *n*-hexane containing 25% dichloromethane for collecting mono-ortho-coplaner PCBs. The initial fraction of *n*-hexane was discarded. Then, the column was reverse eluted with 100 mL of toluene for collecting PCDD/DFs and non-ortho-coplaner PCBs. The both mono-ortho-coplaner PCBs fraction and the PCDD/DFs and non-ortho-coplaner PCBs fraction were concentrated in vacuo to 25  $\mu\text{L}$ . As a result, recovery standards consisting of two [ $^{13}\text{C}$ ]-labeled congeners of PCDD/DFs (Kanto Chemical Co.)

were spiked for HRGC-HRMS analysis.

### **HRGC-HRMS Analysis**

A GC-MS system consisting of an HP-6890 GC system (Agilent, CA, USA) and a JMS-700 MS (JEOL Ltd., Tokyo). For PCBs, an HT8-PCB capillary column (60 m x 0.25 mm, i.d., Kanto Chemical Co.) was used. The temperature program was set as follows; the temperature was initialized at 120°C, ramped at 20°C /min to 180°C, at 2°C /min to 260°C, then at 5°C /min to 300°C (9 min).<sup>[15]</sup> For PCDD/DFs analysis, capillary columns, an Rtx-2330 (60 m x 0.25 mm i.d., 0.10 µm film thickness, Restek Co., PA, USA) and a DB-17HT (30 m x 0.25 mm id, 0.15 µm film thickness, J&W Scientific, CA, USA) were used. The temperature program was set as follows: the temperature was initialized at 130°C (1 min), ramped at 20°C /min to 190°C, at 1°C /min to 225°C, then at 3°C /min to 275°C (5 min) (for Rtx-2330), and 130°C (1 min), ramped at 20°C /min to 240°C, at 3°C /min to 280°C (4 min) (for DB-17HT). The carrier gas used was helium, and the electron impact ionization energy was set at 38 eV. The resolution was kept higher than 10,000 in a selected ion monitoring (SIM) mode. Two ions were monitored for each homologue group and the specific isotope ratios for each congener were checked within 15% of the theoretical values. The recovery of cleanup spikes (calculated using recovery standards) for each congener ranged from 50



to 87% for PCBs and from 50 to 85% for PCDD/DFs. The method quantitation limits (MQLs) of PCBs and PCDD/DFs for individual congeners were 5 pg/g and 1-5 pg/g, respectively. The value of the analytical blank for the individual congeners was less than the MQL.

### **Statistical Analysis**

The principal component analysis (PCA) of normalized PCB congener data was performed using the software package SPSS 16.0J (SPSS Inc., IL, USA). The PCB congeners which account for over 3% of entire PCBs in Kanechlor KC300-600 were selected for statistical analysis. The data were normalized by the concentration ratio of each congener to the total PCB.<sup>[16]</sup> As a result, 30 major congeners were subjected to PCA as input variables.

For determination of the source contribution of PCBs in the illegally-dumped waste oil, the CMB method with major congeners in KC300-600 was applied. The basic principle of the CMB method is that the measured profiles can be reproduced by the linear combinations of several sources.

CMB8J Ver.0.96, software was used for the CMB method.<sup>[17]</sup>

## **RESULTS AND DISCUSSION**

### **PCB Concentration in Waste Oil**

The concentrations of PCBs are shown in Table 1. PCBs were detected in all the illegally-dumped waste oils examined, and the concentrations varied considerably in the range of 0.0032-22 µg/g.

Takasuga et al. reported that the mean concentrations of PCBs in Kanechlor formulations (KC300, 400, 500, and 600) were 870,000, 840,000, 830,000, and 880,000 µg/g, respectively. <sup>[19]</sup> Noma et al. reported the concentrations of PCBs in transformer insulation oil, capacitor insulation oil, stabilizer oil for fluorescent light, stabilizer oil for sodium light, pole transformer oil and the heat transformer medium in the waste PCB stockpiles were 580,000-620,000, 930,000-1,000,000, 900,000-990,000, 1,000,000, 17-19 and 300,000-320,000 µg/g, respectively. <sup>[1]</sup> In this study, the PCB levels in the illegally-dumped waste oils (A-L) were very low.

### **Profiles of the PCB Homologues**

The major commercial PCB formulations used in Japan were Kanechlors, which are known as KC300, 400, 500 and 600. KC300 corresponds to Aroclor (Ar) 1242, KC400 to Ar1248, KC500 to Ar1254, and KC600 to Ar1260 in terms of chlorine content. These formulations have the characteristic profile of PCB homologues. The PCB homologues analyzed were M1CBs (M1),

