



HBCD in waste stream

Tarastenjärvi waste site

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ABSTRACT

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Hexabromocyclododecane (HBCD) has been classified as a persistent organic pollutant and subsequently banned from production and use by the Stockholm convention in 2013. HBCD has been widely used in insulation materials such as expanded and extruded polystyrene to increase their fire-retardant properties.

It is important that hexabromocyclododecane could be detected to ensure that a proper disposal method for polystyrene waste material is utilised.

The purpose of this study was to collect statistical data on the presence of HBCD in different polystyrene waste material in a waste stream of Tarastenjärvi waste site. The work was commissioned by Tampere University of Applied Sciences.

The analysis was divided into on-site screening of polystyrene samples of different types with a handheld x-ray fluorescence gun and acetone extraction with subsequent x-ray fluorescence measurements in laboratory conditions.

Out of 150 samples screened on-site, two expanded polystyrene samples of white colour were detected to contain hexabromocyclododecane and therefore possess the risk of exposure unless disposed in the correct way by incineration.

The collected data, the methods used as well as the equipment could be utilised by construction and waste management companies, or any other interested parties, for research purposes or as a detection method for HBCD in order to determine correct method of disposal for different polystyrene waste material.

Key words: hexabromocyclododecane, detection, polystyrene, waste stream

CONTENTS

1	INTRODUCTION	5
1.1	Hexabromocyclododecane	5
1.1.1	Properties	5
1.1.2	Use	6
1.1.3	Alternatives.....	6
1.1.4	End of life treatment	7
1.2	Detection with X-ray fluorescence	7
1.3	Background of the study	8
2	SCOPE	9
3	MATERIALS AND METHODS.....	10
3.1	Equipment – handheld X-ray fluorescence gun	10
3.2	Samples	11
3.3	Analysis.....	13
3.4	Screening on-site with handheld X-ray fluorescence gun	14
3.5	Laboratory measurements	15
3.5.1	Acetone extraction of Bromine positive samples.....	15
3.5.2	Radiation lab measurements with handheld X-ray fluorescence gun	17
3.6	Calculations	19
3.7	Statistics.....	20
4	RESULTS AND DISCUSSION	21
5	CONCLUSIONS	25
	REFERENCES	26
	APPENDICES.....	29
	Appendix 1. Full data table divided by field days.....	29

ABBREVIATIONS AND TERMS

Br	Bromine
EPS	Expanded polystyrene
FR	Flame retardant
HBCD	Hexabromocyclododecane
PBT	Persistent, bioaccumulative and toxic substance
PolyFR	Brominated butadiene and styrene copolymer
POP	Persistent organic pollutant
PP	Polypropylene
TAMK	Tampere University of Applied Sciences
TBBPA	Tetrabromobisphenol-A
XPS	Extruded polystyrene
XRF	X-ray fluorescence

1 INTRODUCTION

Hexabromocyclododecane, or shortly – HBCD, was classified as a persistent organic pollutant in Annex A (for elimination) of the list of POPs of Stockholm convention in 2013; banning further use and production of this chemical on a global level. (UNEP SC-6/13, 2013)

1.1 Hexabromocyclododecane

1.1.1 Properties

Hexabromocyclododecane has a molecular formula of $C_{12}H_{18}Br_6$ (its structure is shown in figure 1 below) and a molecular weight of 641.7 g/mol. The material safety data sheet of HBCD considers this chemical to be persistent, bioaccumulative and toxic substance (PBT). (ECHA, 2019; PubChem, 2019)

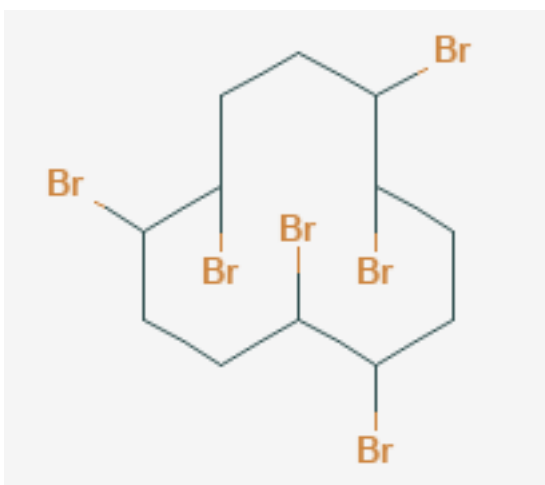


FIGURE 1. Structure of HBCD. (PubChem, 2019)

As such, HBCD appears in the form of white powder. However, when this chemical is used as an additive to polystyrene resin, it cannot be seen by the naked eye, because it has neither evident colour nor smell, and can be detected with chemical analysis only, e.g. gas chromatography. (ECCC, 2016)

The main hazards of HBCD are high toxicity to aquatic life including long-lasting effects and toxicity to mammals that consume aquatic biota, bioaccumulating HBCD (ECCC, 2016). As for humans, HBCD has potential endocrine disruption effects being toxic to thyroid and liver and harming reproductive functions causing developmental problems in infants (Jensen, 2013).

Other hazards include skin, eye and respiratory irritation (PubChem, 2019).

1.1.2 Use

Hexabromocyclododecane has been used in expanded polystyrene (EPS) and extruded polystyrene (XPS) materials that were produced for the construction industry in order to improve flame-retardant properties of the material, so that it would meet fire safety regulations to be used in constructions. (EPA, 2014; Jensen, 2015; ECCC, 2016)

EPS and XPS are widely used as insulation material due to a number of qualities: energy efficiency, high durability and long-term performance up to 100 years, cost-efficiency, water-resistance and resistance to degradation (EPA, 2014).

