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Distribution and transfer pattern of Polychlorinated Biphenyls (PCBs) among the selected environmental media of Ny-Ålesund, the Arctic: As a case study

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ABSTRACT

Polychlorinated Biphenyls (PCBs) were analyzed in multi-environmental samples collected from Ny-Ålesund, the Arctic to explore their legacy and transfer patterns. PCBs were ubiquitously in the environmental media, within the ranges of 1.73–6.27 and 9.18–141.1 pg m^{-3} in vapor and aerosol, 2.76–10.8, 3.09–8.32, 22.5–56.3, 35.4–51.4 and 31.8–39.6 ng g^{-1} (dry weight) in soil, sediment, plant, bird guano and reindeer faeces, respectively. The spatial distribution patterns exhibited a general southward decline in soil and sediment from the bay entrance to the inner bay. The concentration ratios of plants to soil inferred that no distinguished selective adsorption of PCBs congeners by plants existed and PCBs were mainly attributed to the air deposition on plant surface. The fugacity ratios among vapor, aerosol and soil indicted that the equilibrium status has not been reached and the net transferring direction was air–soil.

1. Introduction

About 1.5 million tons of Polychlorinated Biphenyls (PCBs) were produced globally in the form of complex mixtures serving as dielectric fluids in transformers and capacitors, plasticizers agent in paint and rubber sealants since 1930s (Bidleman et al., 2010). In the 1970s, PCBs was banned legally and globally because of their adverse effects on immunity, nerves and endocrine systems, especially, they were capable of pass down to the next generations, resulting in further adverse effects (Zhang et al., 2011). By virtue of PCBs' long-range transport potential, they have been detected in some remote areas which were absent of human activities, such as Tibetan Plateau (Yang et al., 2010; Wang et al., 2012; Zheng et al., 2012), Alps (Tato et al., 2011), and some high latitude areas, especially in the polar areas. Quite a few of investigations have confirmed that PCBs were ubiquitous in the ambient environment of the Arctic including atmosphere, water, soil and sediments, as well as in the biota from zooplankton to polar bears and humans (Jartun et al., 2009; Bustnes et al., 2010, 2012; Mallory and Braune, 2012; Erikstad et al., 2013; Helgason et al., 2013). Since the PCBs legacy in the Arctic did not derived from the local production and usages, the atmospheric transport from mid- and low-latitude sources was regarded as the predominant input-pathway of PCBs to the polar environment (Borghini et al., 2005; de Wit et al., 2006; Hung et al., 2010; Ubl et al., 2012). Besides, it could also be attributed to the oceanic currents, river outflows, continental run-off, snow melting, ice-drift and animal behaviors (Li et al., 2003; Halsall, 2004; Evenset et al., 2007; Rigét et al., 2010).

The PCBs temporal distribution in the Arctic atmosphere exhibited a temporal fluctuation rather than the consistent decline. The data supplied by the Arctic Monitoring and Assessment Programme (AMAP) demonstrated that the PCBs concentrations in air did not descend continuously and consistently from 1993 to 2006, conversely, the temporal variation presented an increasing trends with an apparent first order half-lives (Hung et al., 2010). Moreover, Gioia et al. (2008) found that no evidence supported the overall declines of PCBs in the Arctic region since mid-1990s as well. Similar results were found in organochlorine pesticides (OCPs) and heavy metals concentrations in the atmosphere of Svalbard (Berg et al., 2004). The global distillation or fractionation derived from the condensation in cold polar environments has been proposed as the mechanisms that the polar areas were considered as the sinks for POPs (Schiavone et al., 2009). However, a

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few studies pointed out that the polar areas were vulnerable to the climate changes and the increase of the global warming, which induced the POPs re-mobilization from the melting ice, snow or ocean water into the atmosphere, undergoing the revisable deposition and volatilization continuously and making them available in circulation once again rather than sinking in the sediments or soils (Macdonald et al., 2005; Miljeteig et al., 2009; Letcher et al., 2010; Sonne, 2010; AMAP, 2011; Corsolin et al., 2011; Jiang et al., 2011; Ma et al., 2011).

The dynamics exchange of some semi-volatile compounds among the multi-media in environment could be revealed by calculating the fugacity ratios of the chemical in the respective environmental media, even in food chains and mother-infant transmission (Macdonald et al., 2005; Gioia et al., (2008), Weber et al., 2010; Lin et al., 2012; Quinn et al., 2012). The fugacity ratio of a chemical in two media equal to 1 indicted that the chemical has reached the equilibrium status between these two media; otherwise, it inclined to migrate from the media in which it possessed the higher fugacity value to the other one. Besides, quite a few steady-state models discussing the chemicals exchanging behaviors in the environmental media have been developed, in which some parameters, such as the long range transport potential, distribution ratios, migration directions and fluxes, were defined based on the fugacity. Due to the quantity relationship between the concentration and fugacity, the long-term monitoring PCBs concentrations was thusly essential to reveal their environmental behavior of transfer, tendencies and fates.

