PCBs in Washington State Products: Printing Inks, 2021

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Authored by: Kari Trumbull
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Abstract

In 2020, the Washington State Department of Ecology's (Ecology's) Safer Products for Washington program [Revised Code of Washington (RCW) 70.365] identified consumer products that are significant sources and uses of five priority chemical classes. For the priority chemical class of PCBs, printing inks was one of the chemical-product combinations identified.

In 2021, Ecology's Product Testing program conducted a study to assess the levels of PCBs in some products of the printing inks category. This study was conducted to support the Safer Products for Washington program in the next phase of its implementation process: to determine whether regulatory actions are needed for priority chemical-product combinations, including PCBs in printing inks.

Ecology acquired printing ink products from five different companies. Printing inks consisted of a black, cyan (blue), magenta (red), and yellow ink from a product line at each company. Ecology sent 20 printing ink samples to an analytical laboratory for the analysis of 209 PCB congeners. The lab could not perform reliable quantification of PCB congeners for two of the 20 printing ink samples.

Total PCB (tPCB) concentrations were calculated for 18 printing ink samples. tPCBs ranged from 0.00959 J, as an estimate, to 40,200 ppb, with one non-detected tPCBs result. For the 17 printing ink samples with detected levels of tPCBs, four had tPCBs below 1 ppb, four ranged from 1 to 100 ppb tPCBs, eight ranged from 100 to 1,000 ppb tPCBs, and one was above 1,000 ppb tPCBs.

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Contact Information

Author: Kari Trumbull
Environmental Assessment Program
Washington State Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600
Email: kari.trumbull@ecy.wa.gov

Washington State Department of Ecology – https://ecology.wa.gov

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Shoreline 206-594-0000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Union Gap 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

Background

PCBs

Polychlorinated biphenyls (PCBs) are a family of synthetic chemicals consisting of two benzene rings joined together (a biphenyl molecule) and containing one to 10 chlorine atoms attached to the benzene rings (ATSDR, 2000). Figure 1 shows the basic structure of PCBs, where the numbers 2-6 and 2'- 6' represent possible substitution locations for chlorine. There are 209 possible configurations of chlorine positions around the biphenyl molecule. The 209 individual PCB compounds are known as congeners and designated by a congener number 1 through 209 (EPA, 2022).

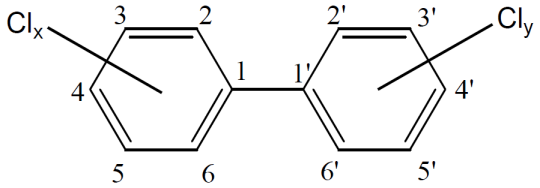

Figure 1. The general chemical structure of chlorinated biphenyls (ATSDR, 2000).

PCBs were manufactured as chemical mixtures made up of a variety of the different congeners. The most common commercial PCB mixtures in the U.S. are known by their industrial trade name Aroclor (EPA, 2022). Aroclors are identified by number (e.g., 1254), with the last two digits representing the percent content of chlorine; higher Aroclor numbers reflect higher chlorine content (ATSDR, 2000). Due to their non-flammability, chemical stability, high boiling point, and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications (Ecology and Health, 2015). PCBs are identified as persistent, bioaccumulative, and toxic chemicals (PBTs). They are persistent in the environment, build up in the food chain, and can cause adverse health effects in humans and wildlife, including cancer and harm to immune, nervous, and reproductive systems (Ecology and Health, 2015).

The manufacture of PCBs, such as Aroclors, for intentional use in products was restricted in the US more than 30 years ago. Products may still contain PCBs at an annual average of less than 25 parts per million (ppm), with a 50 ppm maximum, under the U.S. Toxic Substances Control Act (TSCA; EPA, 1979). PCBs continue to be generated as inadvertent byproducts in manufacturing processes, referred to as "inadvertent PCBs" (Panero et al. 2005). Processes that may result in the creation of inadvertent PCBs involve carbon, chlorine, and high temperatures, such as the production of pigments, dyes, and chlorinated chemicals. Inadvertent PCBs may be released from products, when present, during their use and eventual disposal.

