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Measurement of PCB emissions from building surfaces using a novel portable emission test cell

Nadja Lynge Lyng [a], [*], Lars Gunnarsen [a], Helle Vibeke Andersen [a], Vivi Kofoed-Sørensen [b], Per Axel Clausen [b]

[a] Danish Building Research Institute, Aalborg University Copenhagen, A.C. Meyers Vænge 15, DK-2450 Copenhagen SV, Denmark
[b] National Research Centre for the Working Environment, Lersø Parkallé 105, DK-2100 Copenhagen Ø, Denmark

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ABSTRACT

Polychlorinated biphenyls (PCBs) were used in building materials like caulks and paints from 1930–1970s and in some cases that caused elevated PCB concentrations in the indoor air at levels considered harmful to occupant health. PCBs are semivolatile organic compounds and capable of spreading from the original source to adjacent materials, indoor air and via adsorption from the air to indoor surfaces, causing secondary contaminations. Remediation of buildings with unsatisfactory indoor air concentrations is a complex and difficult task due to the secondary contamination of building materials and there is a need to prioritise remediation measures on different materials. An inexpensive and portable emission test cell was developed to resemble indoor conditions in relation to the area specific ventilation rate. Emissions were measured using the test cell in the laboratory on freshly made PCB paint. Further, the chamber was used for determining emissions from PCB-containing building materials in the field as well as remediated walls. The measurements showed that sorption of PCBs to chamber walls was insignificant after 2–4 days of exposure to the source. Over a period of two weeks emission rates did not change from any of the tested surfaces, however in the laboratory experiment emission rates decreased over a longer period (48 days) and was most pronounced for the lower chlorinated PCBs.

1. Introduction

Elevated concentrations of polychlorinated biphenyls (PCBs) in the indoor air pose a health risk to building occupants. Elevated concentrations of PCBs in blood are found in humans exposed to increased PCB concentration in the air for extended periods of time [1–3]. Human exposure to PCBs is related to adverse health effects such as obesity, diabetes, cardiovascular disease, poorer cognitive development and cancer [4–8]. Primary sources of PCBs in buildings, i.e., building materials manufactured with PCBs include: caulks, ceiling tiles, floor materials, light ballasts and paints, and these have been used from the 1930s until the late 1970s when their use was restricted in most countries [9–11].

Indoor air concentration is associated with emissions of PCB from building materials and some electrical light ballast [12]. The specific emission rate of PCBs from PCB-containing materials is among others related to source characteristics like the PCB content in the material and material properties like resistance to diffusion and affinity to PCB [12–14]. Theoretically up to 209 different PCB congeners exist. The different PCB congeners have between one and ten chlorine atoms. The number of chlorines atoms and their position cause different physicochemical properties such as saturated vapour pressure, enthalpy of evaporation and octanol-air partition coefficient [15–17]. As a result the emission rates vary between congeners. Additionally emission rates depend on a range of environmental factors such as ventilation rate/air velocity, temperature and the presence of airborne particles [13,18–21].

PCBs are categorised as semi-volatile organic compounds (SVOCs) due to their low vapour pressures ranging between 10^{-9} and 10 Pa (25 °C) [22]. SVOCs diffuse from the primary sources (materials originally manufactured with SVOCs) to adjacent materials. Also they partition between source and air and subsequently they adsorb and absorb on other material surfaces [13,22,23]. Materials that have been contaminated over time can change from sinks to sources when conditions are changed including decreasing

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[*] Corresponding author.
E-mail addresses: nal@sbi.aau.dk, nadjalyng@gmail.com (N.L. Lyng), lbg@sbi.aau.dk (L. Gunnarsen), hva@sbi.aau.dk (H.V. Andersen), vks@nrcwe.dk (V. Kofoed-Sørensen), pac@nrcwe.dk (P.A. Clausen).

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air concentrations e.g. due to the removal of primary sources. These sources are termed secondary sources. The change from sink to source can occur rapidly and depends on environmental factors such as temperature and air concentration [13,22]. Secondary sources have the capability of contaminating the indoor air through the re-emission of deposited PCBs after primary sources have been removed from the indoor environment. Therefore, in order to reduce the concentration level of SVOCs e.g. PCBs in contaminated buildings, it might be insufficient only to remove the primary sources of SVOCs e.g. PCBs [22]. The sources in buildings (contaminated via air) may involve large surface areas and mitigation of theses surfaces can be difficult and expensive. There is a need to characterise these PCB sources by measuring their ability to re-emit PCBs in order to prioritise means of mitigation.

Numerous different small-scale emission test chambers exist, most of which require destructive cut-outs of building materials in order to place materials inside the closed chamber. Wolkoff et al., (1995), Yamashita, (2010) and Shinohara et al. (2009) [24–26] describes test cells that differ from regular cubic and rectangular cuboid small-scale chambers by having one open side, and the planar building material (source) constitutes a part of the chamber enclosure during measurements. The field and laboratory emission cell, abbreviated FLEC, provides a unique flow pattern with laminar airflows [27,28]. Emission of SVOCs from solid materials is usually controlled by diffusion in the boundary air layer immediately above the material surface rather than internal diffusion in the source material [29]. Increased ventilation rate and air velocity affect emission rates of SVOCs possibly due to an increased convective mass transfer coefficient and increased gradient between the air concentration immediately above the source and bulk air concentration [30]. In order for measured emission rates to relate to real emissions in buildings, the area-specific ventilation rate as well as air velocity in the chamber or cell should be realistic [31].

