Substance flow analysis of HBCD, considering the switch to its alternatives

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Introduction

Shift to alternative material or an alternative process often takes place precautionary, due to the toxicity of target chemicals of concern. In the current chemical assessment, however, the environmental risk from alternative material or an alternative process has been rarely considered. As a result, poorly understood (or potentially more hazardous) chemicals may be applied and then caused the increase or appearance of other risks. For the comprehensive chemical risk management, an integrated methodology which includes the approach, not for only the evaluation of target chemical risk but for potential impact substituting the target chemical of concern with alternate chemical has been growing importance[1]. Currently, limited research work has focused on the assessment including both target chemical and its alternative. The present study aims to contribute to developing a risk reduction policy for chemicals, considering the switch to its alternatives.

Among the BFRs available commercially, hexabromocyclododecane (HBCD) are important synthetic additives which are used to reduce the flammability of articles. Despite their benefits, however, the occurrence of HBCD in the environment as contaminants have recently an increasing attention because of the widespread use, high chemical stability and bioaccumulation potential. Currently, HBCD has been a highly debated compounds in many countries concerning its risk to wildlife and human health, and whether its use should be phased out as a Persistent Organic Pollutant (POP) candidate. There is the possibility of movement into safer chemical alternatives to HBCD, followed by regulation.

In this study, taking brominated flame retardants (i.e., HBCD) as an example, Environmental emissions from end-products containing HBCD , has been estimated considering the scenario of the switch to its potential alternatives and compared them with its potential alternatives though their life cycle.

Materials and methods

Life cycle inventory analysis

For all the processes in each scenario, we calculated life cycle HBCD and its alternatives emission based on the quantitative data concerning to emissions and flow. We ran calculations for the period 1985–2020 and estimated yearly values of HBCD and its alternatives. The life cycle was divided into four stages: production, industrial use, professional and private use, and disposal. The import of products containing HBCD (e.g., plastics, textiles, and furniture) and the export of waste have not been included, owing to the limitation of available data. For the calculation of HBCD and its its alternatives emissions, details of the procedure have been described elsewhere [2]. Briefly, the environmental emissions were calculated by multiplying the input into each process by an emission factor. Delays between input and output were taken into account in consumer products in the private use phase (i.e., the residence times of products). Emission factors during all processes were estimated according to NITE (National Institute of Technology and Evaluation in Japan) emission factor table[3]. This emission factor was categorized based on life stage (i.e., production, industrial use, private use), application pattern and physicochemical property (vapour pressure and water solubility). For physicochemical property of HBCD and its alternatives, the data were estimated by using EPI suite.

Selection of potential HBCD alternatives

In Japan, XPS and EPS as polystyrene insulating boards make up by far the most important component of HBCD consumption (approximately 80% in 2009). Uses in textiles (i.e., interior textiles and automobile textiles) are less important. In this study, we focused on HBCD alternatives in these four applications. As a first step, potential HBCD alternatives were listed up based on the search from Japanese patent application and then extracted candidate alternatives from the interview with relevant company. In this study among these candidate alternatives, four potential HBCD alternatives were selected as a case study (i.e., Tris[3-bromo-2,2-bis(bromomethyl)propan-1-yl]phosphate (TBNP), tetrabromooctane (TBCO),10-benzil-9,10-dihydro-9-oxa-10-

phosphaphenanthrene-10-oxide (BCA) and Anilinod-iphenylphosphate (ADPP)). These candidates may not reflect the real situation in Japan.

Scenario

Reference scenario (continuous use of HBCD)

We assumed the case that HBCD will not be banned by regulation and thus there are no switch to the HBCD alternatives. Also, HBCD consumption will be increased, followed by the increase in the use of HBCD containing materials. This option was set as reference scenario in this study.

Scenario 1 (introduction of HBCD alternatives)

It is assumed the case that HBCD alternative has been introduced for each application, due to the ban on the use of HBCD. Based on the interview or the literature on each industry, we estimated the parameter for the period of switching to HBCD alternatives and the content of HBCD alternatives in products. For the alternative in XPS (TBNP), the use of HBCD in XPS will be changed into the alternative by 2014 and 1.3 times of the HBCD use will be needed for the same flammability. For the alternative in EPS (TBCO), the use of HBCD in EPS will be stopped by 2013 and 1.4 times of the HBCD use will be needed. For the use of interior textiles (BCA), we assumed 45 % of the HBCD use were switched to the alternative by 2010 and 100 % by 2013 and 1.5 times of HBCD use will be needed. The alternative in automobile textiles (ADPP) will be changed into 60 % by 2008, 70% by 2009 and 100% by 2010.

Results and discussion:

We analyzed substance flows from 1986 to 2020. In the case of continuous use of HBCD (Reference scenario), the consumption of HBCD was estimated to be 3000 t in 2020. Polystyrene as insulating board accounted for 80% of the total use. In the case of scenario 1 (introduction of HBCD alternatives), the estimated consumption of HBCD decreased from 2008, which was the period of switching to alternatives and estimated consumption in 2014 dropped to 0 t/year. On the other hand, the estimated emission of the alternative substances would increase continiously and estimated to 3900 tone/year in 2020.