PCBs in Printing Inks

In 2019, the Washington State Legislature directed Ecology, in consultation with the Washington State Department of Health (Health), to implement a regulatory program to reduce toxic chemicals in consumer products [Revised Code of Washington (RCW) 70.365]. Ecology called the program "Safer Products for Washington." PCBs are one of the five priority chemical classes the law identified.

In 2020, Ecology's Safer Products for Washington program identified consumer products that are significant sources and uses of the priority chemical classes. Printing inks is one of the chemical-product combinations for the chemical class of PCBs (Ecology, 2020).

In 2021, Ecology's Product Testing program conducted a study to assess the levels of PCBs in some products of the printing inks product category. This study was conducted to support the Safer Products for Washington program in the next phase of its implementation process: to determine whether regulatory actions are needed on priority chemical-product combinations, including PCBs in printing inks.

Printing inks were acquired from five different companies and consisted of a black, cyan (blue), magenta (red), and yellow ink from a product line at each company. Twenty printing ink samples were sent to an analytical laboratory for the analysis of 209 PCB congeners.

Methods

Product Collection

From December 2020 through February 2021, Ecology's Product Testing team acquired printing ink products from five different companies. Printing inks consisted of a black, cyan (blue), magenta (red), and yellow ink from each company's product line.

Ecology asked several newspaper companies in Washington State what printing ink products they use, and two companies responded. The companies were contacted to acquire these printing ink products. Ecology purchased four printing ink products from Sun Chemical, and Flint Group kindly donated four samples of printing ink products. Sun Chemical and Flint Group are the top two companies for North American ink sales in the ink industry.[1]

Hewlett Packard's (HP) General Specification for the Environment (GSE) defines the environmental requirements for HP brand products. The HP GSE includes criteria for PCBs in all products: not intentionally added and 0.1 ppm if incidentally present.[2] HP was contacted and kindly donated four samples of printing ink products. HP A50 inks are "water-based formulations designed by HP to meet worldwide regulatory requirements."[3]

The Cradle to Cradle Certified® Products Registry and Material Health Certificate Registry on the Cradle to Cradle Products Innovation Institute[4] website were searched for printing ink products. A few products were identified from these registries and Ecology contacted the companies. The printing ink products were from international companies and not able to be readily purchased in the US.

One of these companies, Siegwerk, has a subsidiary company in the US. Siegwerk in the US was contacted and kindly donated four samples of printing ink products from their US market product profile for UV offset printing. The Technical Data Sheet provided with the ink samples describes

[1] https://www.inkworldmagazine.com/heaps/view/6999/1/
[2] https://h20195.www2.hp.com/v2/GetDocument.aspx?docname=c04932490
[3] https://h20195.www2.hp.com/v2/GetDocument.aspx?docname=4AA7-8761ENW
[4] https://www.c2ccertified.org/

SICURA Plast 770 UV Offset Inks as a "highly versatile UV offset ink system formulated to provide adhesion on a wide variety of substrates printed either in sheet fed or web fed presses."

Ecology performed a search for printing inks readily available to purchase online. Four Epple Druckfarben printing ink products were purchased as a set from a vendor on Amazon.com. The printing inks were advertised for offset printing. The Epple Druckfarben Stability process inks are described on the company's website as "suited for almost any type of printing machines (perfecting machines as well as straight printing presses) and can be used for a large scale of absorbing printing substrates. It is free of mineral oil and formulated on the basis of renewable raw materials."[5]

Sample Processing

The project plan for this study is *Quality Assurance Project Plan: PCBs in Washington State Products* (Trumbull, 2021). Samples were not stored at ambient temperature, but rather at reduced temperature, after processing and during shipment to the analytical lab, a deviation from the project plan. This deviation is more consistent with environmental sample handling procedures and is considered to not have adversely impacted the reported study data quality.

High viscous printing ink products that arrived in large plastic containers (4 Sun Chemical inks) or metal cans (4 Flint Group inks and 4 Epple Druckfarben inks) were subsampled with a decontaminated stainless steel ladle into certified clean 500 milliliter (ml) wide-mouth amber glass sample jars. Jars were filled about half full with ink samples.

The 4 HP printing ink products arrived in small plastic bottles and the entire samples of these non-viscous inks were decanted into glass sample jars due to the limited sample size (about 100 ml each ink). The 4 Siegwerk ink products arrived in small plastic jars, and the entire samples of these high viscous inks in the original sample jars were sent to the lab due to the limited sample size (about 5 grams each ink).