The purpose of the present study was to develop a new emission test cell method for measuring PCB emissions from contaminated surfaces in relation to fairly realistic area-specific ventilation rates and airflow patterns that are not completely met by the otherwise well-described FLEC. Additionally a larger source area was chosen compared with the FLEC in order to reduce sampling time. Although the test device has a configuration which is comparable to small chambers due to the relative large size and cuboid shape, but owing to its open-side configuration makes the device referred to as the emission test cell [32]. It was furthermore investigated whether the proposed test cell was able to reach steady-state air concentrations within a reasonable time. For SVOCs this may take a long time due to the high surface/air partitioning coefficient [33,34] and for di-2-ethylhexyl phthalate (DEHP) emissions in the FLEC may be up to 150 days [35].

2. Materials and methods

2.1. Study design

The emission test cell was developed and PCB-emission rates from building materials were measured in 3 different settings: a contaminated elementary school and an apartment as well as in the laboratory.

In the laboratory test; 2 identical test cells were tested on stainless steel plates (52 cm × 32 cm), which were painted with laboratory-produced PCB paint (containing approx. 4% PCBs, Aroclor 1248, in wet weight). The painted plates were made to ensure 2 homogenous test sources. PCB air samples were taken on 9 occasions during a 48-day period and were analysed for 12 individual congeners; PCB-8, PCB-18, PCB-28/32, PCB-44, PCB-49, PCB-52, PCB-66, PCB-70, PCB-101, PCB-118, PCB-138 and PCB-153.

For the field test, emission rates were measured in 3 different rooms in the elementary school (2 offices and 1 corridor). A total of 6 different surfaces were measured, 2 different surfaces in each of the 3 rooms. In the apartment, emission rates were measured in 2 rooms (the bedroom and corridor). 6 test cells measured 3 different surfaces in pairs. The pairs of cells were placed less than 20 cm apart as duplicate determination of similar surfaces. PCB air samples were taken 3 times during 2 weeks. Eurofins, Denmark analysed air samples were for the 7 indicator PCB congeners; PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-153 and PCB-180.

2.2. Design of test cell

The emission test cell was intended for field use and as a tool for determination of efficient remediation measures of PCB-contaminated buildings. The requirements for the design of the emission test cell included it being portable, robust, fairly inexpensive, easy to use, and reusable. The cell was made of form-pressed stainless steel and was a remodelled food pan for use in industrial kitchens. The cell measured 50 cm × 30 cm x 10 cm with rounded corners and had a total volume of 14.7 l. The cell was placed with the open side towards the building surface (source area = 0.147 m^2). A flow of 1 l/min of clean air was supplied to the test cell, which resulted in a test cell air exchange rate of 4 h^{-1}. The flow of 1 l/min was chosen to match the area-specific ventilation rate of 0.12 $l/(s \cdot m^2)$ as given in the Nordtest method with a model room defined with a total surfaces area of 40 m^2 [36] and an air change rate of 1 h^{-1}.

In order not to pressurise the test cell, it was equipped with one inlet and one outlet used to discharge surplus air in addition to air sampling ports. During all measurements, the sampling flow needed to be significantly lower than the inlet flow of 1 l/min, in order to avoid the infiltration by the surrounding contaminated air. A micro size (17 × 17 × 8 mm) DC axial fan inside the cell ensured good mixing of air. Air velocities were measured in 45 evenly distributed points approx. 2 cm from source, and also in 45 points 2 cm from the bottom of the cell, using APM 360 Thermo anemometer (Alnor Instrument Company, Skokie, IL, US). Air velocity ranged between 0.1 and 0.9 m/s (Fig. S1 in the supplementary material), and was 0.26 m/s in average. The mounted fittings for connecting the tubes were made of stainless steel and brass. O-rings were made of nitrile rubber. Materials where chosen with the objective of minimising the sink effect of the cell. The cells were cleaned with ethanol before placement on the surfaces. The cell was sealed to the material surface with butyl sealing tape. For a test on vertical surfaces, 4 aluminium clamps were mounted on the surface by screws and used to attach the cells. If the test cells were reused, they were disassembled, cleaned with ethanol before and after the cells had been heated to 75 °C and finally new O-rings, sealant and fan were mounted.

2.3. Measuring conditions

2.3.1. Preparation of PCB paint and painted plates for laboratory tests

Paint was prepared from CHS-ALKYD S 471 X 60 as binder with xylene as solvent (91.5%), Lanco™ Antibubble™ LT as defoaming agent (0.3%), Octa-Soligen® Cobalt 8 (0.5%) and Octa-Soligen Zirconium 12 (0.5%) as driers, Methylethylketoxim (0.7%) as anti-skinning agent. The ingredients were mixed in the given order and pre-dispersed in a dissolver. The temperature did not exceed 35 °C during the dissolving process. The paint was then mixed in a shaker for 5 min. PCB oil extracted from 5 small light ballasts, all identified as Aroclor 1248, and mixed before the oil was dissolved in Xylene. The PCB/Xylene (4.0/2.5%) was added to the paint and