D2CBs (D2), T3CBs (T3), T4CBs (T4), P5CBs (P5), H6CBs (H6), H7CBs (H7), O8CBs (O8), N9CBs (N9) and D10CB (D10). The profiles of PCB homologues for the illegally-dumped waste oils (A-L) and Kanechlors (KC300, 400, 500 and 600) are shown in Figure 1. The major homologues for the illegally-dumped waste oils (A-L) were D2, T3, T4, P5 and H6. This result agreed well with that in PCB stockpiles.<sup>[1]</sup> Among the illegally-dumped waste oils (A-L), the profile of PCB homologues of sample A was very similar to KC500, and the profiles of sample C, D, E, F, I, K and L were similar to KC300. However, for samples B, G, H and J, multiple-pollution of Kanechlors was suspected, because their complicated profile of PCB homologues did not fit with that of the respective Kanechlor formulation. As compared to the waste PCB stockpiles, sample A resembles the transformer insulation oil, and samples C, D, E, F, I, K and L seemed to be similar to the capacitor insulation oil and the stabilizer oil for fluorescent lights.<sup>[1]</sup>

### **Principal Component Analysis (PCA)**

To investigate the difference of congener patterns in waste oils, PCA was applied. One benefit of PCA for analyzing large data sets is that only a small number of principal components (PCs) are usually needed to represent most of the information in the data. The result showed the first, second and third principal components (PC1, PC2 and PC3) accounted for 62.6%, 22.9% and 11.3% of the

total variance, respectively. The plots of loading factors and PCA scores for the first two PCs are shown in Figure 2 (a) and (b), respectively. In Figure 2 (a), high scores on PC1 and low scores on PC2 refer to a lowly chlorinated pattern (D2 and T3), high scores on PC1 and PC2 refer to a tetra-chlorinated pattern (T4), low scores on PC1 and high scores on PC2 refer to a moderate chlorinated pattern (P5 and H6), low scores on PC1 and PC2 refer to a highly chlorinated pattern (H6 and H7). Kanechlor formulations (KC300-600) and KC-mix [the mixture of KC300, KC400, KC500 and KC600 (1: 1: 1: 1)] were co-plotted along with 12 samples [Fig. 2 (b)], and twelve samples could be divided into 3 groups. Group 1 was consisted of samples C, D, E, F, I, K and KC300, Group 2 of sample A and KC500, and Group 3 of samples B, G, H, J and KC-mix. However, it was difficult to identify the source contribution. PC3 could not be interpreted.

### **Determination of the Source Contribution by a CMB Method**

By PCA, 12 samples were divided into KC300, KC500 and mixture groups. The source contribution by a CMB method using major congeners was examined. The parameters,  $\chi^2$  value,  $r^2$  and %mass were in the range 5.4-55.4 (less than 5% significance level except sample B), 0.905-0.989 and 86.8-100.8%, respectively. The result is shown in Figure 3. The source contribution of multi pollution groups (B, G, H and J) could be measured. In sample G, double pollution by KC300 and

KC500 was observed. Triple pollution by KC300, 400 and 500 in samples H and J, and quadruple pollution by KC300, 400, 500 and 600 in sample B was suspected. Among these, the contribution ratio of KC300 in sample B was lower than those in other samples. This might be due to the evaporation of lower-polychlorinated biphenyls into the atmosphere in corroded drum. Furthermore, KC-mix, which is a mixture of KC300, 400, 500 and 600 (=1:1:1:1), was used as a positive control. The reliability of the CMB method could be confirmed by this result ( $25.0 \pm 2.9 \%$ ).

### **Co-PCBs (Coplaner PCBs) in the Illegally-dumped Waste Oil**

Percent contributions of Co-PCBs (the sum of four non-ortho and eight mono-ortho PCBs that is listed in WHO-TEFs that were established in 2006<sup>[18]</sup>) to the total PCBs in the illegally-dumped waste oils (A-L) were 12.4, 2.4, 1.4, 1.1, 1.1, 1.6, 6.0, 0.76, 1.3, 0.71, 0.96 and 1.2%, respectively.

Percent contributions of Co-PCBs to the total Co-PCBs in the illegally-dumped waste oils (A-L), Kanechlor formulations (KC300-600), and Yusho rice oil<sup>[6, 19]</sup> are shown in Figure 4. The major congeners of Co-PCBs were IUPAC Nos. 77, 105 and 118 in the illegally-dumped waste oils (A-L). Takasuga et al. reported that the congener pattern of Co-PCBs was dominated by IUPAC Nos. 77, 105 and 118 in KC300 and KC400, but even more so by IUPAC No. 156 in KC500 and 600.<sup>[19]</sup> Our results agreed well with these. In Yusho rice oil, the major congeners of Co-PCBs were IUPAC Nos.

105 and 118, and percent contributions of these congeners were comparable. <sup>[6]</sup> This trend was not found in illegally-dumped waste oils (A-L) and Kanechlor formulations (KC300-600).

