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# The Emission and Distribution of PCDD/Fs in Municipal Solid Waste Incinerators and Coal-fired Power Plant

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## ABSTRACT

The emission and distribution of polychlorinated debenzo-*p*-dioxins/dibenzofurans (PCDD/Fs) was investigated in two municipal solid waste incinerators (MSWIs) and one coal-fired power plant (PP) in southern Taiwan. Samples were collected from stack flue gases (SFG), bottom residues (BR), super heater (SH), economizer (EC), semi-dry absorber (SDA), bag filter (BF), and fly ash pit (FAP) in MSWIs. Stack flue gases, bottom residues and electrostatic dust collectors (ESD) in PP were also collected. In order to compare the difference between the results of MSWIs and PP, samples from SFG, BS, and FAP in a PP were also determined. Seventeen congeners of PCDD/Fs were analyzed by utilizing a high-resolution gas chromatograph/high-resolution mass spectrometer (HRGC/HRMS). Distributions of total PCDD/F-I-TEQ in each unit of MSWI-A and MSWI-B were SFG (0.3%, 0.07%), BR (3.9%, 0.62%), SH (0.17%, 0.24%), EC (4.2%, 0.05%), SDA (1.29%, 7.06%), and BF (90.14%, 91.97%), respectively. However, those in SFG, BS, and FAP of PP were 99.58%, 0.17%, and 0.25%, respectively. The above results indicated 99.5% PCDD/Fs were trapped in the fly ash of MWSI. On the other hand, 99.7% PCDD/Fs was emitted to the atmosphere from PP. The results of this study provide useful information for controlling PCDD/Fs in MSWIs and PP.

***Keywords:*** PCDD/Fs; Coal-fired power plant; Municipal solid waste incinerator.

## INTRODUTION

The sources of PCDD/Fs are mainly human activities, including industrial and heat-treatment processes (Oh *et al.*, 1999; Baker *et al.*, 2000; Tame *et al.*, 2007; Hu *et al.,* 2009; Hu *et al., 2009*), and are known to be persistent in the environment and animal tissue (Chao *et al.*, 2007). The formation of PCDD/Fs in municipal solid waste incinerators had been researched in many countries (McKay, 2002; Altarawneh *et al.*, 2009; Aurell and Marklund, 2009). With the continuous studying, three known PCDD/Fs formation mechanisms were found for PCDD/Fs in stack flue gases; (i) PCDD/Fs originally present in the feedstock of MSWIs; (ii) from precursor compounds in the MSW feed; (iii) from de novo synthesis of relatively innocuous chemical molecules combining together to form dioxins (McKay, 2002). However, the favourable temperature range of de novo synthesis is 250°C–400°C, and can be negligible when fly ash was heated at 400°C or higher temperature (Kakuta *et al.*, 2007; Chen *et al.*, 2008). Chlorine, although it is not a precursor of PCDD/Fs, was found to predominate the forming tendency toward debenzo-*p*-dioxins (PCDDs) or dibenzofurans (PCDFs) with a 0.8–1.1% threshold in the wastes (Wang *et al.*, 2002). The major distributing pathway of PCDD/Fs is through air (Lohmann and Jones, 1998). The amount of PCDD/Fs transported through air is so high that some of the water treatment plants have been suggested to put on a cover (Lin *et al.,* article in press). In order to discover the PCDD/Fs contribution to the environment of several PCDD/Fs emitting activities, the fates of PCDD/F -like compound and PCDD/Fs have been studied for years (Tsai *et al.*, 2001; Kuo *et al.*, 2003; Lee *et al.,* 2004; Van Caneghem *et al.*, 2010). Since tighter emission limits have been applied to incinerators, sinter plants have become the dominating PCDD/F emission sources (Wang *et al.*, 2003). Not only sinter plants, but also secondary aluminum smelters and electric arc furnaces emit more PCDD/Fs to the environment than MSWIs (Chen *et al.,* 2004; Lee *et al.,* 2005). Electric arc furnace dust treatment plant was found to provide PCDD/Fs to the downwind duck farms significantly higher than upwind farms (Lee *et al*., 2009). Attempting to get rid

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to stubborn PCDD/Fs from the soil, thermal treatment had been developed, and is proven as an effective technology to remove 99% PCDD/Fs from heavily contaminated soils when the treatment process was above 750°C (Lee *et al*., 2008). Coal-fired power plant is the dominating PCDD/Fs emission source in southern Taiwan (Lin *et al.*, 2007). The coal ash contains organic constituents of potential environmental concern just like fly ash of MSWIs (Chen *et al.*, 2006; Sahu *et al.*, 2009). Comparison between MSWIs and coal-fired power plant could give us a comprehensive scope of the distribution of PCDD/Fs in different units of each plant due to different types of air pollution control devices were equipped.

## THE SAMPLING INFORMATION

### *Basic Information of Sampling Sites*

The stack flue gas (SFG) samples and ash samples were collected from MSWI-A, MSWI-B, and PP. The three sites are all located in southern Taiwan. During the sampling, there were three furnaces operating in MSWI-A and MSWI-B, the active carbon injected for each furnace in MSWI-A and MSWI-B was 9 kg/hr and 7 kg/hr, respectively; the wastes burnt were 1140 and 1185 metric tonnes/day. The municipal and industrial wastes treated in MSWI-A and B were 40% vs. 60% and 56% vs. 44%, respectively. Each furnace is two-stage and starved-air modular type. The air pollution control devices (dry scrubber, activated carbon injection, and fabric filter) which is the most universal combination in MSWIs of Taiwan installed in each MSWI were recognized as the most effective techniques for PCDD/Fs control (Wang, *et al.*, 2009). For PP, two furnaces and four electrostatic dust collectors (ESD) were functioning, and 4656 metric tonnes/day of coals were consumed as fuel during the sampling.

### *The Stack Flue Gas Sample Collection*

Totally fifteen stack flue gas (SFG) samples, five samples from each site, were collected for PCDD/Fs analysis. The sampling method was in compliance with the standard sampling procedure of Dioxin and Furan in flue pipe, NIEA A807.74C, which was issued by Environmental Analysis laboratory EPA, Executive Yuan, (R.O.C). The stack flue gases were collected isokinetically and then the probe was cleansed with the order of acetone, dichloromethane, and toluene for the sample collecting. The sampling train adopted in this study was comparable with which specified by U.S. EPA modified method 5. No sealing grease was used during the train parts assembling. The gas density determination equipment is qualified with US EPA methods 3 and 4. Amberlite XAD-2® was used as the adsorbent. Prior to sampling, 20–40 g XAD-2® was loaded in the cartridge, and was spiked with PCDD/F surrogate standards pre-labeled with isotopes, $^{37}Cl_4$-2,3,7,8-TCDD, $^{13}C_{12}$-1,2,3,4,7,8-HxCDD, $^{13}C_{12}$-2,3,4,7,8-PeCDF, $^{13}C_{12}$-1,2,3,4,7,8-HxCDF, and $^{13}C_{12}$-1,2,3,4,7,8,9-HpCDF. The PCDD/F surrogate standard recoveries were, 72.4–113.4%, reaching the criteria within 70–130%. After the samples were collected, they were preserved under 10°C and shipped back the lab for further analysis.

### *The Ash Sampling in MSWI Units*

In order to find out the characteristics of PCDD/Fs in MSWI ashes, those in MSWI units and the stack gas flue samples were collected at the same time. The typical ash samples were collected from six different MSWI units and two different PP units, which were bottom residues (BS), super heater (SH), economizer (EC), semi-dryer absorber (SDA), bag filter (BF),and fly ash pit (FAP) in MSWIs; bottom residues (BS) and electrostatic dust collectors (ESD) in PP. The ashes in FAP were the mixture of those in SH, EC, SDA, and BF. Solid waste sample collecting method (NIEA R119.00C) issued by NIEA was enforced to ensure quality of the sample. For each ton of solid waste burnt, ashes collected in each unit of MSWIs were 15%, 1%, 1%, 1%, 9%, and 12% for MSWI-A; and 12.5%, 0.83%, 0.83%, 0.83%, 7.5% and 9.99% for MSWI-B. For each ton of coal burnt, ashes equal to1.46% and 5.86% weight of burnt coal will be generated in BR and ESD of PP. The sampling method of every chosen MSWI and PP part was the same. Ashes were collected every 12 hours for 3 days, and 200 grams were collected each time with the total of 1.2 kilograms. The collected samples were stored in properly sealed containers to prevent the amount of moisture in the samples being affected by air circulation. During the transportation, the samples were preserved under 4 ± 1°C, except the solidified samples.