A tool cleaning hexane rinse sample was collected as a blank quality control (QC) sample during decontamination of the stainless steel ladles. A sample processing water blank sample was collected as a blank QC sample during subsampling and decanting of the printing ink samples.

Printing ink samples were labeled with a unique Ecology identification number (ECY ID). For example, the ECY ID printing ink sample FP-1-1-1 corresponds to: FP for Flint Group, the first 1 indicates the first time Ecology acquired products from FP, the next 1 refers to a unique printing ink product from FP, and the last 1 indicates the first sample from that product.

Laboratory Analysis and Data Quality

SGS Axys Analytical Services, Ltd. (SGS Axys) in Sidney, British Columbia, Canada extracted the printing ink samples with dichloromethane using modification of EPA Method 1668C. The sample extracts were analyzed for all 209 PCB congeners by high-resolution gas chromatography mass spectrometry in accordance with EPA Method 1668C (EPA 2010).

Carlton Environmental, LLC performed a stage 4 validation to verify that the data were generated following the analytical method with no omissions or errors (EPA 2009, EPA 2020).

[5] https://www.epple-druckfarben.com/en/products/standard-process-inks/stability/

Ecology's project manager also reviewed all the data. The project manager retained the "NJ" lab flag as the "NJ" final data qualifier. Data were deemed usable as qualified.

PCB congener concentrations below the limit of quantitation (LOQ) and above the estimated detection limit (EDL) or contract-required detection limit (CRDL) were qualified "J" (indicating that the analyte was positively identified and the associated value is an estimate). PCB congener concentrations at levels less than five times the adjusted concentrations[6] found in the associated lab method blank were qualified as non-detects: either "UJ" when concentrations were reported below the LOQ or "U" when concentrations were reported above the LOQ.

Measurement quality objectives (MQOs) were met with the following exceptions. Two printing ink samples (AM-40-1-1 and HP-1-1-1 with its associated lab duplicate) had quantification surrogate recoveries significantly below analytical method specifications. As a result, reliable quantification of target compounds for these samples could not be performed. These PCB congener results are not included in the study data.

Total PCB (tPCB) concentrations, calculated by the project manager as the sum of PCB congeners in the sample, include only detected congener results that were either unqualified or were qualified "J," as estimates. Data qualified as "NJ" (indicating that the analyte has been tentatively identified and the associated value represents its approximate concentration), "UJ," and "U" were not included in the tPCB sums. Total PCB calculations were qualified "J" when 10% or more of the detected congener concentration results in the sample were qualified "J," as estimates. For sample SC-1-1-1, no detected congener result, either unqualified or qualified "J," was present, and the highest non-detected congener concentration was reported for the tPCB value with the corresponding "U" qualifier.

All PCB concentrations are reported on an as-received (wet weight) basis in picogram per gram (pg/g) and have been converted to nanogram per gram (ng/g) for reporting in Table 1. PCB data are available for download in Ecology's product testing database[7] by searching: *PCBs in Washington State Products - Printing Inks 2021.*

[6] Reported concentrations found in the method blank were adjusted on a sample-by-sample basis to account for differences in relative weights extracted, final extract volumes, and factors to adjust for split sample extracts for comparison to reported concentrations in each sample.
[7] https://apps.ecology.wa.gov/ptdbreporting/

Table 1. Summary results for PCBs in printing ink samples.