### **PCDD/DFs and Co-PCBs in the Illegally-dumped Waste Oils**

The concentrations and TEQs of PCDDs, PCDFs and Co-PCBs in the illegally-dumped waste oils (A-L) are summarized in Table 2. The concentration of PCDDs and PCDFs is presented as the sum of each homologue concentration. The sum of 12 Co-PCBs concentrations listed in WHO-TEFs established in 2006 <sup>[18]</sup> was presented as the concentration of Co-PCBs. The TEQ of congeners which were less than each MQL is shown as 0 in Table 2. The concentration ratios of Co-PCBs in the illegally-dumped waste oils were more than 92%, except for samples B and J [Fig. 5 (a)]. These results correlated with the concentration ratios of Kanechlor formulations (KC300-600) <sup>[19]</sup> and Yusho rice oil. <sup>[6]</sup> The concentration ratios of Co-PCBs of samples B and J were 75% and 19%, respectively. The PCBs concentrations of samples B and J were the lowest in the waste oil samples. Moreover, those samples were suspected to be a multiple-pollution of Kanechlors according to the PCA and CMB methods. Hence, the difference between the concentration ratios of Co-PCBs compared to other waste oil samples might be due to the mixing with low PCB concentration oil or PCB-free oil. Although samples G and H were suspected to be multiple-pollution of Kanechlors,

and those PCB concentrations were very low, the concentration ratios of Co-PCBs were as high as 99% and 96%, respectively.

Regarding Co-PCB concentrations, Takasuga et al. reported KC500 to be highest in Kanechlor formulations.<sup>[19]</sup> A higher contribution of KC500 in samples G and H, compared to samples B and J, was observed. Therefore, it was thought that the concentration ratios of Co-PCBs in samples G and H were high. TEQ ratios of Co-PCBs to total TEQ in the illegally-dumped waste oils were more than 94% as shown in Figure 5 (b) except for samples B, H and J. These results were agreed with Kanechlor formulations (KC300-600) as well as the concentration ratios of Co-PCBs in Figure 5 (a). For samples B and H, TEQ of Co-PCBs was very low, and TEQ ratios of PCDDs and/or PCDFs were relatively high. For sample J, the TEQ of PCDDs was remarkably higher than that of other waste oils. One explanation may be that sample J, contaminated by KC300, KC400 and KC500, was additionally contaminated with PCDDs.

On the other hand, human health was harmed during the 1968 Yusho incident in Japan, where rice oil contaminated with Kanechlor KC400 was used as a heat transfer medium in the deodorization process. Additionally, the increase PCDFs by the denaturation of PCBs caused the increase in the total TEQ of rice oil.<sup>[1, 6, 20]</sup> Therefore, the denaturation of PCBs in the illegally-dumped waste oils which were neglected and exposed to the elements for more than 20 years was evaluated. The concentration ratios of TEQ to PCDFs were used as indicators of denaturation of PCBs. The values

for the illegally-dumped waste oils, Kaneclor formulations and Yusho rice oil were 0.0030-14.5%, 0.0084-0.065% and 5.5%, respectively. The ratios of TEQ to PCDFs in the illegally-dumped waste oils (0%-56.8%) were not similar to that of Yusho rice oil (73.0%).<sup>[6, 19]</sup> Therefore, the denaturation of PCBs in the illegally-dumped waste oils was insignificant. These results agreed with the waste stockpiles that had used PCBs as transformer oil, capacitor oil and heat transformer medium.<sup>[1]</sup>

## CONCLUSION

The determination of PCBs and PCDD/DFs in illegally-dumped waste oil was performed. Waste oil samples exposed to the weather for more than 20 years is rare. Considerably varied concentrations of PCBs in the range of 0.0032-22 µg/g were found. From the profiles of PCB homologues, as determined by the PCA and CMB methods, it was found that the PCBs in illegally-dumped waste oils mainly resulted in Kanechlor KC300 and KC500, and low-chlorinated biphenyls would have evaporated into the atmosphere from corroded drum. Therefore, to control environment pollution of PCBs, it is important to store PCB waste until treating them (e. g. dechlorination) thoroughly.

Furthermore, the ratios of PCDDs/DFs concentrations were much lower than those of PCBs. The denaturation of PCBs in the illegally-dumped waste oils neglected and exposed to the elements for more than 20 years was not observed. The information obtained in this study might be useful for the



denaturation of PCBs.

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## FIGURE CAPTIONS

**Figure 1.** The profiles of PCB homologues for the illegally-dumped waste oil samples (A-L) and Kanechlor formulations (KC300, 400, 500 and 600).

M1, D2, T3, T4, P5, H6, H7, O8, N9 and D10 are M1CBs, D2CBs, T3CBs, T4CBs, P5CBs, H6CBs, H7CBs, O8CBs, N9CBs and D10CB, respectively.

**Figure 2.** The principal component analysis, (a) loading plot and (b) score plot of the PCB congener pattern of the illegally-dumped waste oil samples (A-L), Kanechlor formulations (KC300, 400, 500 and 600) and KC-mix.

PC1 and PC2 accounted for 62.6% and 22.9% of the total variance, respectively.

(a) ○, D2CB; △, T3CB; □, T4CB; ▽, P5CB; ◇, H6CB; +, H7CB

(b) ○, Illegally-dumped waste oil; ▲, Kanechlor formulation and KC-mix.

**Figure 3.** Source contributions of Kanechlor formulations (KC300, 400, 500 and 600) for the illegally-dumped waste oil samples by the CMB method.