### *PCDD/Fs Analysis*

The samples had been pretreated before analysis. The ash samples were put on clean utensils or clean section of the foil, removed the impurities, and then wind-dried naturally or freeze dried. The pellets need to be shattered in order to prevent the dehydrated solid samples from cemented tightly during natural wind-dried process, if the diameter of pellets was greater than 15 mm. Solidified samples could be cracked and crushed to make them smaller than 5 mm before wind-dried naturally. After the drying, the samples were first sieved with 2 mm (10 mesh) standard sieve and then grinded to make them passing the 18 mesh (aperture < 1 mm) version. The sieved ashes were mixed properly and put into the flask to wait for being extracted.

The stack flue gas samples were put in a Soxhlet extractor with internal standard spiking solution (23IS) 30 μL and extracted for 18 ± 2 hours. The extract was then evaporated till almost dry out and was dissolved in dichloromethane three times in order to transfer to a clean tube. Each extract was separated equally into A and B flask. Flask A was taken to be acid-washed and flask B was stored.

The ash samples were put in thimble filters and were then moved in a Soxhlet extractor with internal standard spiking solution (1613LCS) and extracted on heat for the 22 ± 2 hours. The extract was cooled to room temperature and was then evaporated to near dryness.

The extracts were treated with sulfuric acid, and vibrated in an ultrasonic oscillator. A series of sample cleanup and fraction procedures, including acidic silica gel

column, acidic alumina column, and activated carbon chromatography, were used to treat the extract. The final extracts were blown with nitrogen to near dryness and RS (for stack flue gas samples) or ISS (for ash samples) were poured in the concentrates.

The analyses of PCDD/Fs were carried out by a high-resolution gas chromatographer/high-resolution mass spectrometer (HRGC/HRMS). Seventeen PCDD/F congeners were analyzed. The column equipped by HRGC was heated up from 150°C to 190°C with a raise of 20 °C/min, and was then raised up to 220°C with 1.5 °C/min. The temperature was then went up to 310°C with 3 °C/min and was maintained for 2 minutes. The HRMS was equipped with an electron impact (EI+) source. The analytical mode of selected ion monitoring (SIM) had a resolving power of 10,000. The temperature of the ion source was 250°C. The more details of analysis procedure could be found in Wang *et al.* (2003) and Chen *et al.* (2008).

## RESULTS AND DISSCUSION

### *PCDD/Fs Characteristics in Stack Flue Gas Samples*

Table 1 shows the averaged PCDD/F concentration and relative standard deviations (RSDs) for samples collected from MSWI-A, MSWI-B and PP. OCDD (0.3762 ng/Nm$^3$ in MSWI-A, 0.4434 ng/Nm$^3$ in MSWI-B, and 0.0785 ng/Nm$^3$ in PP), and 1,2,3,4,6,7,8-HpCDD (0.248 ng/Nm$^3$ in MSWI-A, 0.336 ng/Nm$^3$ in MSWI-B, and 0.0683 ng/Nm$^3$ in PP) were the dominating congeners, the above results could be compared with the results of Chao *et al.* (2004) and Jin *et al.* (2009). Ratio of PCDFs/PCDDs was greater than 1 in MSWI-B, indicating that the de nova synthesis were the primary PCDD/Fs formation pathway during the combustion (Huang and Buekens, 1995; Everaert and Baeyens, 2002). However, the ratio of PCDFs/PCDDs was 0.382 and 0.988 in MSWI-A and PP which were both smaller than 1, indicating precursors were the primary PCDD/F formation pathway in MSWI-A and PP. The mean PCDD/F toxic equivalent concentrations were 0.0327 I-TEQ/Nm$^3$, 0.0784 I-TEQ/Nm$^3$, and 0.015 I-TEQ/Nm$^3$ which were all lower than the regulation 0.1 I-TEQ/Nm$^3$ for PCDD/F emission in large MSWIs and PP, respectively. The main toxic equivalent in the stacks of MSWI-A and PP were PCDFs which were indicated by the ratio of PCDD equivalent to PCDF equivalent. PP and MSWIs had a similar congener profile, but the PCDD/Fs concentration in the stack flue gas of PP (0.332 ng/Nm$^3$) was much lower than those of MSWIs (0.947 ng/Nm$^3$ for MSWI-A, 1.78 ng/Nm$^3$ for MSWI-B). Table 2 shows the emission rates of PCDD/Fs which were 68.7, 86.9, and 739 μg/hr for MSWI-A, MSWI-B, and PP. From PCDD/Fs equivalent perspective, the emission rates were 2.37, 3.83, and 38.3 μg I-TEQ/hr for MSWI-A, MSWI-B, and PP. In both view points, PP is the major contributor of PCDD/Fs.

**Table 1.** Concentration of PCDD/Fs in the stack flue gas of MSWI-A, MSWI-B, and coal-fired power plant.

| PCDD/Fs | MSWI-A | | MSWI-B | | PP | |
|---|---|---|---|---|---|---|
| | Mean (n = 5) | RSD (%) | Mean (n = 5) | RSD (%) | Mean (n = 5) | RSD (%) |
| 2,3,7,8-TeCDD | 0.00116 | 14.9 | 0.0031 | 54.8 | 0.000481 | 103 |
| 1,2,3,7,8-PeCDD | 0.00582 | 14.8 | 0.0128 | 51.4 | 0.00265 | 72 |
| 1,2,3,4,7,8-HxCDD | 0.00854 | 19 | 0.0152 | 34.1 | 0.00374 | 77.7 |
| 1,2,3,6,7,8-HxCDD | 0.0294 | 25 | 0.0409 | 22.5 | 0.00836 | 81.9 |
| 1,2,3,7,8,9-HxCDD | 0.016 | 25.3 | 0.0243 | 28.3 | 0.00766 | 84.6 |
| 1,2,3,4,6,7,8-HpCDD | 0.248 | 46 | 0.336 | 15.7 | 0.0683 | 96.3 |
| OCDD | 0.376 | 87.7 | 0.443 | 15 | 0.0758 | 71.8 |
| 2,3,7,8-TeCDF | 0.00594 | 14.9 | 0.0183 | 51.2 | 0.00316 | 32.8 |
| 1,2,3,7,8-PeCDF | 0.0102 | 13.9 | 0.0361 | 52.6 | 0.00443 | 54 |
| 2,3,4,7,8-PeCDF | 0.0208 | 12.4 | 0.0506 | 72.9 | 0.0095 | 70.1 |
| 1,2,3,4,7,8-HxCDF | 0.0191 | 14.7 | 0.065 | 55.8 | 0.00966 | 75.7 |
| 1,2,3,6,7,8-HxCDF | 0.0214 | 15.9 | 0.0698 | 56.3 | 0.0111 | 77 |
| 1,2,3,7,8,9-HxCDF | 0.00246 | 33.2 | 0.00784 | 49 | 0.00172 | 97.2 |
| 2,3,4,6,7,8-HxCDF | 0.0356 | 18.3 | 0.103 | 50.9 | 0.023 | 92.4 |
| 1,2,3,4,6,7,8-HpCDF | 0.0743 | 23.7 | 0.265 | 47.6 | 0.0463 | 95.2 |
| 1,2,3,4,7,8,9-HpCDF | 0.0155 | 19.8 | 0.0662 | 32.3 | 0.014 | 87.5 |
| OCDF | 0.0567 | 28.2 | 0.222 | 32.5 | 0.0425 | 93.9 |
| PCDDs | 0.685 | 64.7 | 0.876 | 16.9 | 0.167 | 78.7 |
| PCDFs | 0.262 | 19.7 | 0.904 | 45.9 | 0.165 | 87.6 |
| PCDF/PCDDs | 0.382 | 29.8 | 1.03 | 23.6 | 0.988 | 27.9 |
| Total PCDD/Fs (ng/Nm$^3$) | 0.947 | 50.8 | 1.78 | 31.5 | 0.332 | 82.4 |
| PCDDs (ng I-TEQ/Nm$^3$) | 0.0123 | 23.9 | 0.0214 | 35.9 | 0.00454 | 80.9 |
| PCDFs (ng I-TEQ/Nm$^3$) | 0.0203 | 13.7 | 0.0571 | 61.3 | 0.0105 | 76.6 |
| PCDFs/PCDDs (TEQ) | 1.65 | 11.8 | 2.67 | 18.9 | 2.31 | 13.1 |
| Total TEQ (ng I-TEQ/Nm$^3$) | 0.0327 | 16.9 | 0.0784 | 54.3 | 0.015 | 77.8 |