Number	ECY ID	Product Name	tPCBs (ng/g or ppb)	Ink Color	Highest PCB Congener(s) in Sample above 1 ppb (concentration in ppb)
1	AM-40-1-1	Epple Druckfarben Stability Black	no result*	black	no result*
2	AM-40-2-1	Epple Druckfarben Stability Cyan	547	cyan	PCB-110/115^ (32.1) PCB-129/138/160/163^ (49.0) PCB-130 (41.9) PCB-146 (46.1) PCB-147/149^ (35.0)
3	AM-40-3-1	Epple Druckfarben Stability Magenta	15.2	magenta	PCB-11 (3.92) PCB-16 (1.62) PCB-21/33^ (1.75) PCB-52 (1.50) PCB-56 (3.19)
4	AM-40-4-1	Epple Druckfarben Stability Yellow	323	yellow	PCB-11 (283) PCB-35 (10.3) PCB-77 (29.3)
5	FP-1-1-1	Flint Group Arrowlith Low Rub Super Black	6.32 J	black	PCB-5 (2.43) PCB-12/13^ (1.35) PCB-56 (1.10)
6	FP-1-2-1	Flint Group ROP Process Cyan	438	cyan	PCB-90/101/113^ (19.0) PCB-129/138/160/163^ (32.8) PCB-147/149^ (30.7) PCB-153/168^ (32.3) PCB-180/193^ (29.5)
7	FP-1-3-1	Flint Group ROP Process Magenta	298	magenta	PCB-90/101/113^ (13.7) PCB-129/138/160/163^ (21.6) PCB-147/149^ (20.6) PCB-153/168^ (22.0) PCB-180/193^ (20.7)
8	FP-1-4-1	Flint Group ROP Process Yellow	545	yellow	PCB-11 (314) PCB-129/138/160/163^ (16.0) PCB-147/149^ (15.2) PCB-153/168^ (16.1) PCB-180/193^ (14.6)
9	HP-1-1-1	HP PWP A50 Black	no result*	black	no result*
10	HP-1-2-1	HP PWP A50 Cyan	0.0683 J	cyan	na
11	HP-1-3-1	HP PWP A50 Magenta	0.0207 J	magenta	na

Number	ECY ID	Product Name	tPCBs (ng/g or ppb)	Ink Color	Highest PCB Congener(s) in Sample above 1 ppb (concentration in ppb)
12	HP-1-4-1	HP PWP A50 Yellow	0.00959 J	yellow	na
13	SC-1-1-1	Sun Chemical Standard Black	3.93 U	black	na
14	SC-1-2-1	Sun Chemical Process Blue	0.881 J	cyan	na
15	SC-1-3-1	Sun Chemical Process Red	7.72 J	magenta	PCB-110/115^ (1.49)
16	SC-1-4-1	Sun Chemical Process Yellow	101	yellow	PCB-11 (80.2) PCB-35 (7.69) PCB-77 (11.6)
17	SW-1-1-1	Siegwerk Pro Black Sicura Plast 770	431	black	PCB-3 (22.0) PCB-5 (119) PCB-11 (102) PCB-12/13^ (78.6) PCB-56 (30.1)
18	SW-1-2-1	Siegwerk Pro Cyan Sicura Plast 770	31.5	cyan	PCB-1 (12.5) PCB-2 (1.45) PCB-3 (3.39) PCB-11 (4.74) PCB-12/13^ (1.57)
19	SW-1-3-1	Siegwerk Pro Magenta Sicura Plast 770	105	magenta	PCB-11 (14.2) PCB-18/30^ (12.1) PCB-26/29^ (10.6) PCB-31 (10.6) PCB-52 (17.9)
20	SW-1-4-1	Siegwerk Pro Yellow Sicura Plast 770	40,200	yellow	PCB-2 (72.7) PCB-11 (39,800) PCB-35 (204) PCB-36 (11.6) PCB-77 (43.6)

Green shaded results represent tPCB concentrations above 1 ppb.

*Reliable quantification of target compounds for this sample could not be performed.

^Co-elution of congeners quantified as a mixture of more than one congener during lab analysis (EPA 2010).

J = tPCB calculations were qualified “J” when 10% or more of the detected congener concentration results were qualified “J,” as estimates.

U = No detected congener result, either unqualified or qualified “J,” was present, and the highest non-detected congener concentration was reported for the tPCB value with the corresponding “U” qualifier.

na = PCB congener(s) not above 1 ppb.

Results for Total PCBs

SGS Axys analyzed 20 printing ink samples for all 209 PCB congeners. Reliable quantification of PCB congeners for two of the 20 printing ink samples could not be performed; therefore, this study reports results for 18 samples. Total PCB (tPCB) concentrations were calculated according to the procedure outlined in the Data Quality section, using a five times blank censoring rule and including only detected values.