The addition of flame retardants (FR), in general, to polystyrene foams increases their ignition temperatures and as well reduces the rate of burning and spread of the flame and smoke. HBCD, specifically, was chosen as the flame-retardant to add because of its ability to increase flame retardant characteristics at low concentrations without compromising other properties of the material. (EPA, 2014)

1.1.3 Alternatives

The main alternative to HBCD is brominated butadiene styrene copolymer (PolyFR), which presents better environmental and health performance comparing to HBCD (Beach et al., 2013). Another alternative is Tetrabromobisphenol A – TBBPA (EPA, 2014). PolyFR and TBBPA are two main brominated-flame retardants that are meant to replace banned HBCD in polystyrene foams.

The difference between banned HBCD and its allowed alternatives is in the way how they are incorporated into the polystyrene material:

1. Reactive FR (like PolyFR) is forming a covalent bond with polystyrene material becoming a permanent part of its structure, reducing the risk of separation from material and subsequent exposure of the chemical into the environment. (Guerra et al., 2010; EPA, 2014)
2. Additive FR (like HBCD) is mixed into the polystyrene during compounding but does not form a covalent bond and much more likely than reactive FR to be separated from the material (at any point of life-cycle), increasing risks of exposure. (EPA, 2014; ECCC, 2016)

1.1.4 End of life treatment

Insulation materials that do not contain HBCD (including materials with HBCD's reactive alternatives, like PolyFR) can be reused, if their properties are not compromised, or recycled into new polystyrene insulation boards (EPA, 2014).

HBCD-containing material, in turn, should be disposed of by co-incineration of EPS and XPS along with other waste under high temperatures in a well-functioning waste incineration plant. A study conducted by Plastics Europe proved this option to be a very effective and practical approach to end-of-life treatment of polystyrene foam waste that contains HBCD. (Plastics Europe, 2014)

1.2 Detection with X-ray fluorescence

Detection of HBCD is essential for end-of-life treatment of EPS and XPS as treatment selection depends on the presence of HBCD in the material, which determines whether it can be recycled or should be disposed of by incineration.

As it was mentioned before, HBCD can be directly detected with Gas Chromatography method. However, it can be done only in laboratory conditions, which is making it unsuitable for quick, ideally, all done on-site, analysis.

X-ray fluorescence (XRF) analysis using handheld XRF gun as a tool for screening on-site is an effective method for HBCD detection (Honkala, 2018).

Although, XRF produces elemental analysis and therefore is not able to detect HBCD directly. However, XRF is able to show the presence of Bromine (HBCD has six Br atoms in its structure), which allows to confirm the use of brominated flame-retardants in the material. Further analysis would be needed to differentiate HBCD from reactive flame-retardants. (Schlummer et al., 2015)

1.3 Background of the study

Tampere University of Applied sciences (TAMK) had organized a 4-thesis-project in 2018 on different aspects of HBCD problem like the occurrence of this chemical in buildings in Finland or how to detect it effectively on-site. (Ekman, 2017; Hämmäläinen, 2017; Honkala, 2018; Sandqvist, 2018)

This study is a continuation of TAMK's research on the hexabromocyclododecane and this thesis' focus is on collecting statistical data on the presence of HBCD in Expanded polystyrene (EPS) and Extruded polystyrene (XPS) materials in a waste stream of Tarastenjärvi waste site.

Measurement part (screening) was conducted on-site upon the agreement with Pirkanmaan Jätehuolto, Tampere region' waste management company.

A similar study has been conducted for Koukkujärvi waste site, where the presence of hexabromocyclododecane was investigated by the other student also as a part of TAMK's research on HBCD.

2 SCOPE

The aim of this thesis project is to collect statistical data on the occurrence of HBCD contamination in expanded and extruded polystyrene samples from a waste stream of Tarastenjärvi waste site.

To acquire that data, EPS and XPS samples were analysed on-site through “screening” methodology and more thoroughly in the laboratory conditions utilising XRF analysis and acetone extraction.

The data collected during this project as well as the method of HBCD detection used for sample analysis could be utilised by the waste and construction companies or other interested parties to determine the presence of HBCD in samples and, therefore, the recyclability of the EPS/XPS material in a waste stream.

3 MATERIALS AND METHODS

3.1 Equipment – handheld X-ray fluorescence gun

Equipment for this project was handheld XRF gun “Thermo Scientific Niton XL3t GOLDD”, which has been used for both the screening in the field and for laboratory measurements in the radiation lab. It is shown in picture 1 below.



PICTURE 1. Handheld XRF gun in use.

As the XRF gun emits radiation during analysis and poses certain risks when used in incorrect manner, before working with this XRF device training session has been arranged by the responsible personnel to ensure its proper use and avoid radiation exposure throughout the analytical process.

The device had preconfigured calibration for a suitable type of samples, so it was unnecessary to do any additional configurations to the device. Calibration for “Consumer goods: Plastic” has been used for analysis during this study.

3.2 Samples

Samples analysed for this study were different EPS (expanded polystyrene) and XPS (extruded polystyrene) materials from a waste stream of Tarastenjärvi waste site. The origin of analysed samples is either insulation material used in the construction industry (both EPS & XPS) or packaging material (mainly EPS).

The number of samples analysed during this project is the following:

- *Screening – 150 samples (50 / day)*
- *Lab measurements - 48 samples (from 150 screened)*

As for the sample types, the proportion between the number of EPS and XPS samples analysed in the screening is 90% / 10%, for EPS and XPS respectively.

All XPS samples were “bricks” of yellow colour. EPS samples, in turn, had some variations in shape and colour. Different shapes could be explained by different use cases for the materials, as EPS is a rather widely used material in the construction and packaging industries.