**Figure 4.** Percent contribution of Co-PCBs to the total Co-PCBs for the illegally-dumped waste oil samples (A-L), Kanechlor formulations (KC300, 400, 500 and 600), and Yusho rice oil <sup>[6]</sup>.

**Figure 5.** The percent contribution of the concentration (a) and TEQ (b) of PCDDs, PCDFs and Co-PCBs for the illegally-dumped waste oil samples (A-L), Kanechlor formulations (KC300, 400, 500 and 600) <sup>[17]</sup> and Yusho rice oil <sup>[6]</sup>.

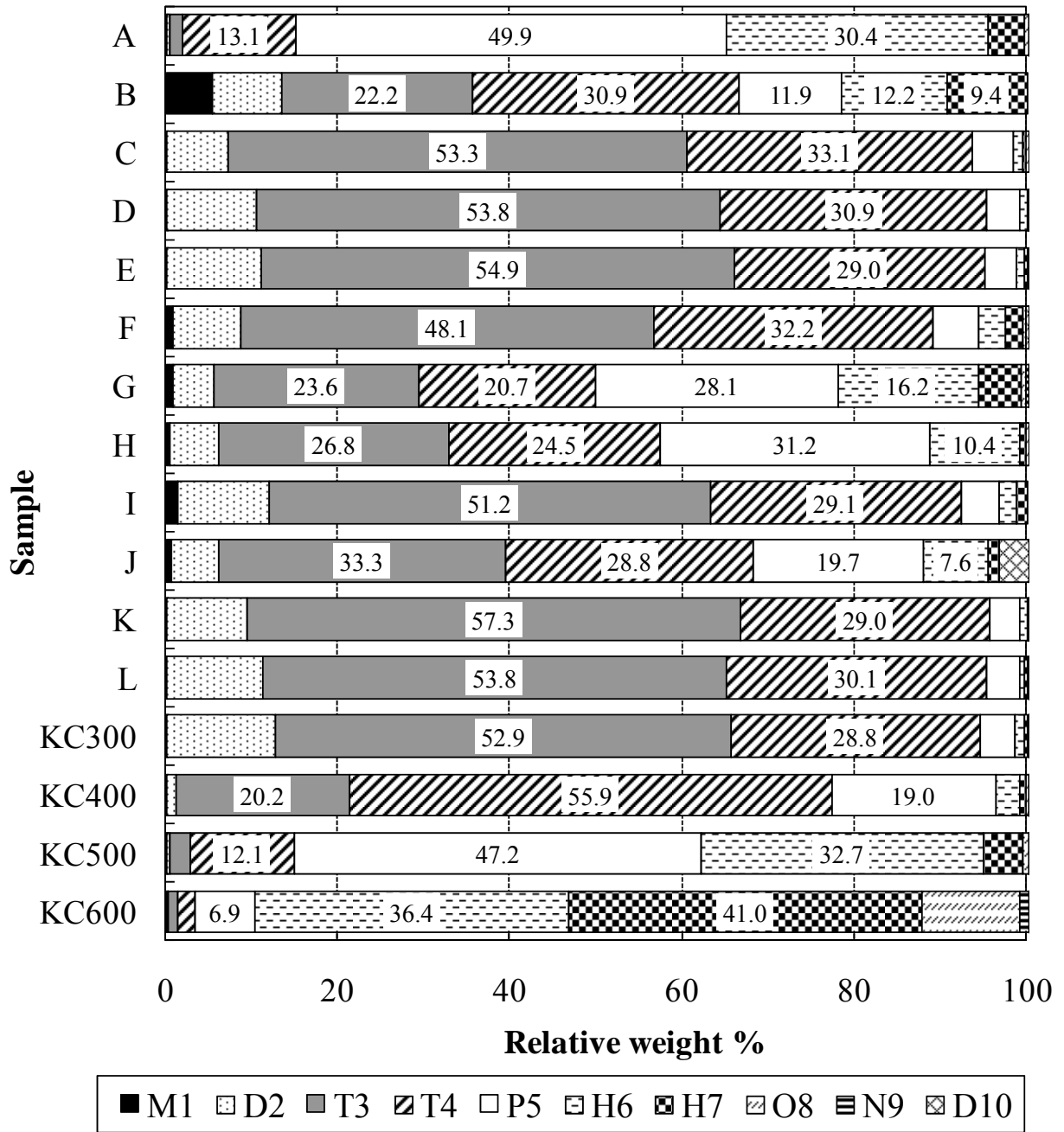


Fig.1

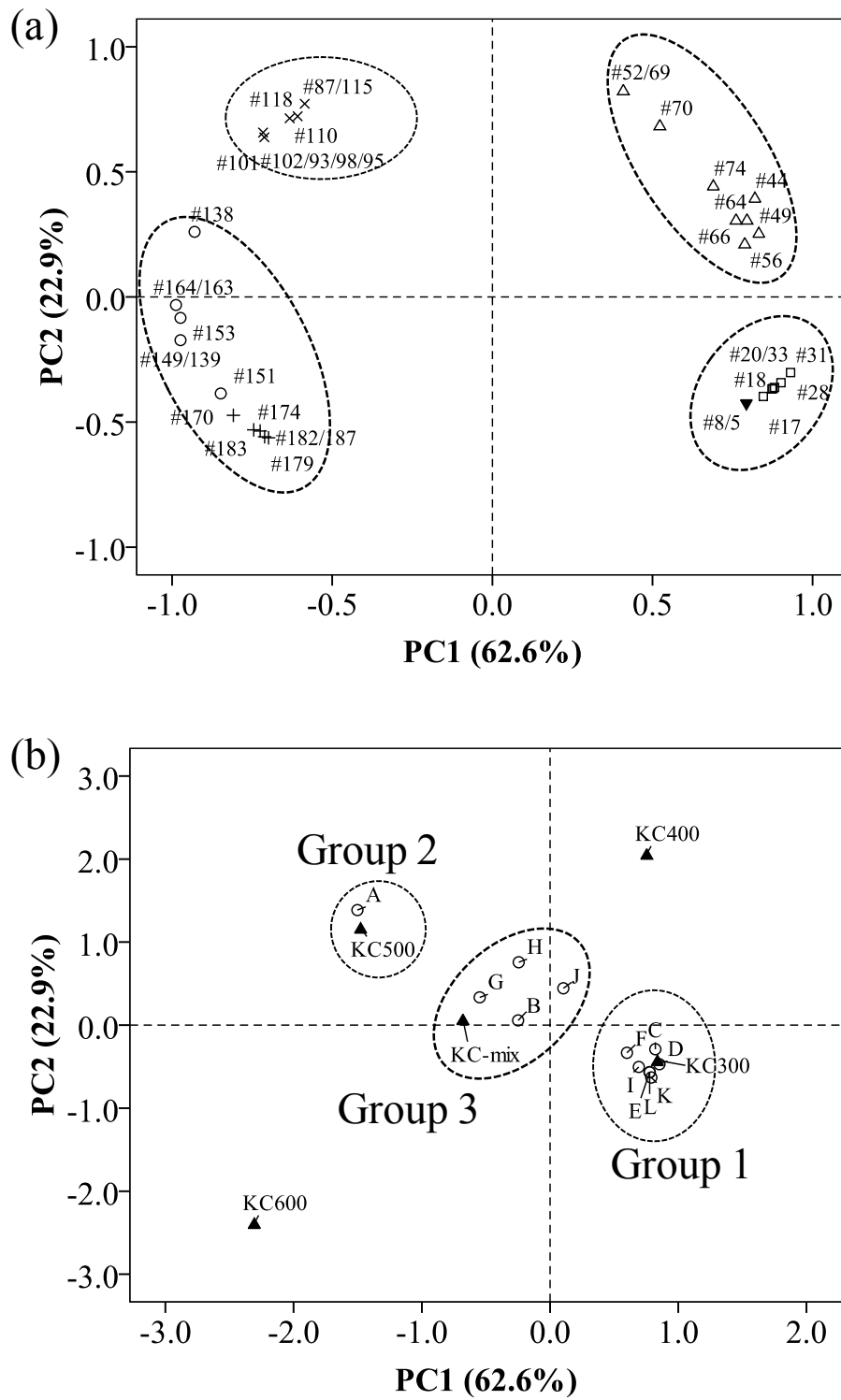