Table 1 reports the results for tPCBs in 18 printing ink samples. The tPCB levels above 1 part per billion (ppb, equivalent to ng/g) in the table are highlighted in green. For the purpose of assessing data in this study, results above 1 ppb tPCBs are identified in the discussion and tables. The value of 1 ppb was selected for discussion purposes and does not represent a regulatory level.

Two collection and processing blank QC samples were included in this study and analyzed similar to the printing ink samples for PCB congeners. The tPCBs for these two blank QC samples are not included in Table 1.

- A tool cleaning hexane rinse blank QC sample was collected during decontamination of the stainless steel ladles. The hexane blank sample had 0.00347 J ppb tPCBs which is well below the tPCB concentrations for the samples of printing inks subsampled with a cleaned ladle and does not adversely impact the quality of the printing ink sample results.
- A sample processing water blank QC sample was collected during subsampling of the printing inks. The water blank sample had a non-detected result of 0.048 UJ ppb tPCBs which is the highest non-detected congener concentration in the sample.

Results by Printing Ink Company Product Line

Figure 2 displays the concentration of tPCBs in each printing ink sample by the company product line.

- *Epple Druckfarben Stability*: tPCBs were reported for three of four printing ink samples[8] (Table 1). All three of these samples had tPCBs above 1 ppb. The highest tPCB concentration of the Epple Druckfarben Stability inks was in the cyan ink sample (AM-40-2-1) at 547 ppb tPCBs.
- *Flint Group*: All four of the printing ink samples had tPCBs above 1 ppb. The Flint Group ROP Process Yellow ink sample (FP-1-4-1) had the highest tPCBs at 545 ppb.
- *HP PWP*: tPCBs were reported for three of four A50 printing ink samples[9]. All three of these samples had tPCB concentrations below 1 ppb.

[8] Reliable quantification of target compounds for the Epple Druckfarben Stability black ink sample (AM-40-1-1) could not be performed and the tPCB concentration not calculated.
[9] Reliable quantification of target compounds for the HP PWP A50 black ink sample (HP-1-1-1) could not be performed and the tPCB concentration not calculated.

- *Sun Chemical*: Two of four printing ink samples had tPCBs above 1 ppb. The highest tPCB concentration of the Sun Chemical inks was in the yellow ink sample (SC-1-4-1) at 101 ppb.
- *Siegwerk*: All four of the Sicura Plast 770 printing ink samples had tPCBs concentrations above 1 ppb. The Siegwerk Pro Yellow Sicura Plast 770 ink sample (SW-1-4-1) had the highest tPCBs at 40,200 ppb.

Of the printing inks samples tested, Epple Druckfarben Stability, Flint Group, and Siegwerk Sicura Plast 770 inks had higher levels of tPCBs, while HP PWP A50 and Sun Chemical inks had lower levels of tPCBs. The HP PWP A50 inks had the lowest tPCBs levels in the reported printing ink samples.