The colour differences among EPS samples screened are the following:

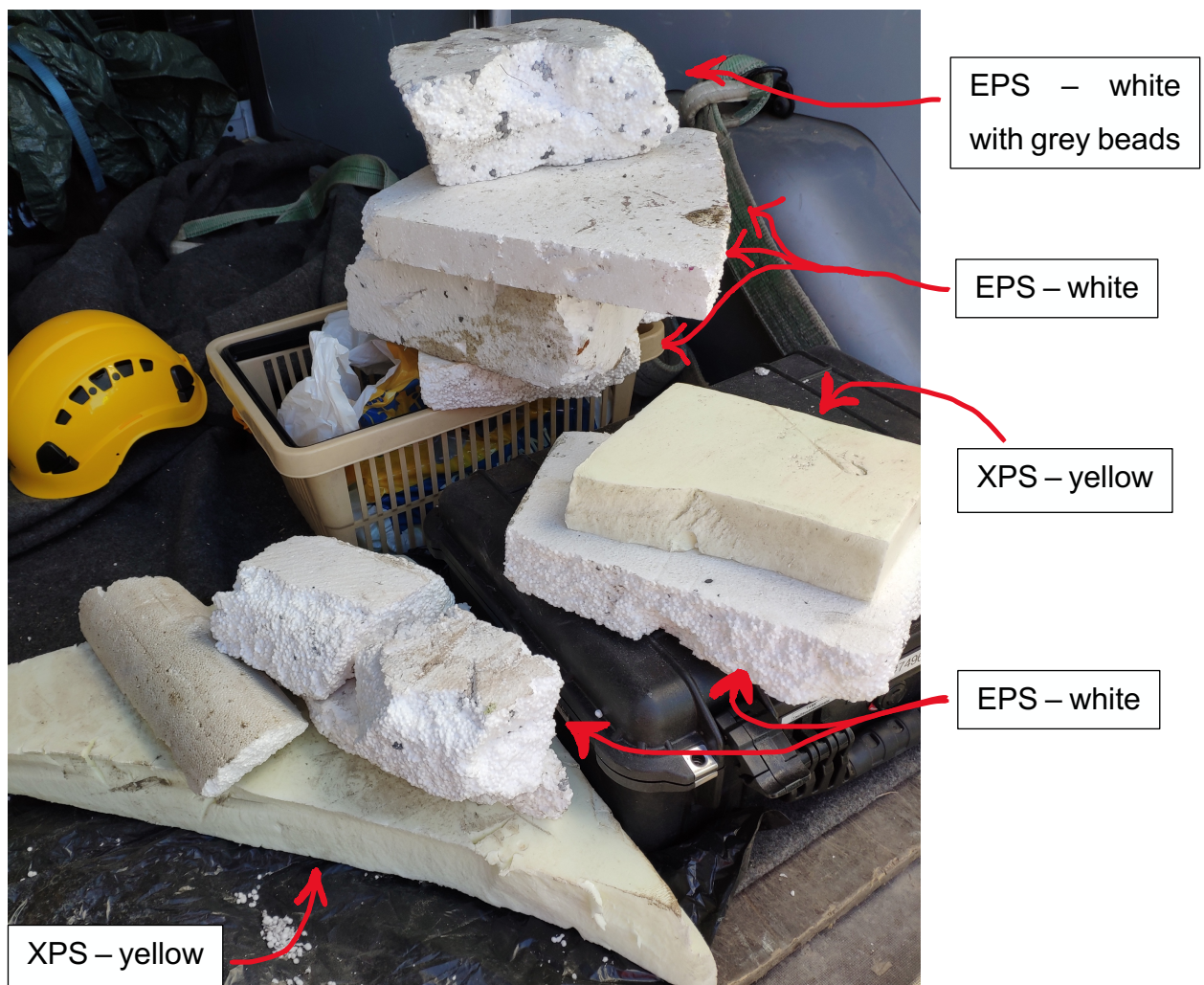
- *White – 60%*
- *White with grey beads – 30%*
- *Grey – 9 %*
- *Others – 1%*



PICTURE 2. White EPS – the most common type of sample.



PICTURE 3. Grey EPS and yellow XPS.



PICTURE 4. A mix of different samples.

3.3 Analysis

Handheld XRF gun performs elemental analysis and therefore is not able to detect HBCD directly, even though the interest of this study was in the detection of HBCD in the samples. Therefore, the focus of the analysis was on the detection of Bromine only; because it is a part of HBCD structure and serves as an indicator for the presence of Br-additive flame retardants in EPS/XPS material.

The analysis for this study was carried out in accordance with the method suggested and tested by Schlummer et al. (2015). The method is based on the fact that PolyFR and other HBCD-alternatives have significantly low solubility in organic solvents (such as acetone used for the study) and therefore are not extractable, whereas HBCD is extractable due to its high solubility in organic solvents (Schlummer et al., 2015). So, to differentiate Br-positive samples that contain HBCD from those that contain HBCD alternatives, they were dissolved in acetone. With the addition of acetone, polystyrene material shrinks, but the polymer structure does not dissolve (Wolf and Molinari, 1973), meaning that extractable HBCD would be dissolved in the acetone, whereas reactive HBCD alternatives would stay in the shrunk polymer structure. If the sample (developed solution) still contains Br after acetone extraction, it indicates the presence of HBCD.