Although some researches' results have elucidated the PCBs distribution in the ambient environmental media including air, water, soil, lake sediment, plants, as well as the species from zooplankton to bear in the Arctic, the small-scale migration among environmental media was rarely discussed, especially between air and soil. In the present study, we would investigate the PCBs concentrations in the selected environmental media, including vapor, aerosol, sediment, soil, plants and animals faeces to well understand the legacy and transfer directions, as well as the factors influencing PCBs distribution status. Therefore, the objectives of this paper are to: (1) reveal the distribution tendencies of PCBs in the atmosphere, soil, sediment, plants and animal faeces; (2) explain the transfer direction of PCBs in the ambient environmental media based on the PCBs fugacity in various media; and (3) calculate the ratios of PCBs in bird and reindeers to explain PCBs input–output in bird and reindeers bodies.

2. Methods and materials

2.1. Study area and sample collection

The Chinese Yellow River Station is built in Ny-Ålesund for the scientific investigation programme of the Arctic, which is one of the northernmost human settlements in the world, locating in Brøgger Halvoya Peninsula, northwestern to Spitsbergen (Jiao et al., 2009; Jiang et al., 2011). The investigation in the present study was completed in the period of July 1st to 29th, 2012, with two transects of 21 sampling stations for collecting the atmospheric samples, soils, sediments, plants, bird guano and reindeer faeces samples. As illustrated in Fig. 1, sediment sampling were conducted at K1–K8 stations in the bay; while atmospheric sample, soil, plant and animal faeces samples were collected at NA01–NA13 stations located in the land.

The atmospheric samples were collected through applying the active high-volume air sampling approach at station NA04. The polyurethane foam plug (PUF, 8 cm in length, 5 cm diameter) disks and the glass fiber filter (GFF) aiming at collecting the gaseous PCBs and particle-bound PCBs respectively were used in active sampling devices. A piece of PUF disk was placed in the sampler chamber, covering the cross section entirely, and then a piece of GFF pre-conditioned at 450 °C in furnace for 48 h was placed above the PUF disk. Twelve atmospheric samples were collected, one of which took about 48 h throughout the sampling period at the suction air flow rate of 0.8 m^3 min^{-1}, with over 2000 m^3 air being collected. Right after the sampling process, the PUF disks and GFFs were packaged in the pre-cleaned aluminum foil and frozen at −20 °C.

The surface sediment samples were collected at the stations of K1–K8. The soil samples were taken with a stainless scoop at the stations of NA01–NA13. The plants and animal faeces samples were picked up from the ground. All the solid samples were packaged with aluminum foil and frozen at −20 °C till they were lyophilized in the laboratory.

2.2. Reagents and materials

All the organic solvents, including *n*-hexane, acetone and dichloromethane (DCM) were of pesticide quality grade, purchased from Tedia Company (US). The sulfuric acid at the guaranteed

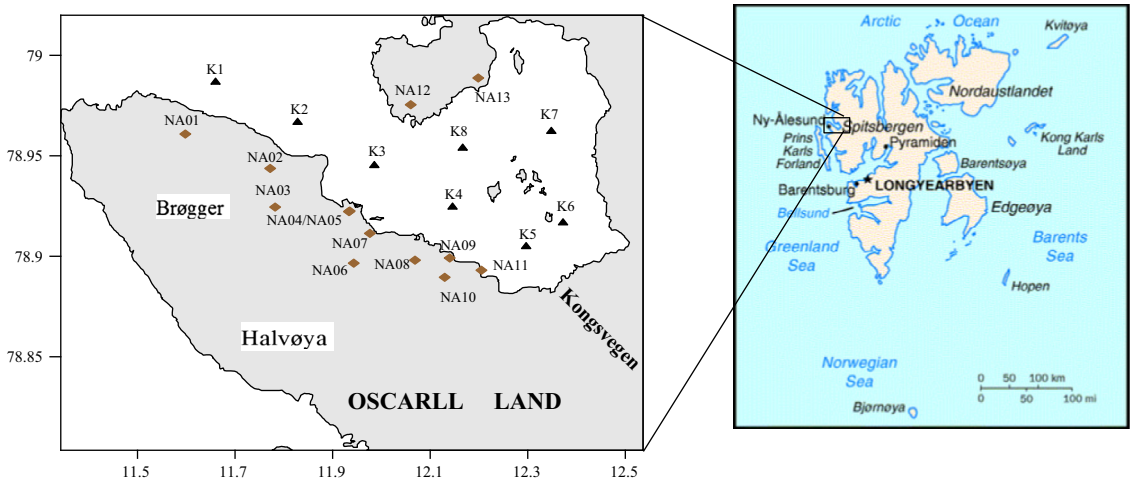

Fig. 1. Location of the sampling stations in the study area. The sediment samples were collected from K1 station to K9 station; the atmospheric samples were collected from the NA04 station with active samplers (PUF/GFF). The Rotten moss was sampled at NA01, and the stations of NA02–NA13 were designed for soil samples. The species of plant collected at the study area were as followed: NA01 (moss), NA02 (*Saxifraga oppositifoli*), NA03 (*Saxifraga oppositifoli*), NA05 (moss), NA06 (*Dryas octopetala*), NA07 (moss), NA08 (*Saxifraga oppositifolia*), NA09 (*Sileneac aulis and Salix polaris*), NA10 (moss), NA11 (*Saxifraga oppositifolia*), NA12 (*Dryas octopetala*) and NA13 (*Saxifraga oppositifolia*). The bird guano were collected at the stations of NA03 and NA05, and the reindeer faeces were collected at the stations of NA01, 03, 05, 07, 08 and 12.