**Table 2.** Emission Rate of PCDD/Fs in MSWI-A, MSWI-B, and coal-fired power plant.

| PCDD/Fs | MSWI-A | | MSWI-B | | PP | |
|---|---|---|---|---|---|---|
| | Mean (n = 5) | RSD (%) | Mean (n = 5) | RSD (%) | Mean (n = 5) | RSD (%) |
| 2,3,7,8-TeCDD | 0.0839 | 14.9 | 0.151 | 55.4 | 1.07 | 105 |
| 1,2,3,7,8-PeCDD | 0.422 | 14.2 | 0.628 | 51.9 | 5.87 | 74.9 |
| 1,2,3,4,7,8-HxCDD | 0.619 | 18.4 | 0.744 | 34.6 | 8.29 | 80.7 |
| 1,2,3,6,7,8-HxCDD | 2.13 | 24.5 | 2 | 23 | 18.5 | 84.9 |
| 1,2,3,7,8,9-HxCDD | 1.16 | 24.7 | 1.19 | 28.7 | 17 | 87.6 |
| 1,2,3,4,6,7,8-HpCDD | 18 | 45.7 | 16.4 | 16.2 | 152 | 99.3 |
| OCDD | 27.3 | 88 | 21.6 | 15.4 | 168 | 74.4 |
| 2,3,7,8-TeCDF | 0.43 | 14.1 | 0.895 | 51.7 | 6.96 | 34.7 |
| 1,2,3,7,8-PeCDF | 0.737 | 13.3 | 1.76 | 53.2 | 9.78 | 56.8 |
| 2,3,4,7,8-PeCDF | 1.51 | 12 | 2.47 | 73.5 | 21.1 | 73 |
| 1,2,3,4,7,8-HxCDF | 1.39 | 14.1 | 3.18 | 56.4 | 21.4 | 78.6 |
| 1,2,3,6,7,8-HxCDF | 1.56 | 15.6 | 3.41 | 56.9 | 24.7 | 80.1 |
| 1,2,3,7,8,9-HxCDF | 0.178 | 33.2 | 0.383 | 49.6 | 3.82 | 100 |
| 2,3,4,6,7,8-HxCDF | 2.58 | 17.7 | 5.05 | 51.4 | 51.2 | 95.5 |
| 1,2,3,4,6,7,8-HpCDF | 5.39 | 23 | 13 | 48.1 | 103 | 98.3 |
| 1,2,3,4,7,8,9-HpCDF | 1.12 | 19.3 | 3.23 | 32.8 | 31.1 | 90.4 |
| OCDF | 4.11 | 27.8 | 10.8 | 33 | 94.6 | 96.9 |
| PCDDs (μg/hr) | 49.7 | 64.9 | 42.7 | 17.3 | 371 | 81.7 |
| PCDFs (μg/hr) | 19 | 19.1 | 44.2 | 46.4 | 368 | 90.6 |
| PCDFs/PCDDs | 0.382 | 29.7 | 1.04 | 23.4 | 0.99 | 27.8 |
| Total PCDD/Fs (μg/hr) | 68.7 | 50.8 | 86.9 | 32 | 739 | 85.5 |
| PCDDs (μg I-TEQ/hr) | 0.892 | 23.5 | 1.04 | 36.4 | 10.1 | 83.9 |
| PCDFs (μg I-TEQ/hr) | 1.47 | 13.2 | 2.79 | 61.8 | 23.3 | 79.6 |
| PCDFs/PCDDs (TEQ) | 1.65 | 11.6 | 2.68 | 18.8 | 2.31 | 13.1 |
| Total I-TEQ (μg I-TEQ/hr) | 2.37 | 16.4 | 3.83 | 54.9 | 33.3 | 80.8 |

Therefore, air pollution control devices (APCDs) in PP must be improved in order to the reduce PCDD/F emission.

***PCDD/F Characteristics in Ash Samples***

TEQs of PCDD/Fs and the averaged PCDD/F concentrations of ash samples collected from different units of MSWIs and PP could be found in Table 3(a1), 3(a2), 3(b1), 3(b2), and 3(c). Fig. 1, Fig. 2, and Fig. 3 show PCDD/F congener profiles in the ashes of each unit and stack flue gases. The averaged PCDD/F concentration in each unit was 0.318, 0.101, 12.9, 2.39, 7.40, and 13.3 ng/g for BR, SH, EC, SDA, BF, and FAP in MSWI-A; 0.405, 5.16, 0.49, 156, 228, and 45.8 ng/g in MSWI-B. In PP, the average PCDD/F concentration was 0.00997 ng/g in bottom residue, and 0.00261 ng/g in electrostatic dust collectors. The bag filter has the first and the second highest PCDD/F content in two MSWIs. In a recent study, bag filter was found having the highest PCDD/Fs concentration (Chang *et al.*, 2006). From PCDD/F equivalent, TEQs of PCDD/Fs were 0.0127, 0.00842, 0.206, 0.0634, 0.491, and 0.639 ng I-TEQ/g for MSWI-A; 0.0164, 0.0095, 0.0202, 2.84, 4.08, and 1.39 ng I-TEQ/g for MSWI-B. The averaged TEQs were 0.000205 and 0.0000746 for PP. The dominating congener in each unit was still OCDD (0.112, 0.122 ng/g in BR; 0.0132, 2.55 ng/g in SH, 7.5, 0.123 ng/g in EC, 1.03, 91.5 ng/g in SDA, and 1.55, 131 ng/g in BF for MSWI-A and MSWI-B; 3.71 and 19.8 ng/g in FAP for MSWI-A and MSWI-B, respectively; 0.00656, 0.00130 ng/g in BR and ESD for PP, respectively.). However, the second dominating congener varies in different units. The control strategies of ashes generated from the MSWI-A, MSWI-B and PP are different, because the toxic content varies. In Taiwan, fly ashes from MSWI are treated as hazardous industrial waste and need to be solidified before burying in landfills. However, fly ashes from PP could be used as resource in embankment.

***The Distribution of PCDD/Fs in MSWIs and PP***

In MSWI-A and MSWI-B, weights of bottom residue were 15% and 12.5% of solid waste feed; weights of fly ash were 8.3% and 6.3% of solid waste feed. In PP, 1.46% weight of coal became bottom residue and 5.56% became fly ash. The emission factors of all congeners could be found in Table 4(a) and 4(b). Fig. 4 and Fig. 5 illustrate the distribution of PCDD/F mass and I-TEQ in MSWI-A, MSWI B and PP, respectively. According to Fig. 4 and Fig. 5, different PCDD/F emitting scenario of MSWIs and PP could be discovered. The concentration of PCDD/Fs in PP was lower than those in MSWIs; however, the emission rate of PCDD/Fs was the highest in PP than those in MSWIs. The extreme outcomes told us that even the PCDD/Fs concentration in PP was low, but the emission does still need to be noticed. The absence of air pollution

**Table 3(a1).** PCDD/F content in each unit of MSWI-A

| PCDD/Fs | MSWI-A | | | | | |
|---|---|---|---|---|---|---|
| | BS | | SH | | EC | |
| | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) |
| 2,3,7,8-TeCDD | 0.000598 | 33 | 0.000491 | 61.8 | 0.0178 | 58.4 |
| 1,2,3,7,8-PeCDD | 0.00203 | 41 | 0.00141 | 39.1 | 0.048 | 8.97 |
| 1,2,3,4,7,8-HxCDD | 0.00175 | 37.2 | 0.00095 | 3.37 | 0.0485 | 30.9 |
| 1,2,3,6,7,8-HxCDD | 0.00422 | 46 | 0.000981 | 8.06 | 0.0803 | 34.4 |
| 1,2,3,7,8,9-HxCDD | 0.00373 | 55 | 0.00132 | 6.06 | 0.0885 | 15.6 |
| 1,2,3,4,6,7,8-HpCDD | 0.0334 | 18 | 0.00561 | 11.6 | 1.14 | 48.9 |
| OCDD | 0.112 | 43.1 | 0.0132 | 66.4 | 7.5 | 72 |
| 2,3,7,8-TeCDF | 0.00529 | 4.35 | 0.00357 | 108 | 0.0235 | 3.84 |
| 1,2,3,7,8-PeCDF | 0.00639 | 25.4 | 0.00683 | 69.4 | 0.0621 | 12.9 |
| 2,3,4,7,8-PeCDF | 0.00995 | 37.2 | 0.00707 | 62 | 0.0793 | 25.4 |
| 1,2,3,4,7,8-HxCDF | 0.0095 | 40.1 | 0.00721 | 41.8 | 0.146 | 30.1 |
| 1,2,3,6,7,8-HxCDF | 0.00957 | 44.6 | 0.00802 | 46.1 | 0.17 | 28.9 |
| 1,2,3,7,8,9-HxCDF | 0.00601 | 129 | 0.00491 | 151 | 0.128 | 145 |
| 2,3,4,6,7,8-HxCDF | 0.00802 | 177 | 0.00332 | 98.6 | 0.155 | 189 |
| 1,2,3,4,6,7,8-HpCDF | 0.043 | 25.8 | 0.0197 | 27 | 1.55 | 49.8 |
| 1,2,3,4,7,8,9-HpCDF | 0.00553 | 40.5 | 0.00493 | 36.5 | 0.137 | 25.6 |
| OCDF | 0.0574 | 14.8 | 0.012 | 54.6 | 1.32 | 43.9 |
| PCDDs | 0.158 | 31.1 | 0.024 | 43 | 8.91 | 67.3 |
| PCDFs | 0.161 | 25.5 | 0.0776 | 48.4 | 3.77 | 42.8 |
| PCDFs/PCDDs | 1.07 | 55.6 | 3.22 | 5.64 | 0.442 | 26.4 |
| Total PCDD/Fs (ng/g) | 0.318 | 1.89 | 0.101 | 46.7 | 12.7 | 60.1 |
| PCDDs (ng I-TEQ/g) | 0.00303 | 32.1 | 0.00159 | 37.2 | 0.0825 | 35.3 |
| PCDFs (ng I-TEQ/g) | 0.00966 | 36 | 0.00684 | 58.1 | 0.123 | 32.5 |
| PCDFs/PCDDs (TEQ) | 3.18 | 4.08 | 4.23 | 22.1 | 1.5 | 2.86 |
| Total TEQ (ng I-TEQ/g) | 0.0127 | 34.6 | 0.00842 | 54.2 | 0.206 | 33.6 |

Note: BR (bottom residues); SH (super heater); EC (economizer).

