Technical Report

Tracking the Fate of Polybrominated Diphenyl Ethers (PBDEs) at the

Regional Water Quality Control Plant

Palo Alto, California

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EXECUTIVE SUMMARY

Polybrominated diphenyl ethers (PBDEs) are a class of compounds that bioaccumulate in the food web and are considered potential endocrine disruptors. An endocrine disruptor is a compound that that can interfere with the normal hormone function in humans and animals that controls metabolism, growth and reproduction. This study attempts to characterize the fate and transfer of PBDEs at the wastewater treatment plant in Palo Alto, California, and compare the results with other treatment plants throughout the world.

In August 2002, samples were collected from the effluent, biosolids, and incinerator stack emissions at the Regional Water Quality Control Plant (RWQCP) in Palo Alto, California. The sampling was performed during a three-day period under normal dry weather operating conditions. Aqueous, gas, and solid phase process flows were monitored for flow volume and concentration, during the sampling.

The effluent and biosolids were analyzed for 41 PBDE congeners. The stack emission was analyzed for ten homologue groups of brominated dioxins and brominated furans. The influent at the plant was not analyzed due to potential interferences. Out of the 41 congeners studied, the scientific community specifically studies six congeners, which include BDE-47 (tetra), BDE-99 (penta), BDE-100 (penta), BDE-153 (hexa), BDE-154 (hexa) and BDE-209 (deca). The typical commercial penta-BDE formulation is actually a mixture of BDE-47, BDE-99, BDE-100, BDE-153 and BDE-154. According to the loading data, the deca (BDE-209), tetra (BDE-47), and penta (BDE-99) are the greatest contributors within the biosolids, whereas tetra (BDE-47) and penta (BDE-99) are the greatest within the effluent. BDE-47 and BDE-99 represent the penta-BDE formulation, which implies that penta is a significant source of PBDEs to the sewage treatment plant. Based on the assumption that the influent equals the effluent and biosolids, less than 0.05 percent of the penta-BDE that enters the plant leaves through the effluent.

The majority of the PBDEs that enter the plant are typically found within the biosolids since they are hydrophobic and tend to sorb onto sediments. At the RWQCP biosolids are incinerated in a multiple hearth incinerator that is equipped with emissions abatement equipment including an afterburner that is greater than 99.99% effective at destroying dioxins (RWQCP 2000). Since PBDEs tend to sorb onto the biosolids, the majority of the PBDEs are incinerated and expected to transform into brominated dioxins and furans. The majority of the brominated furans and brominated dioxins are then destroyed during the incineration process.

Based on this study, the majority of the PBDEs that enter the plant bind strongly to organic matter, with 96 percent associated with the incinerated biosolids. The remaining 4 percent of the PBDEs entering the RWQCP is discharged with the Plant effluent. This mass is estimated to be approximately 2 pounds per year. Because the overall fate and transport of PBDEs to the Bay is poorly understood, it is unclear that the RWQCP is a significant source of PBDEs to the Bay.

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OBJECTIVE

Polybrominated diphenyl ethers (PBDEs) are a class of compounds that bioaccumulate in the food web and are considered potential endocrine disruptors. An endocrine disruptor is a compound that can interfere with the normal hormone function in humans and animals that controls metabolism, growth and reproduction. This study attempts to characterize the fate and transfer of PBDEs at a wastewater treatment plant in Palo Alto, California, and compare the results with other treatment plants throughout the world.

BACKGROUND

As highly flammable synthetic materials have replaced less-combustible natural materials in consumer products, chemical fire retardants have become ubiquitous. One of the most common is a class of bromine-based chemicals known as PBDEs. Today PBDEs are in thousands of products, in which they typically comprise 5 to 30 percent of product weight (World Health Organization, 1994).