For the comparison of the simulated stock levels over time between reference scenario and scenario 1, Stock in the private use stage (i.e., HBCD applied to long life products such as insulation board and textile) increased continuously from1986 to 2020 in reference scenario. Without any ban on HBCD, the stock of HBCD in the use phase was estimated as 40,000 t in 2020. Also, the total stock in landfill related to the waste from industrial and private use was 30,000 t. The cumulative consumption of HBCD from 1986 to 2020 was 76,000 tone in this study. The sum of stocks in the private use phase and landfill was 70,000 tone, in close agreement with the cumulative consumption. This indicates that our estimation of inputs and outputs is almost balanced for all uses during all life stages. Meanwhile the stock of HBCD in scenario 1 decreased following by the cessation of its use after 2008 and finally decreased 70 % in 2020 (26, 000 tone) compared to the continuous HBCD use scenario . HBCD in products remain for decades. HBCD emission from product may continue to some extent for decades, in spite of the introduction of alternatives. These results indicated that products containing HBCD would be a potential source of emission for a long time.

The predicted emissions of HBCD and its alternatives for two scenario are shown in Figure. 1. For reference scenario, the largest component of the emissions entered the aquatic environment and emissions of HBCD increased during the entire period in this study, in good agreement with sediment core data in Tokyo Bay and the historical concentration trend in human blood in Japan[4]. On the other hand, for scenario 1, estimated HBCD emissions decreased between 2009 and 2020, to about 200 kg/year in acuatic environment. These results suggest that environmental emissions of HBCD would decrease by 20 % in 2020 compared to the continuous HBCD use scenario, whereas the estimated emission of the alternative substances would increase by 8.3 tone/year.

The use of a substance flow model, considering the scenario of the switch to its potential alternatives, allowed us to compare possible emission between target chemicals and its alternative. On the other hand, Areas of uncertainty and variability remain in the emission factors. In particular, NITE emission factor table does not contain the emission factor from waste stage (i.e., landfill and incineration). Our study clearly highlights the need for improved understanding and measurement of the emission factors for HBCD and for accurate flows in post-consumer use. So far, there have been only limited data on the emission inventories from the waste stream into the environment compartment. Further study should focus on the potential for releases from the waste stream. Current research also focused on the comparison of life cycle exposure health risk between HBCD and its alternatives based on the estimated emission data.

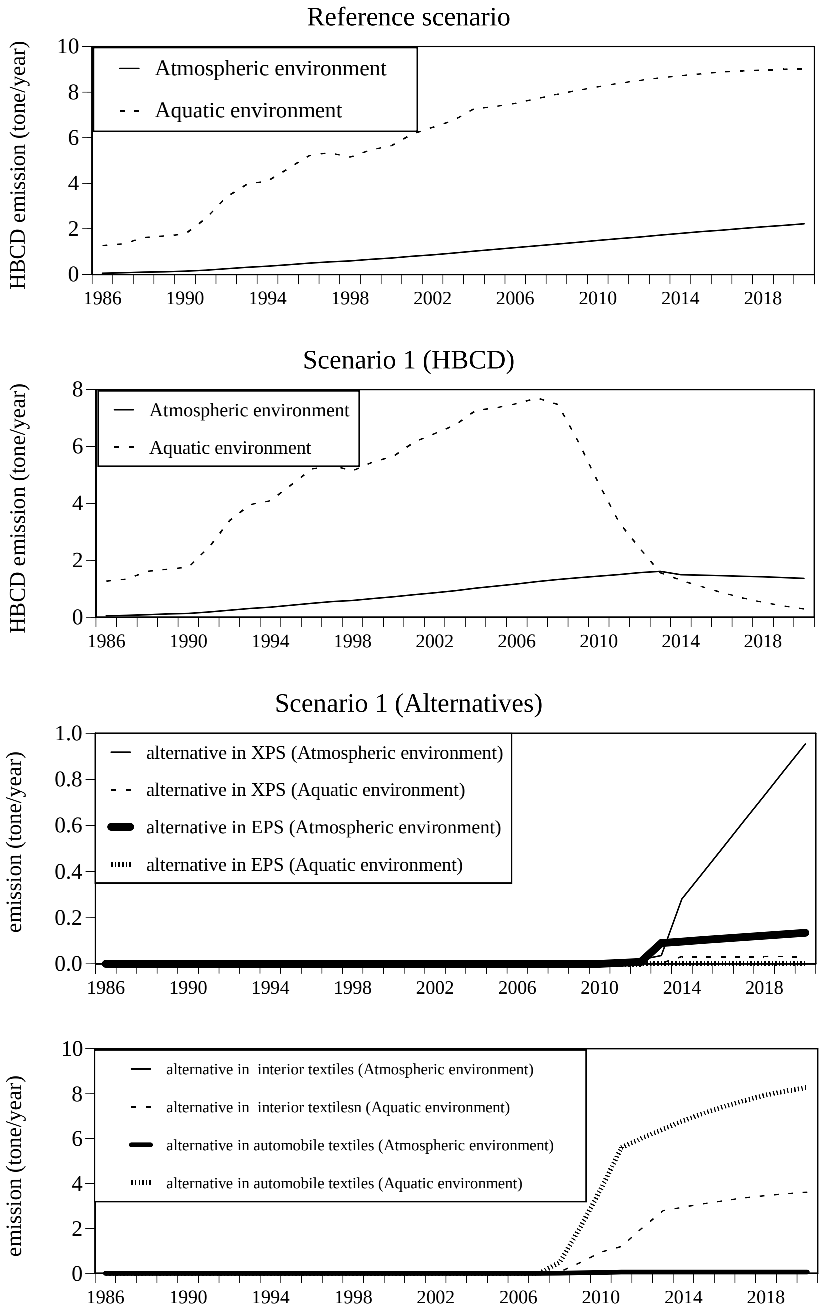

Figure 1 Emissions of HBCD and its alternatives to atmosphere and aquatic environment in Japan

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