**Table 3(a2).** PCDD/F content in each unit of MSWI-A.

| PCDD/Fs | MSWI-A | | | | | |
|---|---|---|---|---|---|---|
| | SDA | | BF | | FAP | |
| | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) |
| 2,3,7,8-TeCDD | 0.00338 | 43 | 0.0331 | 12.4 | 0.0322 | 2.8 |
| 1,2,3,7,8-PeCDD | 0.0121 | 70.9 | 0.0928 | 15.5 | 0.117 | 21.5 |
| 1,2,3,4,7,8-HxCDD | 0.0114 | 78 | 0.06 | 19.5 | 0.107 | 79.7 |
| 1,2,3,6,7,8-HxCDD | 0.0157 | 75.2 | 0.0859 | 7.57 | 0.175 | 99.7 |
| 1,2,3,7,8,9-HxCDD | 0.0199 | 76.1 | 0.0776 | 20.1 | 0.148 | 69.7 |
| 1,2,3,4,6,7,8-HpCDD | 0.187 | 86.6 | 0.541 | 24.2 | 1.32 | 120 |
| OCDD | 1.03 | 98.2 | 1.55 | 25.8 | 3.71 | 134 |
| 2,3,7,8-TeCDF | 0.0144 | 63.8 | 0.181 | 43.8 | 0.168 | 44 |
| 1,2,3,7,8-PeCDF | 0.0295 | 61 | 0.338 | 13.6 | 0.348 | 27.9 |
| 2,3,4,7,8-PeCDF | 0.0354 | 68.7 | 0.356 | 35.4 | 0.441 | 67.6 |
| 1,2,3,4,7,8-HxCDF | 0.0519 | 79.7 | 0.419 | 17 | 0.543 | 68.5 |
| 1,2,3,6,7,8-HxCDF | 0.0596 | 82.8 | 0.476 | 16.2 | 0.629 | 70.2 |
| 1,2,3,7,8,9-HxCDF | 0.0723 | 187 | 0.381 | 179 | 0.63 | 187 |
| 2,3,4,6,7,8-HxCDF | 0.0253 | 161 | 0.224 | 167 | 0.215 | 135 |
| 1,2,3,4,6,7,8-HpCDF | 0.395 | 105 | 1.6 | 18.2 | 2.67 | 118 |
| 1,2,3,4,7,8,9-HpCDF | 0.0515 | 103 | 0.209 | 23 | 0.355 | 118 |
| OCDF | 0.373 | 116 | 0.772 | 24.6 | 1.69 | 147 |
| PCDDs | 1.28 | 95.2 | 2.44 | 20.5 | 5.61 | 123 |
| PCDFs | 1.11 | 103 | 4.96 | 24.8 | 7.68 | 107 |

**Table 3(a2).** *(continued).*

| PCDD/Fs | MSWI-A | | | | | |
|---|---|---|---|---|---|---|
| | SDA | | BF | | FAP | |
| | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) |
| PCDFs/PCDDs | 0.845 | 10.3 | 2.08 | 44.7 | 1.48 | 24.0 |
| Total PCDD/Fs (ng/g) | 2.39 | 98.7 | 7.4 | 9.87 | 13.3 | 114 |
| PCDDs (ng I-TEQ/g) | 0.017 | 70.6 | 0.109 | 9.17 | 0.15 | 45.3 |
| PCDFs (ng I-TEQ/g) | 0.0464 | 81.3 | 0.382 | 31.9 | 0.488 | 75.8 |
| PCDFs/PCDDs (TEQ) | 2.67 | 12.6 | 3.49 | 22.9 | 3.13 | 33.4 |
| Total TEQ (ng I-TEQ/g) | 0.0634 | 78.1 | 0.491 | 26.9 | 0.639 | 68.8 |

Note: SDA (semi-dryer absorber); BF (bag filter); FAP (fly ash pit).

**Table 3(b1).** PCDD/F content in each unit of MSWI-B.

| PCDD/Fs | MSWI-B | | | | | |
|---|---|---|---|---|---|---|
| | BS | | SH | | EC | |
| | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) |
| 2,3,7,8-TeCDD | 0.000476 | 146 | 0.00636 | 199 | 0.000604 | 161 |
| 1,2,3,7,8-PeCDD | 0.00232 | 151 | 0.0219 | 200 | 0.00259 | 200 |
| 1,2,3,4,7,8-HxCDD | 0.00231 | 148 | 0.0248 | 199 | 0.00319 | 188 |
| 1,2,3,6,7,8-HxCDD | 0.00584 | 153 | 0.038 | 199 | 0.00681 | 193 |
| 1,2,3,7,8,9-HxCDD | 0.00436 | 151 | 0.0405 | 200 | 0.00457 | 187 |
| 1,2,3,4,6,7,8-HpCDD | 0.0531 | 161 | 0.531 | 200 | 0.0491 | 192 |
| OCDD | 0.122 | 162 | 2.55 | 200 | 0.123 | 186 |
| 2,3,7,8-TeCDF | 0.00464 | 118 | 0.0109 | 197 | 0.00546 | 185 |
| 1,2,3,7,8-PeCDF | 0.00698 | 130 | 0.0334 | 199 | 0.0192 | 194 |
| 2,3,4,7,8-PeCDF | 0.0122 | 137 | 0.0407 | 198 | 0.0129 | 189 |
| 1,2,3,4,7,8-HxCDF | 0.0142 | 136 | 0.0776 | 199 | 0.0173 | 191 |
| 1,2,3,6,7,8-HxCDF | 0.0146 | 140 | 0.0887 | 199 | 0.0213 | 192 |
| 1,2,3,7,8,9-HxCDF | 0.00587 | 11.4 | 0.0118 | 192 | 0.00637 | 161 |
| 2,3,4,6,7,8-HxCDF | 0.017 | 195 | 0.113 | 200 | 0.0275 | 200 |
| 1,2,3,4,6,7,8-HpCDF | 0.0622 | 144 | 0.591 | 199 | 0.0775 | 187 |
| 1,2,3,4,7,8,9-HpCDF | 0.0109 | 145 | 0.0942 | 199 | 0.0259 | 192 |
| OCDF | 0.0671 | 167 | 0.876 | 199 | 0.0872 | 187 |
| PCDDs | 0.19 | 161 | 3.21 | 200 | 0.19 | 188 |
| PCDFs | 0.216 | 150 | 1.94 | 199 | 0.3 | 189 |
| PCDFs/PCDDs | 1.28 | 28.1 | 1.02 | 82.3 | 1.48 | 14.4 |
| Total PCDD/Fs (ng/g) | 0.405 | 155 | 5.16 | 200 | 0.49 | 189 |
| PCDDs (ng I-TEQ/g) | 0.00354 | 152 | 0.0354 | 200 | 0.00396 | 189 |
| PCDFs (ng I-TEQ/g) | 0.0129 | 139 | 0.0602 | 199 | 0.0163 | 191 |
| PCDFs/PCDDs (TEQ) | 4.07 | 28 | 2.99 | 86.7 | 3.83 | 15.3 |
| Total TEQ (ng I-TEQ/g) | 0.0164 | 142 | 0.0952 | 199 | 0.0202 | 190 |

Note: BR (bottom residues); SH (super heater); EC (economizer).