Identification of HBCD with XRF was tested as well during the HBCD research project of TAMK, where the XRF identification method was compared to gas chromatography for the detection of HBCD and was proven to be an effective tool for on-site screening of waste polystyrene material. (Honkala, 2018)

The analysis itself is divided into two parts that are discussed in subchapters below - screening and lab measurements. For the screening, there were three field measurement days with 50 samples screened each day. Br-positive samples from screening were taken to the lab for further analysis. The process chart for the analysis used for this study is presented in figure 2 below.

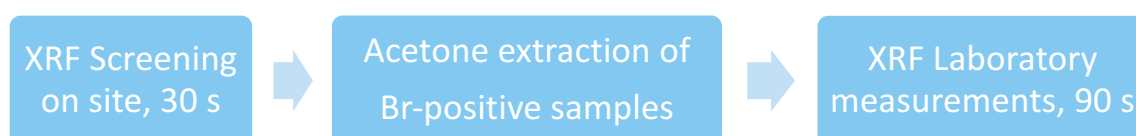


FIGURE 2. Process chart of the analysis.

3.4 Screening on-site with handheld X-ray fluorescence gun

Screening is the first step of analysis that is carried out on site using a handheld XRF gun. For the screening, different EPS and XPS samples were retrieved from a waste pile (Picture 5). In order to analyse as diverse samples as possible and to avoid taking samples that came to the waste site from the same place, samples were retrieved from different spots of the pile. As well, taken samples differ in type and colour. The exact origin of the samples is unknown.

The presence of Bromine in retrieved samples was checked with the XRF device with 30-second settings for quick analysis (Picture 6). If needed, e.g. if the surface of the sample is dirty, samples were cut and analysed from inside to avoid misrepresentation of Bromine presence in the sample itself.



PICTURE 5. Waste pile on Tarastenjärvi waste site.



PICTURE 6. Screening on site.

Bromine positive samples were marked with its code number and packed in small individual bags to avoid contamination during transportation. Those Br-positive samples were put in a big plastic bag and delivered to the laboratory for further analysis. Samples with no Bromine detected were discarded back to the waste pile, as they were of no use for this study anymore.

3.5 Laboratory measurements

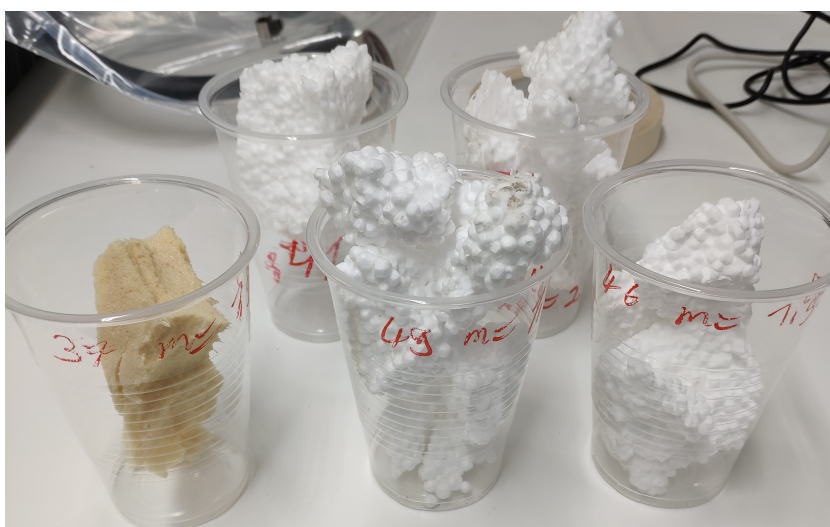
Laboratory measurements for this study consist of two parts: acetone extraction of the samples, which was carried out in the ENVE lab in TAMK and the XRF analysis in laboratory conditions carried out in the Radiation lab in TAMK.

3.5.1 Acetone extraction of Bromine positive samples

Process of acetone extraction of the samples is the following:

1. *Weight 2 g of sample in polypropylene cup*
2. *Take 5 g (6 ml) of acetone*
3. *Pour acetone to the sample and cover it with the lid*
4. *Let sample dissolve in the acetone for 10 minutes*
5. *Pour developed solution into a vial*

Weighted samples were put in polypropylene (PP) cups that could withstand the effects of the acetone and would not be destroyed in the process (Picture 7). Actual masses of the samples were noted as they were used for calculations of HBCD concentration later on.

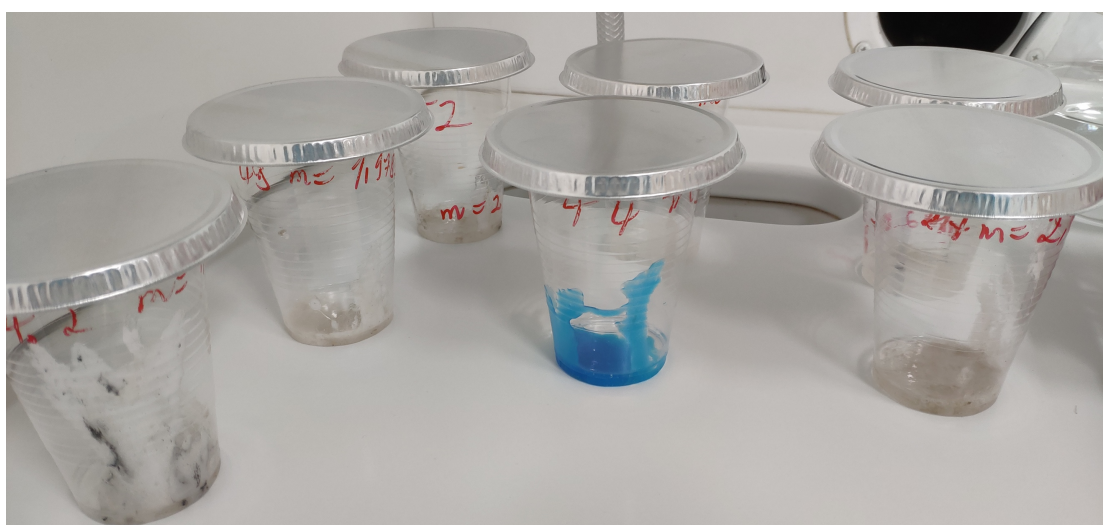


PICTURE 7. Weighted samples in PP cups.