There are 209 congeners of PBDEs classified by the number of bromine atoms: for example, pentabromodiphenyl ether (penta-BDEs) have five bromine atoms, octa-BDEs have eight, deca-BDEs have ten. Six out of the 209 PBDE congeners are typically found within the three commercial mixtures; therefore researchers have conducted a significant amount of research regarding these six congeners (BDE-47, BDE-99, BDE-100, BDE-143, BDE-154 and BDE-209), of these BDE-47, BDE-99, BDE-100 are penta or tetra compounds, while BDE-143, BDE-154 and BDE-209 are hexa or deca compounds. The lower brominated compounds such as tetra and penta are believed to bioaccumulate in the body fat of animals more readily than higher brominated compounds such as deca, octa, and hexa.

Commercial Uses

PBDEs are used as flame-retardants in thermoplastics; some specific plastic materials that utilize PBDEs as flame-retardants are listed in Table 1 (DHHS, 2002). Three PBDEs are commercially available as technical mixtures of brominated diphenyl ethers (BDEs): penta-BDE, octa-BDE, and deca-BDE (Danish EPA, 1999; Hardy, 2000). The various commercial products consist of a mixture of substances. For example, “penta-BDE” consists of a mixture of tetra-BDE (BDE-47), penta-BDE (BDE-99 & BDE-100) and hexa-BDE (BDE-143 & BDE-154). The penta formulation is used in polyurethane foam in seat cushions and carpet padding. The deca formulation (BDE-209) is primarily used in computer cases, carpet backing, and textiles. According to the worldwide distribution of PBDEs, commercial deca-BDE constituted about 53.6 million pounds (72 percent), while commercial mixtures of octa- and penta-BDE were 3.0 and 18.3 million pounds (4 percent and 24 percent) of this total respectively (BSEF 2002). North America accounts for about 98 percent of the global demand for penta-BDE (Renner 2000).

Table 1. Uses of Penta-, Octa-, and Decabromodiphenyl Ethers Commercial Mixtures in Resins, Polymers, and Substrates

Resin/ Polymer/ Substrate	**Example of Final Product**	**Penta -BDE**	**Octa-BDE**	**Deca-BDE**
ABS	Molded parts (e.g. TV sets/ business machines, computer housings, household appliances [hairdryer, curler], automotive parts, electronics, telecommunications)		X	
Epoxy-resins	Circuit boards, protective coatings (e.g., computer, ship interiors, electronic boards)			X
Phenolic resins	Printed circuit boards (e.g., paper laminates/ glass prepregs for circuit boards)	X		X
PAN	Panels, electrical components (e.g., lighting panels for elevators and rooms, housing of electrical appliances)			X
PA	Electrical connectors, automotive interior parts (e.g., computers, connectors, housing in electrical industry, board, electrical connectors, automotive industry, transportation)		X	X
PBT	Electrical connectors and components (e.g., switches fuse, switch box, computer housing, switchboard electrical connectors, stereos, business machines, military electronics)		X	X
PE/XPE	Cross-linked wire and cable, foam tubing, weather protection, and moisture barriers (e.g., power cable, building conduit, portable apparatus building control, instrument, shipboard, automotive, marine appliances, insulation of heating tubes)			X
PET	Electrical components (e.g., boxes, relays, coils, bobbins)			X
PVC	Cable sheets (e.g., wire and cables, floor mats, industrial sheets)	X		X
PUR	Cushioning materials, packaging, padding (e.g., furniture, sound insulation, panels, wood limitations, transportation)	X		
UPE	Circuits boards, coatings (e.g., electrical equipment, coatings, military and marine applications, construction panels)	X		X
Rubber	Transportation (e.g., conveyor belts, foamed pipes for insulation)	X		X
Paints/ lacquers	Coatings (e.g., marine and industry lacquers for protection of containers)	X		X
Textiles	Coatings (e.g. back coatings: impregnation, carpets, automotive seating, furniture in homes and office buildings, aircraft, subways, tents, trains, and military safety clothing)	X		X

Source: WHO (1994a)