Fig.2

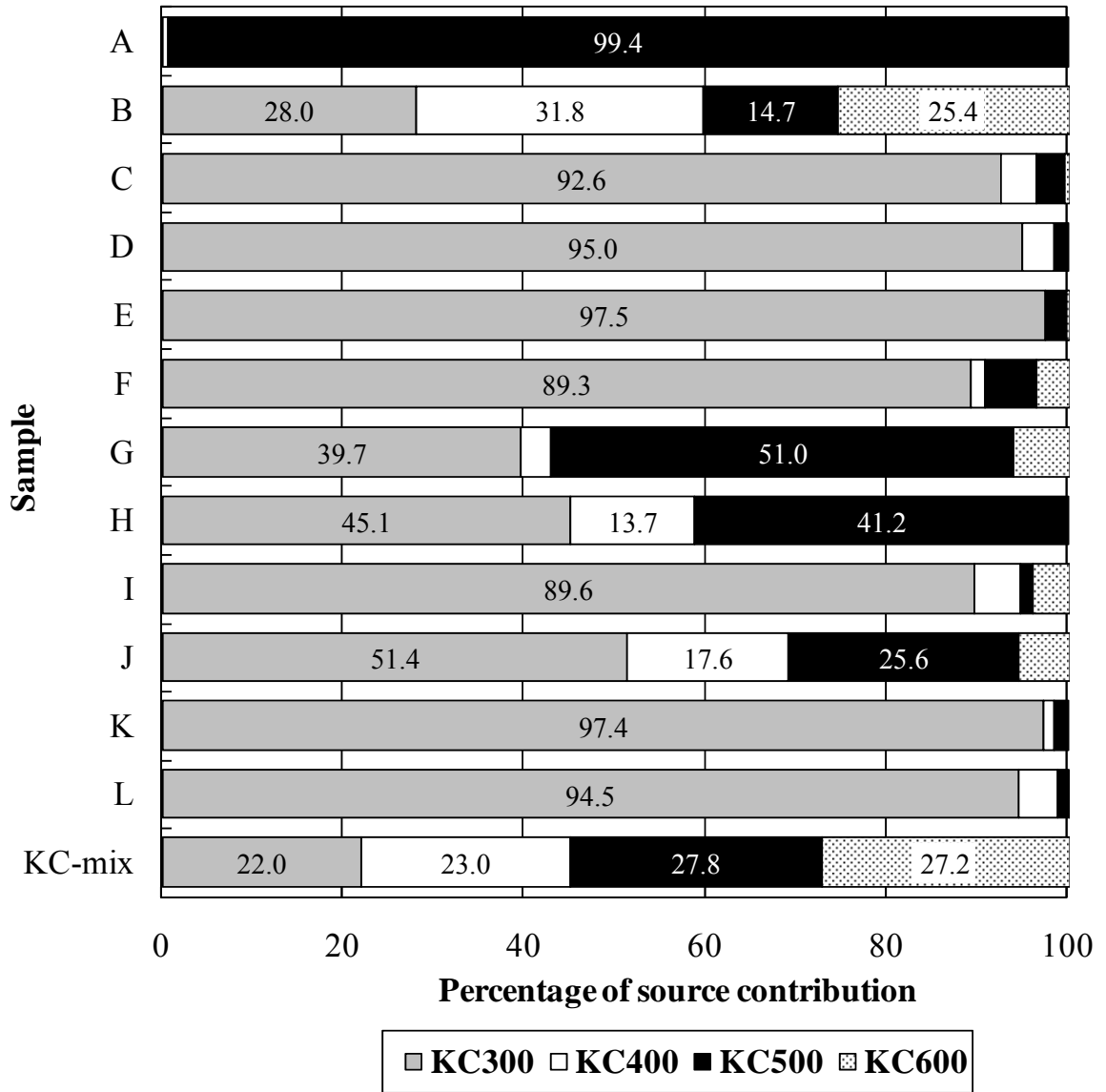


Fig.3

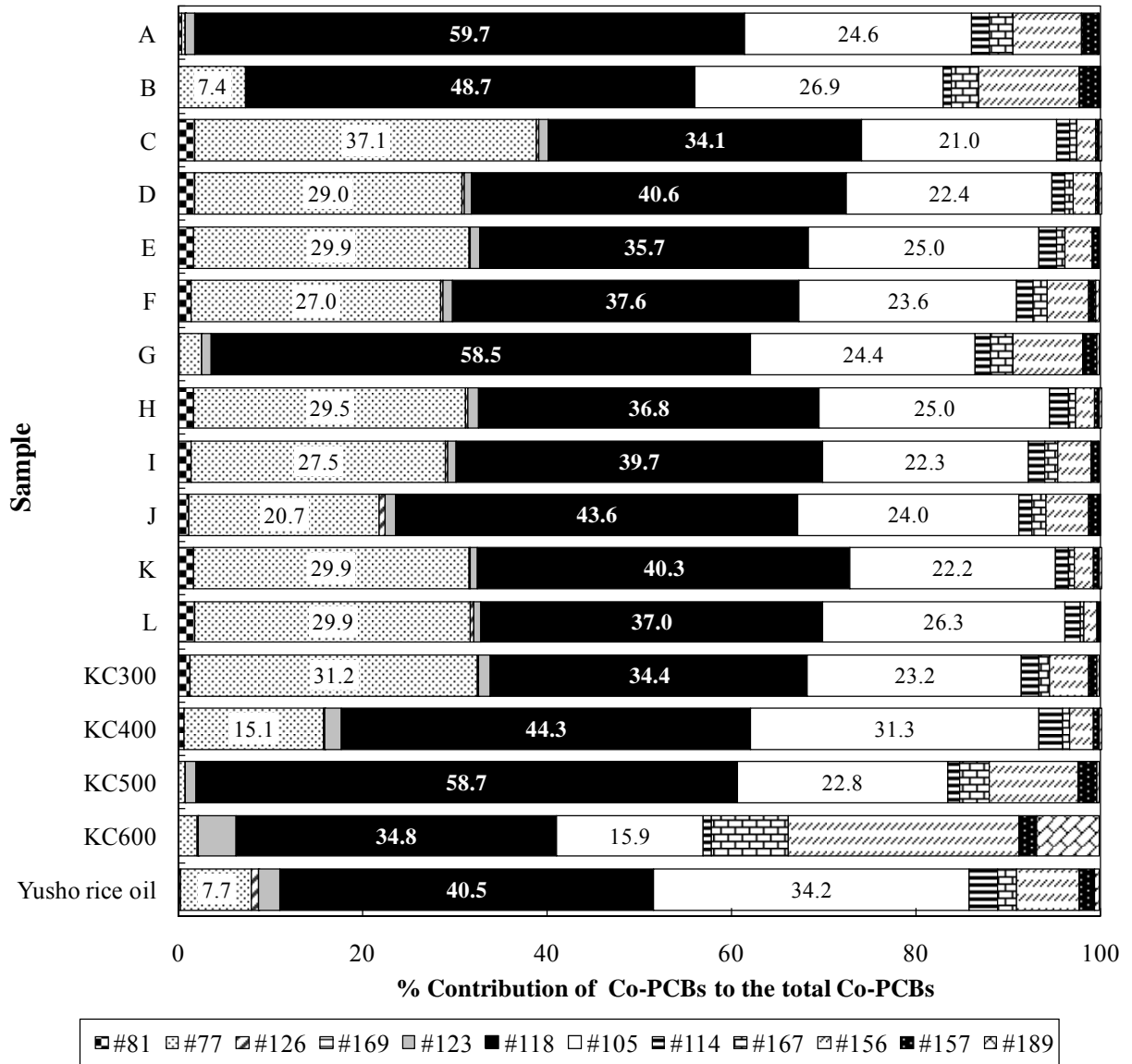


Fig.4



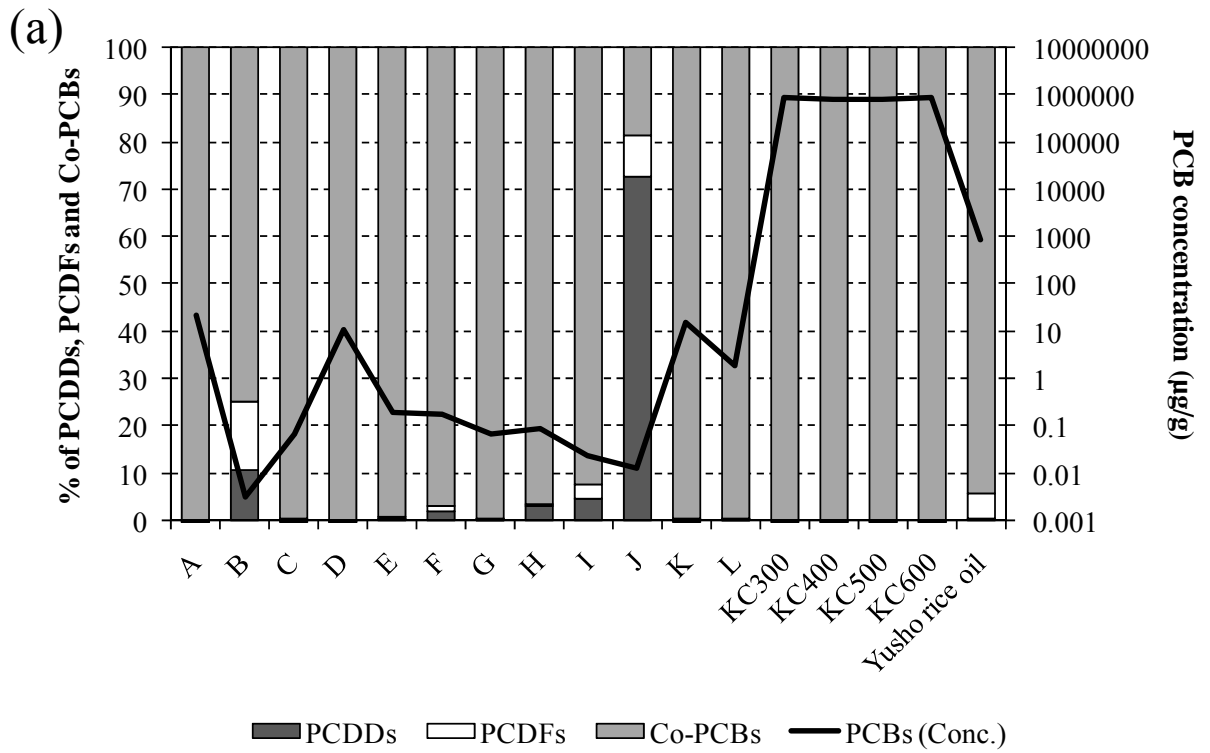


Fig.5 (a)