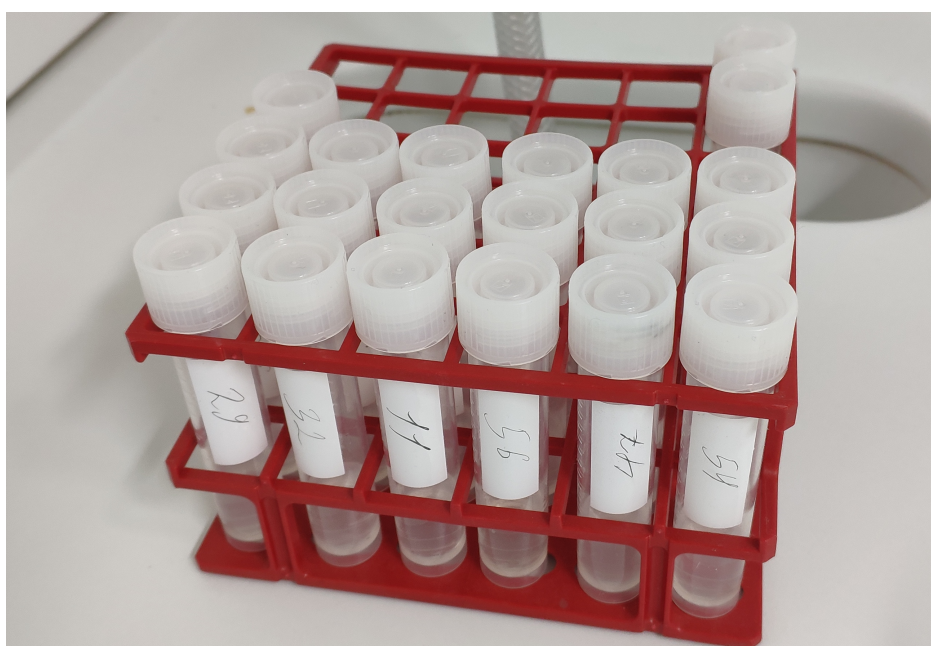
Acetone in a volume of 6 ml was poured to the cups with samples, and cups were covered with aluminium lids to avoid evaporation of acetone due to its high volatility. Then samples were left to dissolve for 10 minutes.

In fact, EPS and XPS materials immediately shrink when acetone is added. However, the dissolution process was performed for ten minutes to ensure that the end result of acetone extraction would be plausible. (Picture 8)

A combination of 2 g sample and 5 g (6 ml) of acetone is the most practical approach for acetone extraction of polystyrene material (Schlummer et al., 2015).



PICTURE 8. Samples are dissolved in acetone for 10 minutes.



PICTURE 9. Prepared samples in vials.

Safety measures were considered during the acetone extraction of the samples. Laboratory coat and gloves were worn all the time; all actions with acetone were carried out under the hood. Leftover cups and vials were disposed of in a reasonable manner.

Leftovers of the samples, as only two grams of each were used, were packed back and placed in the storage in case they would be needed for further studies on HBCD projects organized by TAMK.

3.5.2 Radiation lab measurements with handheld X-ray fluorescence gun

Prepared vials with the samples were taken to the radiation lab for further measurements in the laboratory. Analysis in the radiation lab was still carried out using handheld XRF gun, but in more controllable conditions due to the addition of special stand and a PC with software that allows managing the measurements from a computer instead of manual trigger pulling. The measurement time was set up to 90 seconds; each sample was analysed three times to avoid misreadings.



PICTURE 10. Radiation lab setup.



PICTURE 11. Vial with the sample on the stand.

The data on Bromine concentrations collected during the field measurements as well as laboratory measurements was exported from XRF device using PC software from a manufacturer – NDT 5.

All data collected during the study was then combined in a single table to make the analysis of the results of the project easier.

After the measurements, vials with acetone extraction samples were left under the hood in the ENVE lab so that acetone would evaporate, and vials could be disposed of.

3.6 Calculations

HBCD concentrations were calculated by the formula 1 and 2 below.

The first formula is used to estimate HBCD content in the sample from Bromine readings in the screening phase, but it is not necessary that the sample indeed contains HBCD (because it is known only after acetone extraction). Therefore, this formula is the most suitable in the situation when it is known that the sample contains HBCD and calculated HBCD concentrations could be compared between the on-site measurements and measurements after acetone extraction.

The second formula was mainly used for this study. It represents HBCD concentrations calculated from Bromine readings after the acetone extraction phase when it becomes clear if the sample contains HBCD or not.

$$\text{On-site screening: } \frac{\text{Br concentration}}{0.75} = \text{HBCD}, \quad (1)$$

Where “Br concentration” is Bromine content in ppm from on-site measurements. Division by 0.75 represents that HBCD contains 75% of Br in its structure.

$$\text{After acetone extraction: } \frac{\text{XRF result (Br)} * \frac{m + 5 \text{ g}}{m}}{0.70 * 0.75} = \text{HBCD}, \quad (2)$$

Where “XRF result (Br)” is Bromine content of the sample (in ppm) from the readings that are done by XRF after acetone extraction. Division by 0.75 represents once again that Bromine makes up 75% of HBCD structure. Mass of the sample (in grams) is noted as “*m*” in the formula.