ABS= Acrylonitrile Butadiene Styrene; PA= Polyamide; PAN= Polyacrylonitrile; PBT= Polybbutylene Terephthalate; PE= Polyethylene; PET= Polyethylene Terephthalate; PP= Polypropylene; PUR= Polyurethane; PVC= Polyvinyl chloride; UPE= Unsaturated polyester; XPE= Cross-linked polyethylene

Environmental Health Concerns

The widespread use of PBDEs over the past 30 years has resulted in their ubiquitous presence in the environment. PBDEs are released into the environment from their manufacture, use and disposal. PBDEs are structurally similar to polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT); therefore, their chemical properties, persistence and distribution in the environment follow similar patterns (Hooper and McDonald 2000). Concentrations of PBDEs found in environmental samples are now higher than those of PCBs (Raham et al. 2001, Rayne et al. 2003). Evidence to date demonstrates that PBDEs are a growing problem in the environment and concern over their fate and effects is warranted. PBDEs are found throughout the environment in sewage sludge, sediments, wildlife (marine mammals, fish and bird eggs) and humans (milk, serum, and adipose tissue) (Hooper and McDonald 2000, Law et al. 2003). Many researchers state that PBDEs are the next persistent organic compounds that are similar to PCBs (McDonald 2002).

PBDEs are a potential health concern since they bioaccumulate and are potential endocrine disrupting compounds. The lower brominated compounds such as tetra (BDE-47) and penta (BDE-99 & BDE-100) are believed to bioaccumulate in the body fat of animals more readily than higher brominated compounds such as deca and octa. Deca-BDE is poorly absorbed to fatty tissue, rapidly eliminated, and does not bioaccumulate (Hooper and McDonald, 2000). There is a concern that deca and octa may eventually break down in the environment into the potentially more harmful lower brominated derivatives (DHHS 2002). Long-term exposure to these substances may cause adverse environmental effects.

Fate and Transport

The fate and transport of PBDEs is not fully understood. PBDE-containing waste may either be incinerated as municipal waste, deposited in landfills, discharged to municipal wastewater treatment plants, or emitted to the atmosphere (Darnerud et al. 2001). PBDEs are strongly adsorbed to soil and sediment and persist in the environment. Adsorption generally increases with an increase in either bromination or solids organic carbon content. As a result, PBDEs have little or no mobility in soil and are not expected to leach, however monitoring studies indicate that PBDEs are transported globally. Atmospheric, water, and biota levels of PBDEs tend to be dominated by the lower brominated congeners (e.g., BDE-47). Biota data indicate that PBDE concentrations increase with lower brominated congeners being preferentially bioconcentrated. PBDE concentrations increase with respect to trophic level; thus, organisms that reside higher on the food chain tend to have higher concentrations of PBDE (DHHS 2002).

When PBDEs are heated up to 1652 ºF (900 ºC), PBDEs are transformed into polybrominated dibenzodioxins (PBDDs) and polybrominated dibenzofurans (PBDFs) (Buser 1986; EU 2001). In order to control the emissions of dioxins and furans many incinerators have pollution control devices designed to destroy dioxins and furans.

METHODS

In August 2002, samples were collected from the effluent, biosolids, and incinerator stack emissions at the Regional Water Quality Control Plant (RWQCP) in Palo Alto, California. The sampling was performed during a three-day period under normal dry weather operating conditions. During the sampling process flows were monitored for flow volume and concentration.

Sampling Locations

Three sampling locations were selected to characterize the mass balance for the incinerator and overall facility:

1. Biosolids (input to incinerator)
2. Effluent
3. Incinerator stack emission

Influent sampling was not conducted due to the analytical interferences in the influent; the method detection limits would be significantly greater than the anticipated parts per trillion (ppt) concentrations.

Sampling Methods

All samples were collected and handled to minimize contamination and be most representative of daily averages. Sampling was conducted for three consecutive days. On each day, staff and contractors collected the following samples:

- Stack emissions were collected as a partial day (6-hour) composite.
- Effluent samples were collected five times throughout the 6-hour stack emission sampling and composited into a daily sample.
- Biosolid samples were collected five times throughout the 6-hour stack emission sampling and composited into a daily sample.