**Table 3(b2).** PCDD/F content in each unit of MSWI-B.

| PCDD/Fs | MSWI-B | | | | | |
|---|---|---|---|---|---|---|
| | SDA | | BF | | FAP | |
| | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) |
| 2,3,7,8-TeCDD | 0.0498 | 179 | 0.0462 | 18.6 | 0.0367 | 40.7 |
| 1,2,3,7,8-PeCDD | 0.349 | 190 | 0.451 | 14.4 | 0.206 | 49.5 |
| 1,2,3,4,7,8-HxCDD | 0.555 | 193 | 0.756 | 10.2 | 0.281 | 47.4 |
| 1,2,3,6,7,8-HxCDD | 3.25 | 198 | 4.45 | 59.2 | 1.03 | 6.96 |
| 1,2,3,7,8,9-HxCDD | 1.72 | 196 | 2.18 | 33.6 | 0.574 | 13.4 |
| 1,2,3,4,6,7,8-HpCDD | 37.3 | 198 | 54.5 | 67.9 | 8.76 | 51.1 |
| OCDD | 91.5 | 196 | 131 | 33.6 | 19.8 | 70.7 |

**Table 3(b2).** *(continued).*

| PCDD/Fs | MSWI-B | | | | | |
|---|---|---|---|---|---|---|
| | SDA | | BF | | FAP | |
| | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) |
| 2,3,7,8-TeCDF | 0.44 | 193 | 0.516 | 51.8 | 0.244 | 20.1 |
| 1,2,3,7,8-PeCDF | 0.823 | 191 | 1.12 | 37 | 0.508 | 36.6 |
| 2,3,4,7,8-PeCDF | 1.67 | 193 | 2.39 | 44.9 | 0.914 | 45.2 |
| 1,2,3,4,7,8-HxCDF | 1.44 | 187 | 2.3 | 6.09 | 0.972 | 46.9 |
| 1,2,3,6,7,8-HxCDF | 1.78 | 189 | 2.77 | 5.42 | 1.12 | 35.4 |
| 1,2,3,7,8,9-HxCDF | 2.63 | 199 | 2.52 | 162 | 0.829 | 147 |
| 2,3,4,6,7,8-HxCDF | 0.163 | 42.9 | 2.12 | 179 | 0.949 | 184 |
| 1,2,3,4,6,7,8-HpCDF | 5.56 | 177 | 9.85 | 43.7 | 4.52 | 42.5 |
| 1,2,3,4,7,8,9-HpCDF | 1.27 | 189 | 2.21 | 63 | 0.844 | 9.72 |
| OCDF | 5.21 | 177 | 8.69 | 94.6 | 4.14 | 20.6 |
| PCDDs | 135 | 196 | 194 | 43.9 | 30.8 | 58.9 |
| PCDFs | 21 | 184 | 34.5 | 35.1 | 15.1 | 31.2 |
| PCDFs/PCDDs | 0.421 | 128 | 0.194 | 76.1 | 0.56 | 86.1 |
| Total PCDD/Fs (ng/g) | 156 | 195 | 228 | 31.6 | 45.8 | 29.1 |
| PCDDs (ng I-TEQ/g) | 1.24 | 195 | 1.69 | 46.9 | 0.436 | 8.26 |
| PCDFs (ng I-TEQ/g) | 1.59 | 191 | 2.4 | 21.7 | 0.952 | 39.6 |
| PCDFs/PCDDs (TEQ) | 1.87 | 64.6 | 1.47 | 25.9 | 2.17 | 31.6 |
| Total TEQ (ng I-TEQ/g) | 2.84 | 193 | 4.08 | 31.9 | 1.39 | 29.6 |

Note: SDA (semi-dryer absorber); BF (bag filter); FAP (fly ash pit).

**Table 3(c).** PCDD/F content in each different unit of the coal-fired power plant.

| PCDD/Fs | PP | | | |
|---|---|---|---|---|
| | BS | | ESD | |
| | Mean (n = 2) | RPD (%) | Mean (n = 2) | RPD (%) |
| 2,3,7,8-TeCDD | ND | - | ND | - |
| 1,2,3,7,8-PeCDD | 0.0000465 | 153 | 0.00000800 | 200 |
| 1,2,3,4,7,8-HxCDD | 0.0000045 | 200 | 0.00000850 | 200 |
| 1,2,3,6,7,8-HxCDD | 0.0000615 | 122 | 0.00000950 | 200 |
| 1,2,3,7,8,9-HxCDD | 0.0000465 | 131 | 0.0000105 | 200 |
| 1,2,3,4,6,7,8-HpCDD | 0.000687 | 81.8 | 0.000214 | 75.7 |
| OCDD | 0.00656 | 148 | 0.00130 | 143 |
| 2,3,7,8-TeCDF | 0.000294 | 169 | 0.0000320 | 18.8 |
| 1,2,3,7,8-PeCDF | 0.000186 | 164 | 0.0000490 | 16.3 |
| 2,3,4,7,8-PeCDF | 0.000162 | 137 | 0.0000670 | 2.99 |
| 1,2,3,4,7,8-HxCDF | 0.000104 | 103 | 0.0000715 | 23.8 |
| 1,2,3,6,7,8-HxCDF | 0.000106 | 108 | 0.0000675 | 28.1 |
| 1,2,3,7,8,9-HxCDF | 0.000022 | 200 | 0.0000390 | 200 |
| 2,3,4,6,7,8-HxCDF | 0.000085 | 191 | 0.0000330 | 200 |
| 1,2,3,4,6,7,8-HpCDF | 0.000433 | 132 | 0.000291 | 27.2 |
| 1,2,3,4,7,8,9-HpCDF | 0.000049 | 118 | 0.0000335 | 2.99 |
| OCDF | 0.00113 | 181 | 0.000375 | 103 |
| PCDDs | 0.00739 | 141 | 0.00155 | 126 |
| PCDFs | 0.00258 | 157 | 0.00106 | 40.3 |
| PCDFs/PCDDs | 0.309 | 36 | 1.34 | 98.0 |
| Total PCDD/Fs (ng/g) | 0.00997 | 145 | 0.00261 | 91.2 |
| PCDDs (ng I-TEQ/g) | 0.000048 | 132 | 0.0000103 | 99.2 |
| PCDFs (ng I-TEQ/g) | 0.000157 | 139 | 0.0000639 | 5.79 |
| PCDFs/PCDDs (TEQ) | 3.16 | 11.5 | 0.159 | 94.7 |
| Total TEQ (ng I-TEQ/g) | 0.000205 | 137 | 0.0000742 | 18.7 |

Note: BR (bottom residues); ESD (electrostatic dust collectors).