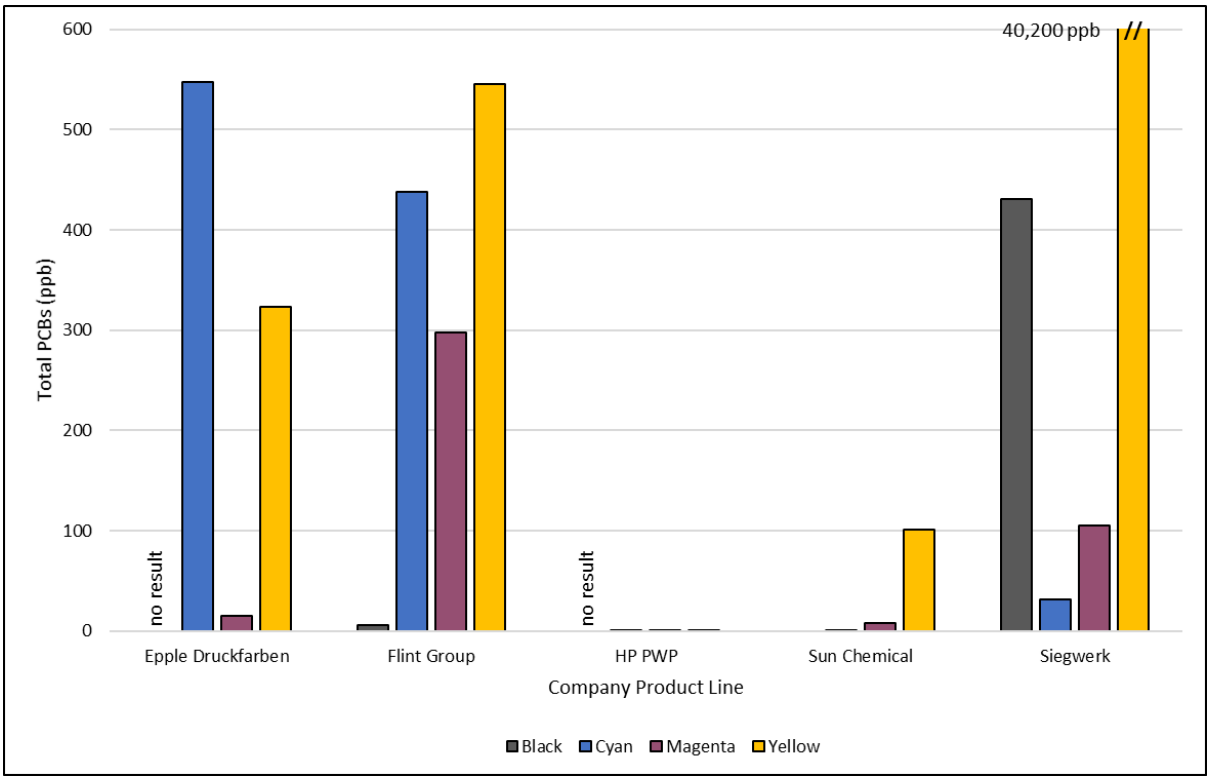

Figure 2. Total PCBs (ppb) in printing ink samples by company product line.

Results by Printing Ink Color

Figure 2 also displays the concentration of tPCBs in each printing ink sample color.

- *Black*: tPCBs were reported for three of five black printing ink samples.[8,9] Two of the three black inks had tPCBs above 1 ppb. Siegwerk Pro Black Sicura Plast 770 ink sample (SW-1-1-1) had the highest tPCBs at 431 ppb.
- *Cyan*: Three of five cyan printing ink samples had tPCBs above 1 ppb. The highest concentration of the cyan ink samples was the Epple Druckfarben Stability Cyan ink sample (AM-40-2-1) at 547 ppb tPCBs.

- *Magenta*: Four of the five magenta printing ink samples had tPCBs above 1 ppb. The Flint Group ROP Process Magenta (FP-1-3-1) had the highest tPCBs at 298 ppb.
- *Yellow*: Four of the five yellow printing ink samples had tPCBs above 1 ppb. The highest tPCB concentration of the yellow ink samples was the Siegwerk Pro Yellow Sicura Plast 770 ink sample (SW-1-4-1) at 40,200 ppb tPCBs.

Yellow ink samples had the highest tPCB levels compared to other color inks in three of the five company product lines: Flint Group, Sun Chemical, and Siegwerk. Siegwerk Pro Yellow Sicura Plast 770 ink (SW-1-4-1) had the highest tPCBs of the yellow inks and the highest tPCBs of all the printing ink samples at 40,200 ppb tPCBs. The cyan ink sample had higher tPCB levels compared to the other colors in Epple Druckfarben Stability inks.

Results for PCB Congeners

PCB congeners (individual or co-eluting) detected at the highest concentrations and above 1 ppb in each printing ink sample are listed in Table 1. In 13 of the 18 printing ink samples, at least one or more PCB congener was detected above 1 ppb.

Black Ink

Two of three black printing ink samples with reported results had one or more detected PCB congener concentrations higher than 1 ppb. PCB-5 was the congener detected at the highest concentration in these two black ink samples:

- Flint Group Arrowlith Low Rub Super Black (FP-1-1-1) at 2.43 ppb PCB-5.
- Siegwerk Pro Black Sicura Plast 770 (SW-1-1-1) at 119 ppb PCB-5.

PCB-5 comprised higher than 25% of the tPCB results in both these samples, 38.4% and 27.6% respectively.