AXYS Analytical Services LTD conducted the lab analyses for the effluent and biosolids samples. They analyzed samples for the presence of 41 of the 209 PBDE congeners. Samples were analyzed in a single batch carried intact through the entire analytical process. The sample data were reviewed and evaluated in relation to the batch QC samples. The recoveries of some labeled compounds in the laboratory blanks were above the method specified limits (130%). It has been the experience at AXYS that the apparent over-recoveries of labeled BDE compounds does not affect the quantification of the target analytes.

Alta Analytical analyzed the stack emission samples for the presence of brominated dioxins and furans (PBDFs). Alta Analytical looked for the presence of 10 homologue groups of brominated furans and dioxins (PBDFs and PBDDs), which represents 136 congeners. The samples were analyzed using High Resolution Gas Chromatography coupled with High Resolution Mass Spectrometry. The samples quantitative values were calculated by a combination isotope dilution and internal standard method. The sample data were reviewed and evaluated in relation to the batch QC samples. An ongoing precision and recovery (OPR) sample was prepared and analyzed in the same preparation batch to assess recoveries. The recoveries of the native analytes in the OPR ranged from 87-119%. The internal standard recoveries in the samples ranged from 8-60%.

Calculation Methodology

Three calculation methods were used to quantify mass flow rates for effluent, stack emission, and biosolids. In each case, when the analytical results indicated “non-detect,” a concentration equal to one-half of the detection limit was used, in order to be consistent with other studies in the local region.

Example 1. Liquid Phase (Effluent) Mass Transfer

Mass transfer of PBDE for the aqueous phase, low solids process streams is calculated directly as the mass concentration (mg/L) of PBDE multiplied by the volumetric flow rate (MGD) and the corresponding unit conversions.

Flow Rate (MGD) x Concentration ($\frac{mg}{L}$ **)** x $\frac{3.78\text{x}10^6\ \text{L}}{\text{MGD}}$ x $\frac{\text{lb}}{0.45\text{x}10^6\ \text{mg}}$ = **Loading (** $\frac{\textbf{lb}}{\textbf{day}}$ **)**

Example 2. Gas Phase Mass Transfer (Stack emission)

Mass transfer of the incinerator stack gas is calculated as the dry weight, volumetric air transfer rate times the dry weight concentration.

Flow Rate (dscfm) x **Concentration (** $\frac{\textbf{ug}}{\textbf{m}^3}$ **)** x $\frac{1\ \text{m}^3}{35.31\ \text{ft}^3}$ x $\frac{1440\ \text{minutes}}{\text{day}}$ x $\frac{\text{lb}}{4.54\text{x}10^8\text{ug}}$ = **Loading**

($\frac{\textbf{lb}}{\textbf{day}}$ **)**

Example 3. Biosolids Mass Transfer

Biosolid loading was calculated using a solids balance across the belt-press just prior to incineration. It is expected that 96 percent of the solids are retained for incineration. Solids capture through the belt press was assumed to be 96 percent based on typical belt press performance (Metcalf & Eddy 1991). The other 4 percent remains with the water fraction from the belt press and returns to the plant headworks. The mass rate of solids to the incinerator was calculated using the thickened sludge mass transfer rate times the percent solids of the thickened sludge. The wet weight concentration was converted to a dry weight and multiplied by the mass transfer rate of solids. The solids balance technique was used, as there was no direct manner to calculate the sludge mass loading rate to the incinerator. Sludge calculations perform the volume to mass conversion using the density of water (62.4 lb/ft^3) and the specific gravity of the sampled sludge (1.02). Percent solids were measured each minute and the average over 3 days was used in the balance.