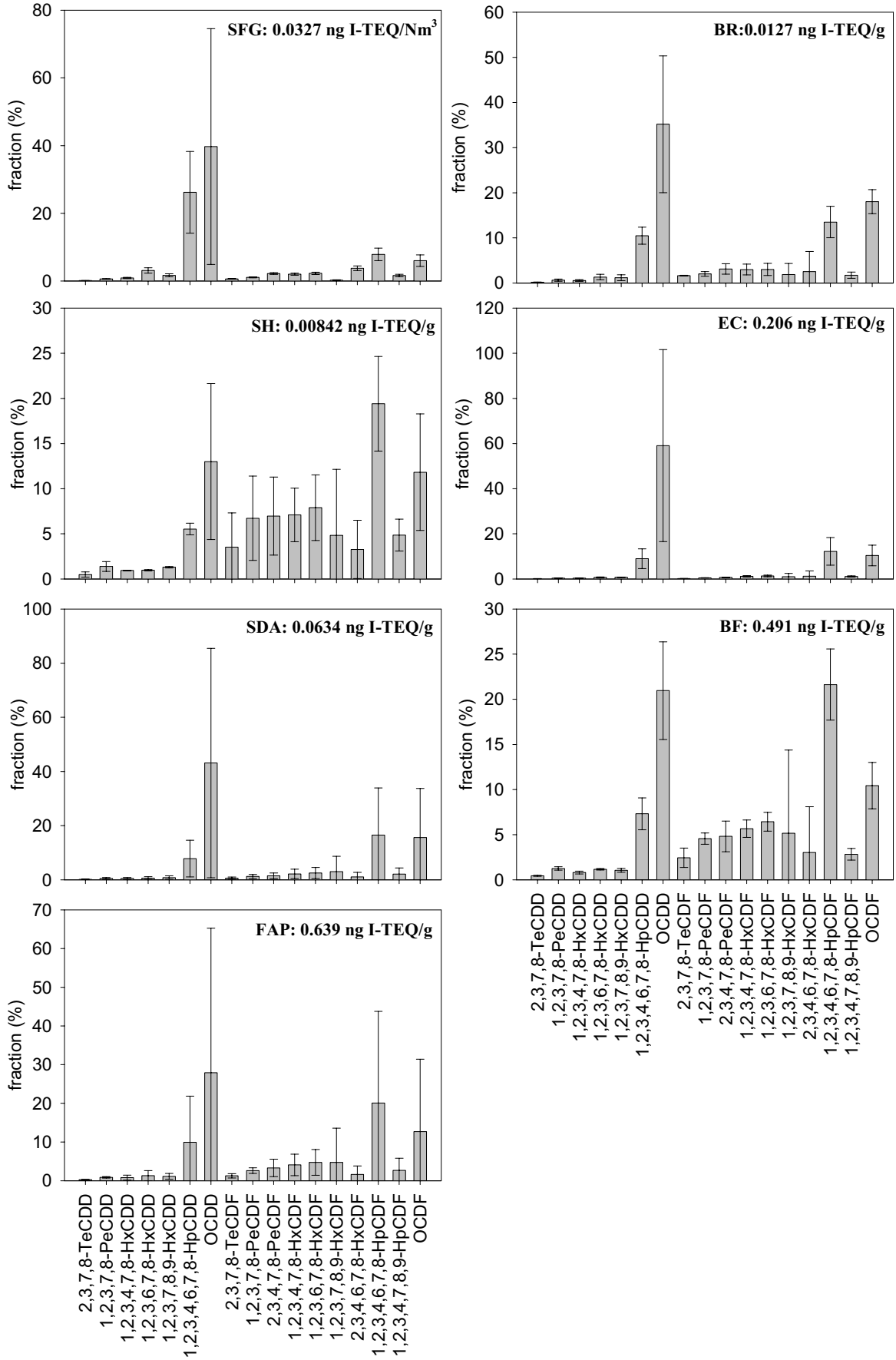


**Fig. 1.** PCDD/F congener profiles for MSWI A.

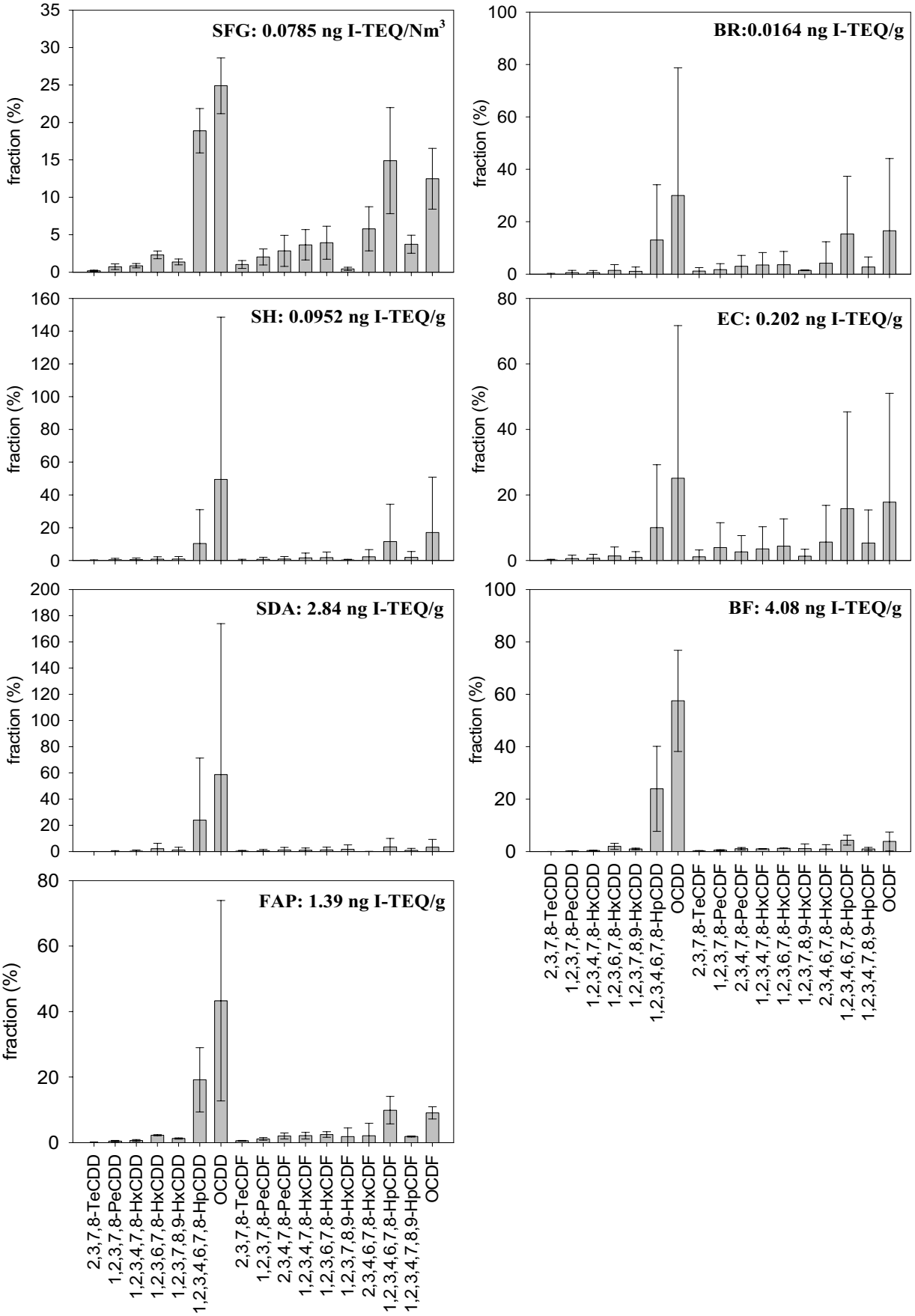


**Fig. 2.** PCDD/F congener profiles for MSWI B.

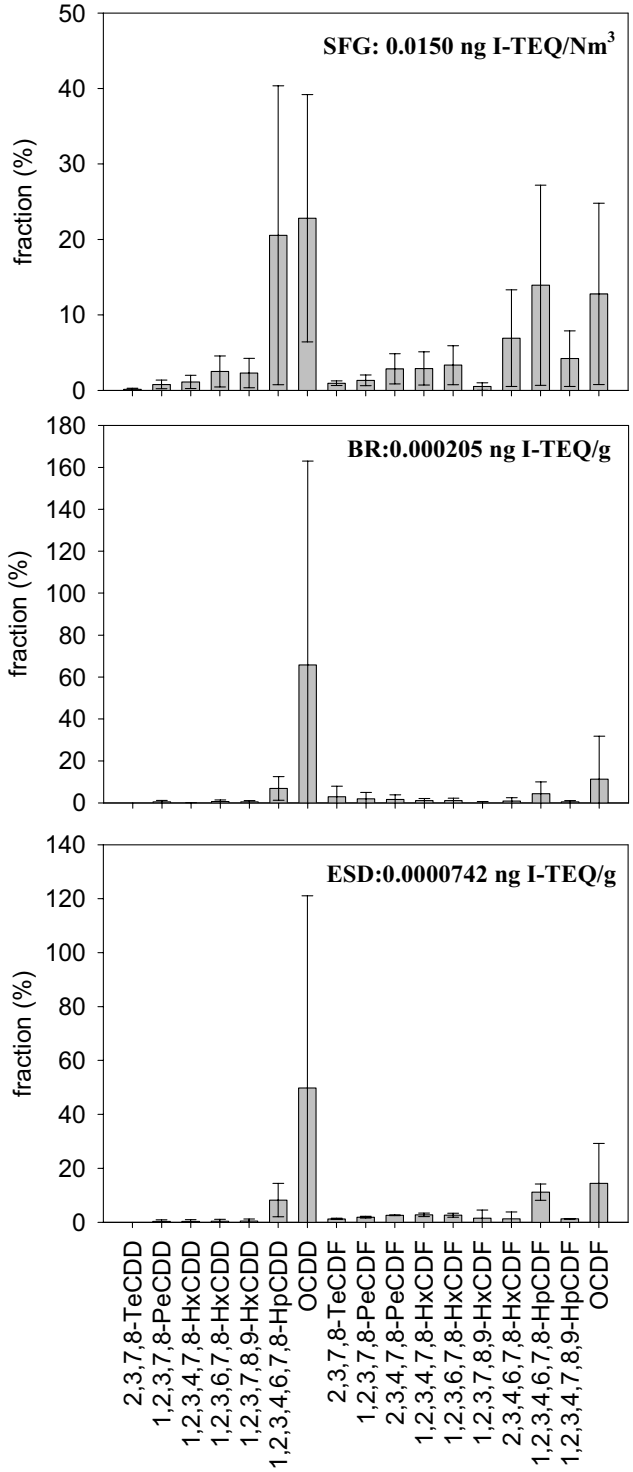


**Fig. 3.** PCDD/F congener profiles for PP.

control devices suitable for PCDD/F elimination in PP has made the situation worse, 99.58% PCDD/Fs I-TEQ has dispersed into the atmosphere for each ton-coal burnt, instead of trapped in the fly ash just like MWSIs. Only 0.5% or lower PCDD/F amount has been escaped to the environment for every ton-waste treated. The combination of dry scrubber, activated carbon injection, and bag filter installed in MSWIs has been recognized as the most effective technique for PCDD/Fs control. 71.31% and 91.43% of PCDD/F mass and I-TEQ in MSWI A were trapped in the semi-dryer absorber and the bag filter; 99.45% and 99.03% PCDD/F mass and I-TEQ in MSWI B were found in the semi-dryer absorber and the bag filter, respectively. However, 99.69% of PCDD/F mass and I-TEQ were emitted to the atmosphere from PP. The necessity of installing effective PCDD/F control devices