Cyan Ink

Three of five cyan printing ink samples had one or more detected PCB congener concentrations higher than 1 ppb. PCB-129/138/160/163 was detected at the highest concentration in two of these three ink samples:

- Epple Druckfarben Stability Cyan (AM-40-2-1) at 49.0 ppb.
- Flint Group ROP Process Cyan (FP-1-2-1) at 32.8 ppb.

PCB-129/138/160/163 comprised less than 10% of the tPCB results in both these samples.

PCB-1 was detected at the highest concentration in the other cyan printing ink sample. PCB-1 comprised 39.7% of the tPCB result in the Siegwerk Pro Cyan Sicura Plast 770 ink sample (SW-1-2-1) at 12.5 ppb.

Magenta Ink

Four of five magenta printing ink samples had one or more detected PCB congener concentrations higher than 1 ppb. Different PCB congeners (individual or co-eluting) were detected at the highest concentration in each of these four magenta ink samples:

- PCB-11 was detected in Epple Druckfarben Stability Magenta (AM-40-3-1) at 3.92 ppb, and 25.8% of the tPCB result.

- PCB-153/168 was detected in Flint Group ROP Process Magenta (FP-1-3-1) at 22.0 ppb, and 7.4% of the tPCB result.
- PCB-110/115 was detected in Sun Chemical Process Red (SC-1-3-1) at 1.49 ppb, and 19.3% of the tPCB result.
- PCB-52 was detected in Siegwerk Pro Magenta Sicura Plast 770 (SW-1-3-1) at 17.9 ppb, and 17.0% of the tPCB result.

Yellow Ink

Four of five yellow printing ink samples had one or more detected PCB congener concentrations higher than 1 ppb. PCB-11 was detected at the highest concentration in these four yellow ink samples:

- Epple Druckfarben Stability Yellow (AM-40-4-1) at 283 ppb PCB-11, and 87.6% of the tPCB result.
- Flint Group ROP Process Yellow (FP-1-4-1) at 314 ppb PCB-11, and 57.6% of the tPCB result.
- Sun Chemical Process Yellow (SC-1-4-1) at 80.2 ppb PCB-11, and 79.4% of the tPCB result.
- Siegwerk Pro Yellow Sicura Plast 770 (SW-1-4-1) at 39,800 ppb PCB-11, and comprised 99.0% of the tPCB result.

Conclusions

In the 18 printing ink samples, detected tPCB concentrations ranged from 0.00959 J to 40,200 ppb, with one non-detected tPCB result. These results were below the 50 ppm TSCA limit. Thirteen of the 18 printing ink samples had tPCBs above the 1 ppb discussion level. Table 2 displays the distribution of tPCB results by concentration range in the printing ink samples.

Table 2. Total PCB results by concentration range.

Printing Inks	< 0.50 ppb	0.50 to < 1 ppb	1 to < 10 ppb	10 to < 100 ppb	100 to < 500 ppb	500 to < 1000 ppb	≥ 1000 ppb
18	4*	1	2	2	6	2	1

*Includes non-detected tPCB result.

The exact source of PCBs in the printing ink samples is unknown, as the individual ingredients in the inks were not tested. The printing inks tested contain a mixture of ingredients. Pigments are the most likely source, as pigments are a known source for inadvertent PCBs in products and have previously been detected in pigments and pigment-printed material (Guo et al. 2014; Shang et al. 2014; and Stone, 2016). PCBs detected in the printing ink samples may not only be from the pigments in the inks. Different PCB levels were reported in similar color printing inks and, for some similar colors, different dominant congener(s) (Table 1). It is unknown if the same pigments were used in the printing ink samples of similar color.

PCB-11 is considered a key indicator of inadvertent PCBs, as it is not typically found in Aroclor mixtures and is primarily associated with color pigments, especially yellow pigment (Hu and Hornbuckle 2010). PCB-11 was the predominant PCB congener detected in the yellow printing ink samples with tPCBs above 1 ppb. PCB-11 was detected at the highest

concentration of a PCB congener in the 18 printing ink samples at 39,800 ppb in the Siegwerk Pro Yellow Sicura Plast 770 ink sample (SW-1-4-1), and comprised 99.0% of the tPCB result.

PCB concentrations detected in printing ink samples from this study are consistent with levels reported in the literature for pigments, inks, paints, and printed materials from consumer products (for a summary of studies see Ecology, 2020).

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