Sludge Flow Rate (gpm) X $\frac{1440\ \text{min.}}{\text{day}}$ X $\frac{1\ \text{ft}^3}{7.48\ \text{gal}}$ X $\frac{62.4\ \text{lb}}{\text{ft}^3}$ X 1.02 X **Percent Solids (%)** X

($\frac{\textbf{0.96 lb solids out of belt press}}{\textbf{1 lb solids in to belt press}}$ **)** X **Dry Weight PBDE Concentration (** $\frac{\textbf{mg}PBDE}{\textbf{kgsolids}}$ **)** x $\frac{kg}{1000000mg}$ =

PBDE loading ($\frac{\textbf{lb}PBDE}{\textbf{day}}$ **)**

RESULTS

The effluent and biosolids were analyzed for 41 PBDE congeners, whereas the stack emission was analyzed for ten homologue groups of brominated dioxins and brominated furans. The influent was not analyzed due to analytical interferences in the influent; the detection limits would be significantly greater than the anticipated parts per trillion (ppt) concentrations. For the non-detect congeners, the concentration and loading data for the biosolids, effluent and the stack emission are based on half of the detection limit. Non-detect values account for 24 percent of the effluent data, 32 percent of the biosolids data and 90 percent of the emission stack data. Out of the 41 congeners studied, there are nine congener groups; four of those congener groups represent greater than 75 percent of the mass loading for both the effluent and biosolids (Table 2 and 3).

One assumption is that there is no chemical or biological degradation of the PBDEs within the treatment plant and that the influent into the plant equals the effluent plus the biosolids. At the RWQCP, the biosolids are burned in a multiple hearth incinerator with an emission control device. Since PBDEs are hydrophobic and tend to sorb onto sediment, the majority of the PBDEs are incinerated. Since the RWQCP incinerator and emission control device operates at about 1300 ºF, another assumption is that the majority of the PBDEs are destroyed during the incinerator process and that PBDDs and PBDFs are released. Based on this assumption, the RWQCP tested the stack emissions for PBDFs and PBDDs; nine out of ten homologue groups of PBDFs and PBDDs were non detect (Table 4). The incinerator and emission control device are designed to destroy 99.99 percent of the dioxins that enter the plant (RWQCP 2000), which explains the small emission concentrations of PBDDs and PBDFs.

Table 2: Summary of the PBDE congeners groups ranked in order of highest concentration to least in the biosolids.

Congener Group	# Congeners analyzed	# Detected	Biosolid Concentration (dry weight) (ug/kg or ppb)	Biosolid Mass Loading (lbs/yr)
DecaBDE (BDE-209)	1	1	1,183	17
PentaBDE (BDE-99 & BDE-100)	7	5	1,147	16
TetraBDE (BDE-47)	6	5	800	11
HexaBDE (BDE-153 & BDE-154)	5	5	173	3
NonaBDE	3	3	49	0.7
TriBDE	7	6	20	0.30
HeptaBDE	3	3	12	0.20
DiBDE	6	4	1.0	0.01
MonoBDE	3	0	<0.7	<0.01
Total	**41**	**32**	**3,955**	**48**

Note: All values based on the sums of each congener group. Concentrations based on half of the detection limit for non-detects. Less than value denotes that group detected less than half of the time.

Table 3: Summary of the PBDE congeners by group for the effluent ranked from highest concentration to least.

Congener Group	# Congeners analyzed	# Detected	Effluent Concentration (ug/L or ppb)	Effluent Mass Loading (lbs/yr)
PentaBDE (BDE-99 & BDE-100)	7	4	0.014	0.95
TetraBDE (BDE-47)	6	5	0.011	0.77
HexaBDE (BDE-153 & BDE-154)	5	5	0.002	0.14
DecaBDE (BDE-209)	1	1	0.0017	0.12
TriBDE	7	3	<0.00048	<0.034
NonaBDE	3	3	0.00019	0.013
MonoBDE	3	0	<0.00011	$<7.4 \times 10^{-3}$
HeptaBDE	3	2	0.00009	0.0062
DiBDE	6	3	<0.00002	<0.0017
Total	**41**	**26**	**0.03**	**2**

Note: All values based on the sums of each congener group. Concentrations based on half of the detection limit for non-detects. Less than value denotes that group detected less than half of the time.