**Table 4(a).** The emission factors of BS, SFG and FAP (ESD for PP) in MSWI-A, MSWI-B and the coal fired power plant (unit: μg/ton-waste; μg/ton-coal for PP).

| Mg/ton-waste | SFG | | | BS | | | FAP (ESD for PP) | | |
|---|---|---|---|---|---|---|---|---|---|
| | MSWI-A | MSWI-B | PP | MSWI-A | MSWI-B | PP | MSWI-A | MSWI-B | PP |
| 2,3,7,8-TeCDD | 0.0053 | 0.0087 | 0.0545 | 0.0896 | 0.0593 | ND | 3.86 | 3.66 | ND |
| 1,2,3,7,8-PeCDD | 0.0266 | 0.0361 | 0.308 | 0.304 | 0.289 | 0.000679 | 14.0 | 20.6 | 0.000469 |
| 1,2,3,4,7,8-HxCDD | 0.0391 | 0.0429 | 0.435 | 0.262 | 0.287 | 0.0000657 | 12.8 | 28.0 | 0.000498 |
| 1,2,3,6,7,8-HxCDD | 0.134 | 0.115 | 0.973 | 0.633 | 0.727 | 0.000898 | 21.0 | 103 | 0.000557 |
| 1,2,3,7,8,9-HxCDD | 0.0732 | 0.0687 | 0.894 | 0.559 | 0.542 | 0.000679 | 17.7 | 57.3 | 0.000615 |
| 1,2,3,4,6,7,8-HpCDD | 1.14 | 0.949 | 7.97 | 5.01 | 6.60 | 0.0100 | 158 | 875 | 0.0125 |
| OCDD | 1.72 | 1.25 | 8.59 | 16.8 | 15.1 | 0.0957 | 445 | 1,978.0 | 0.0764 |
| 2,3,7,8-TeCDF | 0.0272 | 0.0516 | 0.363 | 0.793 | 0.577 | 0.00429 | 20.2 | 24.3 | 0.00188 |
| 1,2,3,7,8-PeCDF | 0.0465 | 0.101 | 0.51 | 0.959 | 0.868 | 0.00271 | 41.7 | 50.7 | 0.00287 |
| 2,3,4,7,8-PeCDF | 0.0953 | 0.142 | 1.1 | 1.49 | 1.52 | 0.00237 | 52.9 | 91.3 | 0.00393 |
| 1,2,3,4,7,8-HxCDF | 0.0876 | 0.182 | 1.12 | 1.42 | 1.77 | 0.00151 | 65.2 | 97.1 | 0.00419 |
| 1,2,3,6,7,8-HxCDF | 0.0982 | 0.196 | 1.29 | 1.43 | 1.81 | 0.00155 | 75.4 | 112 | 0.00396 |
| 1,2,3,7,8,9-HxCDF | 0.0113 | 0.022 | 0.2 | 0.902 | 0.730 | 0.000321 | 75.6 | 82.8 | 0.00229 |
| 2,3,4,6,7,8-HxCDF | 0.163 | 0.290 | 2.69 | 1.20 | 2.11 | 0.00124 | 25.8 | 94.8 | 0.00193 |
| 1,2,3,4,6,7,8-HpCDF | 0.340 | 0.745 | 5.39 | 6.44 | 7.74 | 0.00632 | 320 | 452 | 0.0170 |
| 1,2,3,4,7,8,9-HpCDF | 0.0709 | 0.186 | 1.64 | 0.830 | 1.36 | 0.000715 | 42.6 | 84.3 | 0.00196 |
| OCDF | 0.259 | 0.625 | 4.96 | 8.60 | 8.35 | 0.0166 | 202 | 413 | 0.0220 |
| PCDDs | 3.14 | 2.47 | 19.2 | 23.6 | 23.6 | 0.108 | 673 | 3,071.9 | 0.0910 |
| PCDFs | 1.2 | 2.54 | 19.3 | 24.1 | 26.9 | 0.0376 | 922 | 1,503.5 | 0.0619 |
| PCDFs/PCDDs | 0.568 | 0.193 | 0.24 | 1.02 | 1.14 | 0.349 | 1.37 | 0.489 | 0.681 |
| Total PCDD/Fs | 4.34 | 5.02 | 38.5 | 47.7 | 50.5 | 0.145 | 1,596.6 | 4,570.4 | 0.153 |
| PCDDs (μg I-TEQ/ton-waste) | 0.0563 | 0.0602 | 0.527 | 0.454 | 0.441 | 0.000700 | 18.0 | 43.6 | 0.000603 |
| PCDFs (μg I-TEQ/ton-waste) | 0.0931 | 0.160 | 1.22 | 1.45 | 1.60 | 0.00229 | 58.6 | 95.1 | 0.00374 |
| PCDFs/PCDDs (TEQ) | 0.157 | 0.0794 | 0.107 | 3.19 | 3.64 | 3.28 | 3.25 | 2.18 | 6.20 |
| Total PCDD/Fs (μg I-TEQ/ton-waste) | 0.149 | 0.220 | 1.75 | 1.91 | 2.05 | 0.00300 | 76.6 | 138 | 0.00435 |

**Table 4(b).** The emission factors of SH, EC, SDA, and BF in MSWI-A and MSWI-B (unit: μg/ton-waste; μg/ton-coal for PP).

| μg/ton-waste | SH | | EC | | SDA | | BF | |
|---|---|---|---|---|---|---|---|---|
| | MSWI-A | MSWI-B | MSWI-A | MSWI-B | MSWI-A | MSWI-B | MSWI-A | MSWI-B |
| 2,3,7,8-TeCDD | 0.00491 | 0.0528 | 0.178 | 0.00501 | 0.0338 | 0.414 | 2.97 | 3.47 |
| 1,2,3,7,8-PeCDD | 0.0141 | 0.181 | 0.480 | 0.0429 | 0.121 | 2.90 | 8.35 | 33.8 |
| 1,2,3,4,7,8-HxCDD | 0.00950 | 0.206 | 0.485 | 0.0265 | 0.114 | 4.61 | 5.40 | 56.7 |
| 1,2,3,6,7,8-HxCDD | 0.00981 | 0.316 | 0.803 | 0.0566 | 0.157 | 27.0 | 7.73 | 333 |
| 1,2,3,7,8,9-HxCDD | 0.0132 | 0.336 | 0.885 | 0.0379 | 0.199 | 14.3 | 6.98 | 163 |
| 1,2,3,4,6,7,8-HpCDD | 0.0561 | 4.40 | 11.4 | 0.408 | 1.87 | 310 | 48.6 | 4,088 |
| OCDD | 0.132 | 21.2 | 75.0 | 1.02 | 10.3 | 759 | 140 | 9,825 |
| 2,3,7,8-TeCDF | 0.0357 | 0.0908 | 0.235 | 0.0453 | 0.144 | 3.65 | 16.2 | 38.7 |
| 1,2,3,7,8-PeCDF | 0.0683 | 0.278 | 0.621 | 0.159 | 0.295 | 6.83 | 30.4 | 84.2 |
| 2,3,4,7,8-PeCDF | 0.0707 | 0.338 | 0.793 | 0.107 | 0.354 | 13.9 | 32.0 | 179 |
| 1,2,3,4,7,8-HxCDF | 0.0721 | 0.644 | 1.46 | 0.144 | 0.519 | 11.9 | 37.7 | 173 |
| 1,2,3,6,7,8-HxCDF | 0.0802 | 0.736 | 1.70 | 0.177 | 0.596 | 14.8 | 42.8 | 207 |
| 1,2,3,7,8,9-HxCDF | 0.0491 | 0.0977 | 1.28 | 0.0528 | 0.723 | 21.8 | 34.3 | 189 |
| 2,3,4,6,7,8-HxCDF | 0.0332 | 0.939 | 1.55 | 0.457 | 0.253 | 1.35 | 20.2 | 159 |
| 1,2,3,4,6,7,8-HpCDF | 0.197 | 4.90 | 15.5 | 0.643 | 3.95 | 46.2 | 144 | 739 |
| 1,2,3,4,7,8,9-HpCDF | 0.0493 | 0.782 | 1.37 | 0.215 | 0.515 | 10.5 | 18.8 | 165 |
| OCDF | 0.120 | 7.27 | 13.2 | 0.724 | 3.73 | 43.2 | 69.5 | 652 |