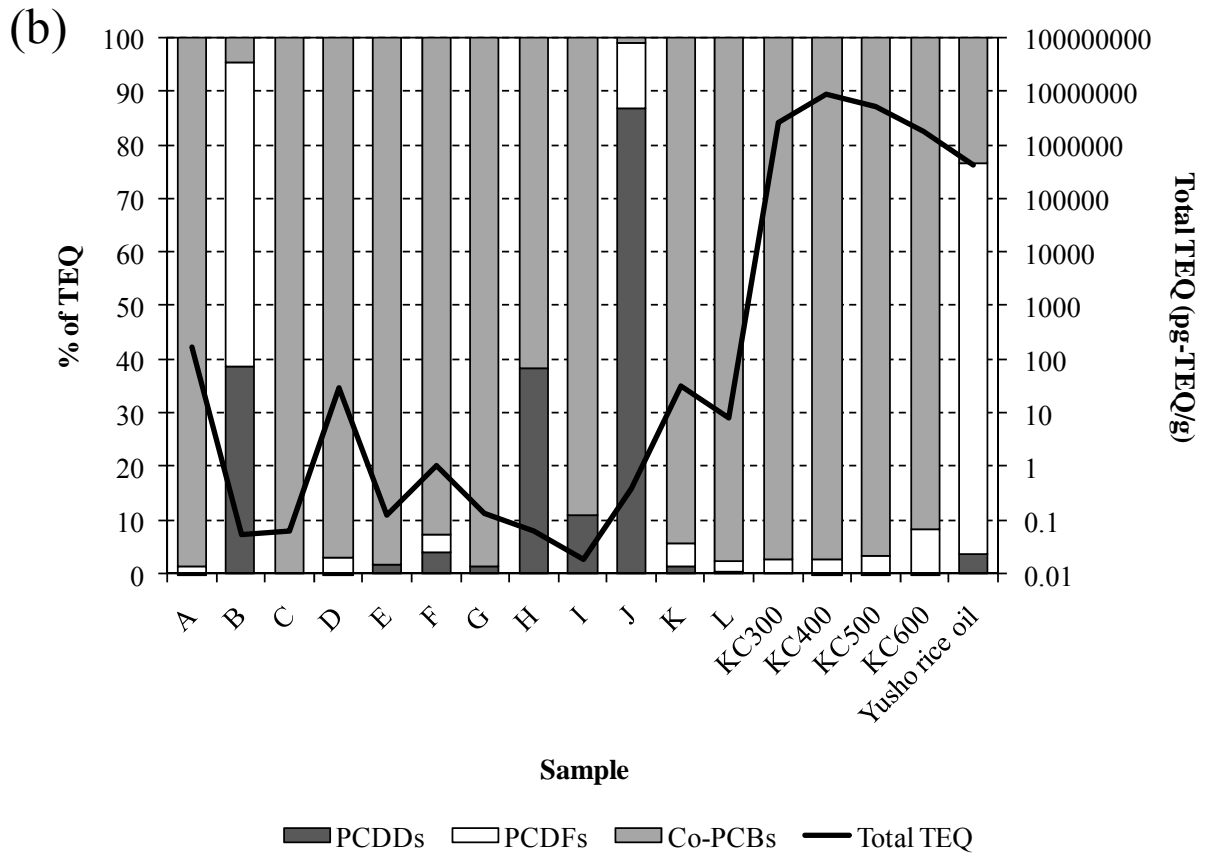


Fig.5 (b)

**Table 1.** PCB concentrations of the waste oil samples.

Sample_ID	Concentration ( $\mu\text{g/g}$ )
A	22
B	0.0032
C	0.069
D	11
E	0.20
F	0.18
G	0.068
H	0.090
I	0.025
J	0.013
K	15
L	1.9

**Table 2.** The concentration and TEQ of PCDDs, PCDFs and Co-PCBs in the waste oil samples.

Sample_ID	PCDDs	PCDFs	Co-PCBs
Concentration (pg/g)			
A	8.8	81	2700000
B	11	15	78
C	1.1	1.3	1000
D	39	70	120000
E	11	7.0	2200
F	53	45	2900
G	10	12	4100
H	22	2.7	680
I	16	11	330
J	360	45	92
K	250	110	140000
L	48	25	22000
TEQ (pg-TEQ/g)			
A	0.0024	2.3	180
B	0.021	0.031	0.0026
C	0	0	0.063
D	0.047	0.85	29
E	0.0024	0	0.13
F	0.042	0.038	0.99
G	0.0021	0	0.14
H	0.025	0	0.040
I	0.0021	0	0.017
J	0.36	0.050	0.0038
K	0.42	1.4	31
L	0.042	0.15	8.5

The 2,3,7,8-tetrachlorodibenzo-*p*-dioxin equivalents (TEQs) of 2,3,7,8-chlorine-substituted PCDD/DFs and coplanar PCBs (non- and mono-ortho PCB congeners) were calculated using the World Health Organization's (WHO) mammalian toxic equivalency factors (TEFs) that were established in 2006. <sup>[18]</sup>

## Article Outline

### **PCBs and PCDD/DFs in Waste Oil Illegally-dumped Neglected for More Than 20 Years**

#### ABSTRACT

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#### MATERIALS AND METHODS

The Illegally-dumped Waste Oil Sample

PCBs Analysis

PCDD/DFs Analysis

HRGC-HRMS Analysis

Statistical Analysis

#### RESULTS AND DISCUSSION

PCB Concentration in the Waste Oil

Profiles of the PCB Homologues

Principal Component Analysis (PCA)

Determination of the Source Contribution by a CMB Method

Co-PCBs (Coplaner PCBs) in the Illegally-dumped Waste Oil

PCDD/DFs and Co-PCBs in the Illegally-dumped Waste Oil

#### CONCLUSION

#### REFERENCES