Table 4: Summary of brominated dioxins and brominated furans by family for the stack emission.

Congener Group	Group Detected	Incinerator Emissions (ug/m^3)	Incinerator Emissions (lbs)
Total TBrDF	Detected	82	7.6×10^{-11}
Total PeBrDF	Non Detect	<37	$<3.4 \times 10^{-11}$
Total HxBrDF	Non Detect	<532	$<4.9 \times 10^{-10}$
Total HpBrDF	Non Detect	<428	$<4.0 \times 10^{-10}$
Total OBrDF	Non Detect	<117	$<1.1 \times 10^{-10}$
Total TBrDD	Non Detect	<3	$<2.9 \times 10^{-12}$
Total PeBrDD	Non Detect	<64	$<5.9 \times 10^{-11}$
Total HxBrDD	Non Detect	<193	$<1.8 \times 10^{-10}$
Total HpBrDD	Non Detect	<156	$<1.5 \times 10^{-10}$
Total OBrDD	Non Detect	<191	$<1.8 \times 10^{-10}$
Total		**<1,803**	**$<1.7 \times 10^{-09}$**

Note: Less than signs denote that the value was not detected in the sample

DISCUSSION

The mass loading data presented in Table 5 presents the effluent, biosolid and stack emission data for all 41 PBDE congeners and nine homologue groups of PBDFs and PBDDs. One assumption is that there is no chemical or biological degradation of the PBDEs within the treatment plant and that the influent into the plant equals the effluent plus the biosolids. Based on this assumption, 96 percent of the PBDEs that enter the plant sorb to the biosolids. PBDEs typically are found within the biosolids since they are hydrophobic and tend to sorb onto sediments.

Out of the 41 PBDE congeners studied, there are nine congener groups; four of those congener groups represent greater than 75 percent of the mass loading for both the effluent and biosolids. Within these four groups, the scientific community specifically studies six congeners, which include BDE-47 (tetra), BDE-99 (penta), BDE-100 (penta), BDE-153 (hexa), BDE-154 (hexa) and BDE-209 (deca). The penta-BDE formulation includes BDE-47, BDE-99, BDE-100, BDE-153 and BDE-154.

Comparing the effluent and biosolid breakdown of the six well-studied congeners provides valuable information (Figure 1). According to the PBDE load, the deca (BDE-209), tetra (BDE-47), and penta (BDE-99) are the greatest contributors within the biosolids, whereas tetra (BDE-47) and penta (BDE-99) are the greatest within the effluent (Figure 1, Table 2 and 3). The deca-BDE formulation (BDE-209) is the largest concentration within the biosolids. BDE-209 was primarily seen in the biosolids due to its affinity to sorb to sediments. Some researchers believe that BDE-209 may break down into the lower molecular weight congeners, which may bioaccumulate (McDonald 2002). The other two largest contributors to the biosolids are BDE-47 and BDE-99, which represent the commercial penta-BDE formulation; penta is a significant source of PBDEs to the sewage treatment plant. Less than 0.05 percent of the penta-BDE that enters the plant leaves through the effluent.

Table 5: Mass loading for effluent and biosolids for PBDEs and stack emission for PBDF and PBDE Based on a sum of all congeners (half of the detection limit was used to calculate totals)

Sample Location	Analytes	Number of Congeners Analyzed	Number of Congeners Detected	Lbs/day*	Lbs/yr*	Notes
Effluent	PBDEs	41	26	0.0056	2.0	Based on 3 day average and total for all PBDE congeners
Biosolids	PBDEs	41	30	0.13	48	Based on 3 day average and total for all PBDE congeners
Stack emission	Brominated Furans and Brominated Dioxins	10	1	$<1.7 \times 10^{-9}$	$<6.1 \times 10^{-7}$	Three-day average and total of all brominated furans/ dioxins**

* When the analytical results indicated "non-detect," a concentration equal to one-half of the detection limit was used for that congener.

** A single homologue group of brominated furans was detected in the stack emission. The remaining 9 furan and dioxin homologue groups were not detected. These calculations assume that all 9 were present at half the detection limit.