Acetone was added to the sample in a volume of 6 ml. However, to make units corresponding, 6 ml volume was converted into the mass value. Mass is equal to volume multiplied by the density of the substance (density of acetone is 0.78 g/cm³). Therefore, the mass of the acetone added to the sample is approximately 5 grams, which is noted in the formula. These mass values are needed because the sample was diluted in acetone and therefore real HBCD values are higher.

As the sample (solution) is measured through the vial, making the result lower than real HBCD value, the result should be additionally divided by 0.70 according to standards given by the manufacturer. (Honkala, 2018)

Since the XRF result for Bromine concentration is presented in ppm, then the end result of the formula – HBCD concentration – is in ppm as well. However, ppm values were converted to more common in scientific articles values of mg/kg. The conversion factor between ppm and mg/kg is 1:1 for mass conversion scenario (which is suitable for the case of this study). Therefore, HBCD concentration in ppm is equal to HBCD concentration in mg/kg.

Final values for hexabromocyclododecane concentrations were noted in mg/kg.

3.7 Statistics

For the results to be statistically feasible, it was decided to screen 50 different samples each day of field measurements. More samples would be interesting, but it is hard to achieve because it simply depends on a number of possible samples in the waste pile on a particular day; which in case of this study was just enough to find 50 samples, but not many more than that. There were three field measurement days, resulting in 150 samples being screened for this study.

Additionally, acetone extraction samples were analysed three times per sample to ensure correct measurement results and avoid unnecessary mistakes from readings of Bromine content in the samples.

4 RESULTS AND DISCUSSION

The full data table is presented in the appendix section. The table 1 below represents numbers of Bromine positive and HBCD positive samples in response to the number of samples screened each day as well as the total amount.

In order for the sample to be HBCD-positive, its Bromine concentration measured after acetone extraction should be more than the threshold value of 100 mg/kg. Samples with Bromine concentrations after acetone extraction less than 100 mg/kg are considered to not contain HBCD. (Schlummer et al., 2015)

TABLE 1. Results of the study.

<i>Field day</i>	Number (N) of samples screened	N of Br-positive, screening	N of Br-positive, acetone extraction	Number of HBCD-positive
27.03	57	21	10	1
29.03	43	15	5	0
16.04	50	12	8	1
<i>Total</i>	150	48	23	2
		32%	15%	1%

The mean value for HBCD concentrations collected during this study (after acetone extraction measurements) was calculated and is equal to 483 mg/kg HBCD (0.024% HBCD wet weight). This value is less than the mean value of 785 mg/kg (0.08% HBCD w/w) for construction EPS, derived during the study of different EPS/XPS materials from Geoje, South Korea (Rani et al., 2014). Although, the number of analysed samples was less in case of Korean study ($n = 5$), which makes the comparison less plausible.

Mean HBCD concentration from this study (0.024%) is as well less than HBCD concentrations generally used in polystyrene material for the construction industry within Europe (0.5 - 0.7% HBCD w/w) noted by Persistent Organic Pollutants Review Committee (2011).

Apart from workplaces in direct contact with HBCD, the main exposure paths for humans are indoor dust and food products (Jensen, 2015). Several studies on HBCD levels in house dust have identified HBCD in all of the analysed samples from offices and private houses (Leonards et al., 2001; Stapleton et al., 2004).

Although these exposure paths might seem unrelated to the case of this study, HBCD can leach out from the material residing on a waste site; and due to its persistence and biomagnification characteristics, HBCD can reach the food products through the food chain.

The percentage of Br-positive samples in the screening (Table 1) is quite high at the level of 32% of all screened samples. It is that high due to the fact that at the beginning of the study some samples with Bromine level less than 100 mg/kg were taken, although those samples clearly could not contain HBCD.

After acetone extraction, those samples, that still contained Bromine, had very low concentrations of it, appearing under the threshold value of 100 mg/kg and therefore being HBCD-free, but likely to contain reactive HBCD alternatives. Another possible source for a small amount of Bromine in the samples after acetone extraction is that those samples were recycled from material that contained HBCD or brominated flame retardants in general. (Schlummer et al., 2015)

Two samples have been considered as HBCD-positive with HBCD concentrations being 790 mg/kg and 6862 mg/kg (Br concentrations were 119 mg/kg and 1025 mg/kg respectively). The first sample has quite low concentration and might contain one of the reactive flame retardants instead of suspected Hexabromocyclododecane, while the second one clearly shows the presence of HBCD in this sample, possessing the risk of exposure unless properly disposed of. Both HBCD-positive samples were white EPS insulation boards.

Percentage of HBCD positive samples for this study (1%) is less than HBCD-positivity percentages (2% and 6%) found in plastic components of vehicles, electronics and building material samples during two studies in Switzerland in 2004 and 2010 (POPRC, 2011), even though wider range of samples was analysed for those studies and the results should not be compared directly.

Limited data is available on HBCD concentrations in waste polystyrene material. Most studies focus on HBCD concentrations in the environment (air, soil, water, sediment, wastewater, biota), humans (e.g. breast milk) or in indoor air and dust.

HBCD has been found in all compartments of the environment. Furthermore, some studies that analysed time trends identified an increase in HBCD concentrations. However, as the research interest has arisen recently (the data does not cover long time periods) and some studies do not identify significant time trends, it is hard to clarify HBCD increase/decrease over time. (Covaci et al, 2006)

As an example of increasing time trend for HBCD, lake sediment studies in Switzerland showed increasing concentrations of HBCD since the 1980s (Kohler et al. 2008). Studies on HBCD in the wildlife as well showed an increase in HBCD concentrations in ringed seals from East Greenland (Vorkamp et al., 2011) and peregrine falcon from Sweden since the 1980s (Johansson et al., 2011).