**Table 4(b).** *(continued).*

| μg/ton-waste | SH | | EC | | SDA | | BF | |
|---|---|---|---|---|---|---|---|---|
| | MSWI-A | MSWI-B | MSWI-A | MSWI-B | MSWI-A | MSWI-B | MSWI-A | MSWI-B |
| PCDDs | 0.240 | 26.7 | 89.1 | 1.58 | 12.8 | 1,118.4 | 220 | 14,513 |
| PCDFs | 0.776 | 16.1 | 37.7 | 2.49 | 11.1 | 174 | 446 | 2,584 |
| PCDFs/PCDDs | 3.24 | 0.603 | 0.423 | 1.58 | 0.866 | 0.156 | 2.03 | 0.178 |
| Total PCDD/Fs | 1.01 | 42.8 | 127 | 4.07 | 23.9 | 1,291.6 | 666 | 17,100 |
| PCDDs (μg I-TEQ/ton-waste) | 0.0159 | 0.294 | 0.825 | 0.0329 | 0.170 | 10.3 | 9.81 | 126 |
| PCDFs (μg I-TEQ/ton-waste) | 0.0684 | 0.499 | 1.23 | 0.135 | 0.464 | 13.2 | 34.4 | 180 |
| PCDFs/PCDDs (TEQ) | 4.31 | 1.70 | 1.49 | 4.11 | 2.73 | 1.28 | 3.50 | 1.42 |
| Total PCDD/Fs (μg I-TEQ/ton-waste) | 0.0842 | 0.790 | 2.06 | 0.168 | 0.634 | 23.5 | 44.2 | 306 |

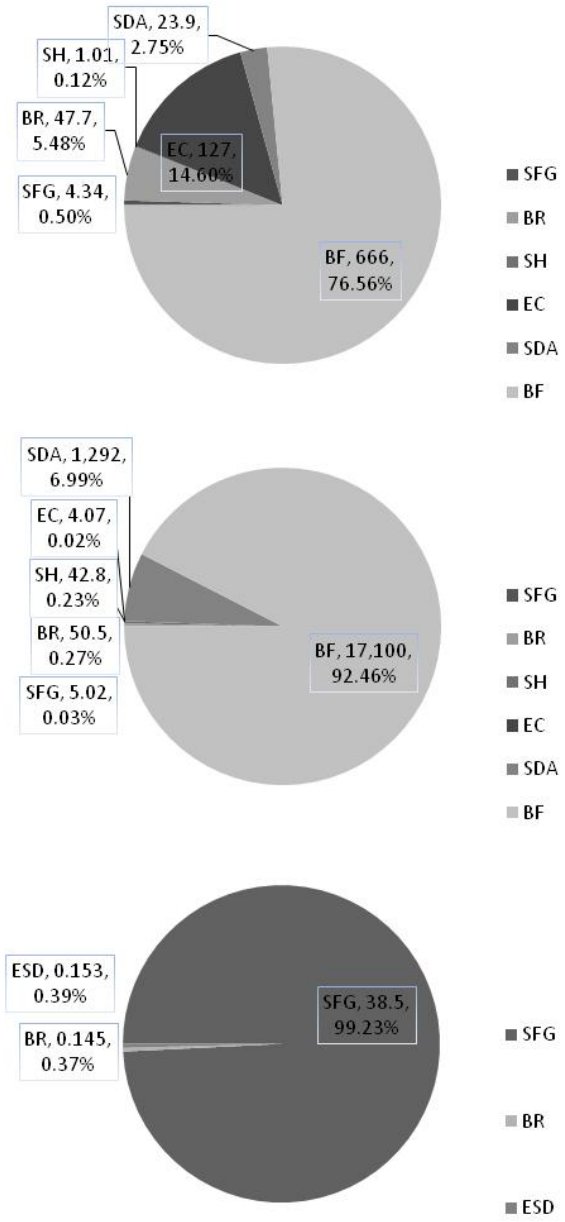


**Fig. 4.** PCDD/F. mass distribution in municipal solid waste incinerator A, B, and coal-fired power plant.

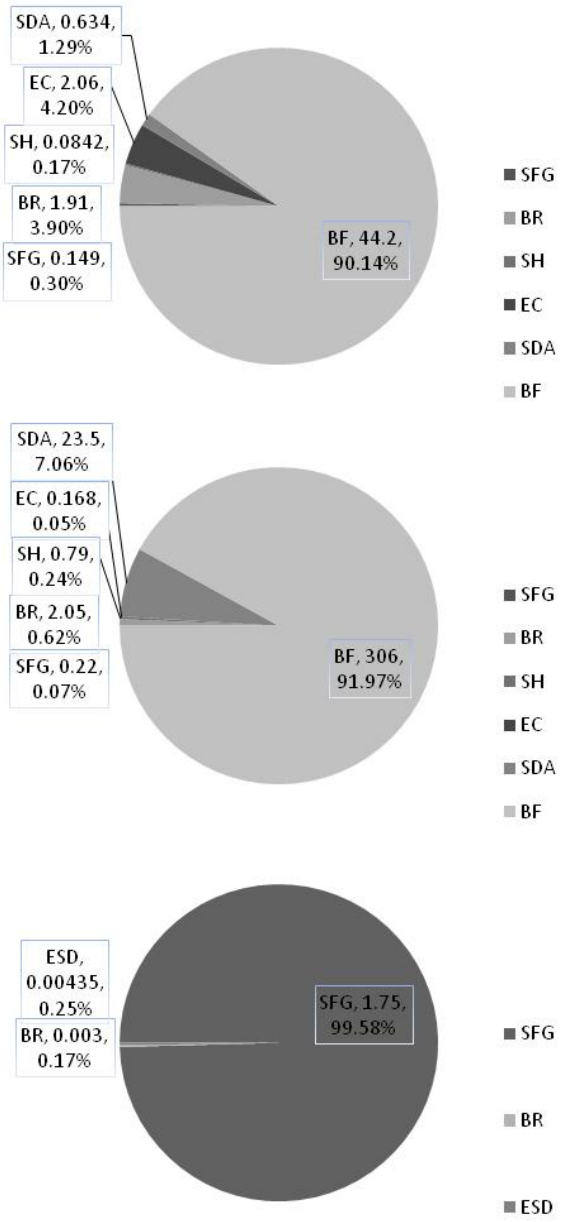


**Fig. 5.** PCDD/F I-TEQ distribution in municipal solid waste incinerator A, B and coal-fired power plant.

such as activated carbon injection and bag filters in coal-fired power plant needs to investigate further in order to mitigate PCDD/F emission from PP. The pattern of PCDD/F mass and I-TEQ distribution was very similar in each MSWI; however, the resemblance between the MSWIs is unapparent. The different PCDD/F emission characteristics of MSWIs and coal-fired power plant should be noticed. The PCDD/F emission rate is high in coal-fired power plant and low in MSWIs, but the emitting PCDD/F concentration is high in MSWIs and low in the coal-fired power plant. Thus, the PCDD/F contribution of the coal-fired power plant still needs to be marked, because the average amount of coal burnt in PP were 16,442 ton/day, and the solid waste burnt in MSWIs was 1140–1185 ton/day. Although the emission factor of PCDD/Fs from PP is low. After multiplying with the coal burnt per day, the mass of PCDD/Fs provided by PP would be 29102 μg I-TEQ/day, which could be compared with those of PCDD/Fs emitted from MSWIs (84,360–97,170 μg I-TEQ/day). The PCDD/F emission provided by PP is 29.9%–34.5% of those provided by MSWIs.

Improving PCDD/F control devices for the coal-fired power plant is suggested.

## CONCLUSIONS

According to the experimental results, the following conclusions could be made:

1. Total PCDD/F mass and I-TEQ distribution of municipal solid waste incinerator A are SFG (0.5%, 0.3%), BR (5.48%, 3.90%), SH (0.12%, 0.17%), EC (14.6%, 4.2%), SDA (22.75%, 12.9%), and BF (76.56%, 90.14%), respectively.
2. Total PCDD/F mass and I-TEQ distribution of municipal solid waste incinerator B are SFG (0.023%, 0.07%), BR (0.27%, 0.62%), SH (0.23%, 0.24%), EC (0.02%, 0.05%), SDA (6.99%, 7.06%), and BF (92.46%, 97.97%), respectively.
3. Total PCDD/F mass and I-TEQ distribution of the coal-fired power plant are SFG (99.23%, 99.58%), BR (0.37%, 0.17%) and ESD (0.39%, 0.25%), respectively. The patterns of total PCDD/F I-TEQ and mass distribution in each site represent a similarity. The semi-dryer absorber and the bag filter prevented 79.31% and 99.03% of PCDD/F mass and I-TEQ in MSWI A, 99.23% and 99.58% of PCDD/F mass and I-TEQ in MSWI B, escaping to the environment. Moreover, only 0.77% PCDD/F mass and 0.42% PCDD/F I-TEQ were found in the ashes of coal-fired plant. The improvement of air control devices for PCDD/F in the coal-fired power plant is advised.

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