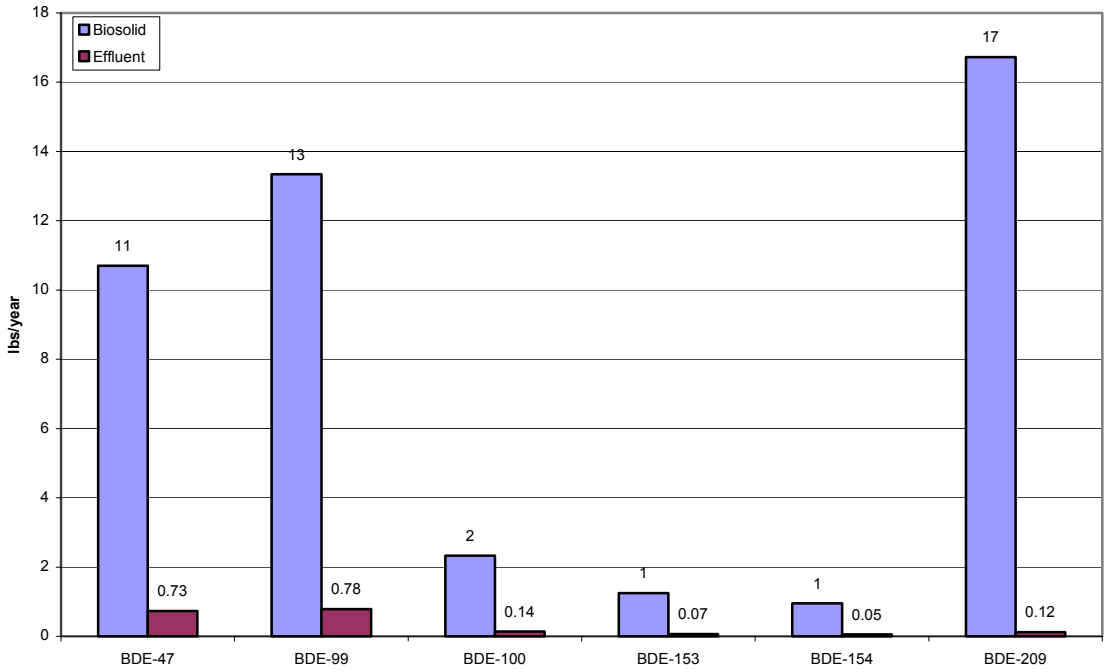

Figure 1: The mass of PBDEs entering the biosolids and effluent per year for the "penta-like" BDEs (BDE-47, BDE-99, BDE-100, BDE-153, BDE-154) and Deca-BDE (BDE-209).

The majority of the PBDEs within the RWQCP are the "penta-like" congeners and the deca-BDE. Researchers in Europe and the United States have analyzed PBDEs in sewage biosolids for similar congeners. Hale analyzed PBDEs in biosolids from four different regions in the United States. The RWQCP range is very similar to that seen in Hale's study; the RWQCP range is based off of three samples whereas Hale's is based off of eleven samples throughout the USA (Table 6). According to Hale et al. (2001), the total concentrations of "penta-like" PBDE in biosolids ranged from 1,100 to 2,290 µg/kg dry weight; the levels of PBDE were high and consistent, regardless of the region of origin. The total concentration of "penta-like" PBDE in biosolids at the wastewater plant in Palo Alto ranges from 1,918 to 2,086 ug/kg of dry weight basis. Since California has the most stringent fire retardant standard in the USA, it is logical that the RWQCP's range would be slightly greater than Hale's range. The RWQCP concentrations of deca-BDE are between 1,010 and 1,440 ug/kg dry weight. National concentrations of deca-BDE (BDE-209) varied widely among biosolids from different regions; the concentration of BDE-209 ranged from 84.8 to 4,4890 µg/kg dry weight in the biosolid samples (Hale 2001).