A Swedish study on HBCD levels in the milk of Stockholm mothers reports four-five times increase in HBCD concentration during the time frame from 1980 to 2002 (Fängström et al, 2008).

Studies that analysed HBCD trends in food webs show higher HBCD concentrations in top food chain species, presenting biomagnification potential for HBCD (Covaci et al., 2006). For example, HBCD biomagnification study for the food web of a Lake Winnipeg showed 10 times higher concentrations at the step from forage fish to predator fish (Law et al., 2005).

Although few XPS samples appeared to be Bromine positive in the screening phase of this study, there were no Br-positive XPS samples after the acetone extraction. Actually, two of those already few XPS samples did not dissolve in the acetone at all. It might have happened because those samples were actually some different material or still XPS but with differences in the structure or in the compounds added to it.

One white EPS sample did not dissolve in the acetone as well, which could be probably explained as differences in the structure, the same as with XPS material.

Almost all the Bromine positive samples (in screening) were EPS material. The samples with the highest rate of Bromine positivity were EPS of grey colour and white ones with grey beads; appearing that almost 100% of screened samples of these particular colours being Bromine positive in the screening phase. Although, none of these samples showed a presence of HBCD after all.

Bromine positive samples, both in screening and after acetone extraction, were a mix of white EPS and EPS of white with grey beads with the addition of few grey EPS samples, with a percentage deviation between them being approximately at the levels of 50% / 45% / 5% respectively for each type.

The collected results on types of the samples correspond with South Korean study in terms of EPS material having higher HBCD concentrations than XPS and therefore being more dangerous as HBCD pollutant source (Rani et al., 2014).

Substance flow analysis on HBCD conducted in Japan points out that the highest amount of pollutant is released when buildings are renovated or demolished. According to the study, construction materials' emissions of HBCD would be still occurring for several decades to the future being a long-term HBCD pollution source. The stock of HBCD polluted material on waste sites or landfills is also a long-term source for HBCD pollution. (Managaki et al., 2009)

Therefore, it is important to identify HBCD pollution in the material and dispose it in the correct manner by incineration rather than leaving it as it is on a waste site.

Taking into consideration all of the above mentioned, EPS and XPS material treated with HBCD possess a significant risk on any stage of life-cycle, especially during demolition/renovation process or when residing on a waste site, as HBCD could leach out of the material into the environment and eventually (due to persistence and bioaccumulation) end up in the food, the water or the air, poisoning humans unless HBCD polluted material is identified and disposed of properly.

5 CONCLUSIONS

The results of this study show that only 2 samples (1%) from 150 samples analysed were considered as HBCD-positive and therefore possess a certain risk to human health and environment unless treated in correct manner of incineration.

Although the number of HBCD-positive samples is quite low and not that alarming, it is still more than the target level of zero percent of HBCD-positive samples in a waste stream, as Hexabromocyclododecane has been banned from production and use globally by Stockholm convention.

XPS samples during this study did not appear to be of risk in terms of HBCD contamination due to a small number of Br-positive samples, low Bromine concentrations in Br-positive samples and zero samples being Bromine positive after the acetone extraction. However, XPS samples should be still screened, because HBCD has been widely used in both EPS and XPS insulation materials.

EPS material, in turn, is of concern for possible HBCD contamination, as approximately every third EPS sample was Bromine positive in the screening phase and around half of the Br-positive screened samples were Br-positive after acetone extraction as well. Although these samples are likely to contain allowed HBCD alternatives, the study still detected two HBCD-positive samples among EPS.

The equipment and methods utilised during this study has been effective in detection of HBCD from EPS and XPS material from a waste stream and could be used by construction and waste management companies to detect HBCD in the samples and determine the correct disposal way for the waste material; whether it could be recycled or should be incinerated at the waste incineration plant.

For future development of HBCD detection, field measurement kit could be created to allow all the analysis including acetone extraction to be conducted on-site; which would significantly speed up the detection process resulting in faster pre-disposal process and easier disposal of polystyrene waste material.

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APPENDICES

Appendix 1. Full data table divided by field days.

Nr.	Sample code	Color	Type	Bromine content, screening in ppm	Bromine content, acetone extraction in ppm	Standard deviation, acetone extraction in ppm	Sample mass in g	Sampling date	Sampling location	Comment	HBCD content, acetone extraction in mg/kg	HBCD positive
1	9	white	EPS	3863,44	9,18 9,16 9,12	0,030550505	2,0660	27.03.2019	Tarastenjärven jätekeskus		59,630	
2	5	white	EPS	535,25	2,11 7,86 6,61 6,42	1,218209088	1,9880	27.03.2019	Tarastenjärven jätekeskus		0,000	
3	36	white	EPS	3750,45	5,09 5,67 6,42	0,782225593	1,9279	27.03.2019	Tarastenjärven jätekeskus		47,662	
4	39	white	EPS	3352,84	5,09 5,67 6,42	0,666808318	2,0940	27.03.2019	Tarastenjärven jätekeskus		38,123	
5	22	white	EPS	441,22	117,15 120,36 120,36	1,850414988	2,0201	27.03.2019	Tarastenjärven jätekeskus		789,593	yes
6	50	white	EPS	231,88	40,57 41,1 41,32	0,385529938	2,0030	27.03.2019	Tarastenjärven jätekeskus		273,019	
7	4,2	white with grey beads	EPS	41,57	0 0 0	0	1,9950	27.03.2019	Tarastenjärven jätekeskus		0,000	
8	27	white	EPS	261,73	0 0 0	0	2,0300	27.03.2019	Tarastenjärven jätekeskus		0,000	
9	52	white	EPS	375,74	0 0 0	0	2,0000	27.03.2019	Tarastenjärven jätekeskus		0,000	
10	37	light green	?	103,37	n/a n/a n/a	n/a	n/a	27.03.2019	Tarastenjärven jätekeskus	did not shrink in acetone	n/a	
11	46	white	EPS	63,92	0 0 0	0	1,9720	27.03.2019	Tarastenjärven jätekeskus		0,000	
12	41	white	EPS	40,17	3,94 3,64 3,95	0,176162803	2,0100	27.03.2019	Tarastenjärven jätekeskus		25,531	
13	49	white	EPS	77,94	24,06 24,07 24,71	0,372424489	1,9780	27.03.2019	Tarastenjärven jätekeskus		163,153	
14	47	white with grey beads (few)	EPS	185,14	0 0 0	0	1,9930	27.03.2019	Tarastenjärven jätekeskus		0,000	
15	12	light green	?	128,19	n/a n/a n/a	n/a	n/a	27.03.2019	Tarastenjärven jätekeskus	did not shrink in acetone	n/a	
16	32	white with grey beads	EPS	372,6	0 0 0	0	2,0880	27.03.2019	Tarastenjärven jätekeskus		0,000	
17	56	white	EPS	79,06	22,76 22,85 23,17	0,213775583	1,9150	27.03.2019	Tarastenjärven jätekeskus		157,713	
18	29	white with grey beads	EPS	1447,87	0 0 0	0	2,0260	27.03.2019	Tarastenjärven jätekeskus		0,000	
19	44	light blue	XPS	26,93	0 0 0	0	2,0480	27.03.2019	Tarastenjärven jätekeskus		0,000	
20	54	white	EPS	74,19	19,04 19,6 19,21	0,388873414	2,0300	27.03.2019	Tarastenjärven jätekeskus		127,638	
21	11	white	EPS	84,33	26,3 26,33 26,93	0,355387113	2,0940	27.03.2019	Tarastenjärven jätekeskus		171,131	

1	15	white with grey beads	EPS	120,76				0	0	1,9610	29.03.2019	Tarastenjärven jätekeskus		0,000	
2	17	white with grey beads (few)	EPS	488,47				0	0	2,0050	29.03.2019	Tarastenjärven jätekeskus		0,000	
3	3	grey with white beads (few)	EPS	9337,09				0,618304132	38 38,13 37	2,0050	29.03.2019	Tarastenjärven jätekeskus		250,952	
4	16	white with grey beads	EPS	93,24				0	0	2,0620	29.03.2019	Tarastenjärven jätekeskus		0,000	
5	32	white	EPS	317,27				1,270170592	2,2 0	2,0820	29.03.2019	Tarastenjärven jätekeskus		0,000	
6	14	grey with white beads (few)	EPS	444,92				0	0	1,9670	29.03.2019	Tarastenjärven jätekeskus		0,000	
7	8	white	EPS	575,44				1,223982571	2,12 0	2,0420	29.03.2019	Tarastenjärven jätekeskus		0,000	
8	26	grey	EPS	9330,02				1,275199331	79 79,92 81,52	2,0150	29.03.2019	Tarastenjärven jätekeskus		531,470	
9	41.1	white	EPS	39,96				n/a	n/a n/a n/a	1,9930	29.03.2019	Tarastenjärven jätekeskus	did not shrink in acetone	n/a	
10	38	white	EPS	83,37				2,033202663	92,13 87,97 90,25	1,9980	29.03.2019	Tarastenjärven jätekeskus		601,207	inconclusive
11	4	white	EPS	510,32				0	0	2,0370	29.03.2019	Tarastenjärven jätekeskus		0,000	
12	2	grey with white beads	EPS	8960,6				1,523690695	35,26 35,43 37,98	1,9660	29.03.2019	Tarastenjärven jätekeskus		244,472	
13	31.2	white	EPS	4165,64				0,260832002	10,92 11,43 11,27	2,0250	29.03.2019	Tarastenjärven jätekeskus		74,052	
14	39	white with grey beads (few)	EPS	592,31				0	0	2,0350	29.03.2019	Tarastenjärven jätekeskus		0,000	
15	5	white with grey beads (few)	EPS	219,8				0	0	2,0760	29.03.2019	Tarastenjärven jätekeskus		0,000	

1	12	white	EPS	181,46				0	0	0	0,000	
2	15	white with grey beads (few)	EPS	2110,2				1,772465326	0	1,9800	0,000	
3	23	white with grey beads (few)	EPS	1299,37				1,033198916	0	1,9240	99,737	
4	25	white with grey beads (few)	EPS	1824,47				1,168631679	0	1,9860	129,851	
5	38	white with grey beads (few)	EPS	814,25				1,045291028	0	1,9540	121,973	
6	46	white with grey beads (few)	EPS	2575,39				1,601218286	0	1,9260	247,546	
7	42	white	EPS	742,46				0,473849484	0	1,9660	47,018	
8	33	white	EPS	143,95				0	0	1,9700	0,000	
9	3	white	EPS	3377,11				2,834713389	0	1,9880	6862,193	yes
10	45	white with grey beads	EPS	282,44				0,366651515	0	2,0420	21,261	
11	41	white with grey beads	EPS	688,99				1,200930195	0	2,0100	27,148	
12	49	white with grey beads	EPS	204,23				0	0	1,9820	0,000	