When the RWQCP data is compared with European concentrations, the RWQCP biosolid concentrations are at least 10-fold greater (Table 6). The United States is the greatest consumer of the polybrominated flame-retardants, specifically penta-BDE formulation that contains BDE-47. Based on consumption, the RWQCP biosolids would have higher concentrations than in Europe. The European Union has committed to a phase out penta-BDE in 2004; therefore the amount of pent-BDE has declined in Europe. The EU is currently researching deca and octa-BDE to decide if these compounds should be phased out as well. Prior to the EU's phase out of penta-BDE, Europe's consumption of the brominated flame-retardants is significantly less than that of the USA.

Table 6: Comparison of PBDE Biosolid Results from Palo Alto, CA to other plants in the United States and throughout Europe.

Source/ Location	PBDE Congener Concentration (ug/kg, dry basis)							Reference
	BDE-47 (tetra-)	BDE-99 (penta-)	BDE-100 (penta-)	BDE-153 (hexa-)	BDE-154 (hexa-)	Total "Penta-like": BDEs	BDE-209 (deca-)	
USA Results								
Range for 3 samples taken at Palo Alto, CA in August 2002	722-778	894-973	158-172	83-91	61-72	1918-2086	1010-1440	Current study
Range for 11 biosolid samples from Virginia, Maryland, New York state and California	359-754	931-1157	89-255	56-199	58-172	1100-2290	85-4890	Hale et al 2001
European Results [a]								
Gothenburg, Sweden	15	19	3.5	No data	No data	38[b]	No data	Nylund et al 1992
Klippan, Sweden	22	18	5.4	No data	No data	45.4[b]	No data	Seelstrom 1999; Sellstrom and Jansson 1995
Rimbo, Sweden	53	53	13	No data	No data	119[b]	No data	Sellstrom 1999; Sellstrom and Jansson 1995
Three plants, Stockholm, Sweden	39-91	48-120	11-28	No data	No data	98-239[b]	140-350	Sellstrom et al. 1999
Germany	No data	No data	No data	No data	No data	0.4-15[b]*	No data	Hagenmaier et al 1992

[a] European results, source de Wit 2002.
[b] PBDE is the sum of BDE-47, BDE-99, and BDE-100, but if more congeners are included, this is marked with an asterisk (*) Source de Wit 2002.

CONCLUSIONS

The primary focus of this study is to determine the fate and transport of PBDEs within the treatment plant and its potential contribution to the Bay. Based on this study, the majority of the PBDEs that enter the plant bind strongly to organic matter, with 96 percent associated with the incinerated biosolids. Based on other studies, PBDEs in the biosolids are believed to be transformed into brominated dioxins and furans, after which 99.99 percent are destroyed in the incinerator and afterburner.

The remaining 4 percent of the PBDEs entering the RWQCP is discharged with the Plant effluent. This mass is estimated to be approximately 2 pounds per year. Because the overall concentration and mass of PBDEs to the Bay is poorly understood, it is unclear that the RWQCP is a significant source of PBDEs to the Bay.

The City of Palo Alto surveyed the literature regarding the potential sources of PBDEs to the treatment plant and pollution prevention options. As of August 2003, legislation was passed in the California legislature and signed by the Governor that will prohibit on and after January 1, 2008 a person from manufacturing, processing, or distributing in commerce a product, or flame retarded part of a product, containing more than 1 percent penta-BDE or octa-BDE, by mass (AB 302). Even once this ban is in place, PBDEs will remain in thousands of existing consumer products and their contribution of PBDEs into San Francisco Bay will continue.

PBDEs are fairly ubiquitous in consumer products; over time the products that contain PBDEs break down, which enables the release of brominated flame-retardants. Based on commercial PBDE uses, a significant source of PBDEs to wastewater is likely from steam cleaning consumer products that contain PBDEs. Based on the literature, pollution prevention strategies for PBDEs in consumer products are not clearly defined. The City of Palo Alto will continue to stay abreast of new information and will search for feasible pollution prevention options for local governments.

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