

Comparison of trihalomethanes in the air of two indoor swimming pool facilities using different type of chlorination and different types of water

Therese B. Nitter, Wolfgang Kampel, Kristin v. H. Svendsen and Bjørn Aas

ABSTRACT

Certain aspects of the distribution of disinfection by-products (DBPs) in the air of indoor swimming pools, the exposure of the users, and possible health effects, have not been well documented. To determine the distribution of trihalomethanes (THMs), measurements were performed at 0.05 m, 0.60 m and 1.50 m above the water surface. These heights were chosen to measure the exposure in the breathing zone of the users. Air samples were collected from two indoor swimming pool facilities in Norway. Facility 1 uses calcium hypochlorite and facility 2 uses sodium hypochlorite for water treatment. In facility 2, one of the swimming pools is filled with 33% seawater, while the other pools in this study were filled with freshwater. Higher values were measured at 0.05 m compared to 1.50 m. Negligible differences between the measurements at 0.60 m and 1.50 m above floor levels were obtained. On average, 282% higher concentrations of total THM (tTHM) were measured in facility 2. Different disinfection products and ventilation concepts are possible explanations. Swimmers are exposed to higher concentrations compared to users by the poolside. For future studies, it is crucial to measure as close to the water surface as possible.

Key words | brominated THM, calcium hypochlorite, distribution of THMs, seawater, sodium hypochlorite, ventilation

Therese B. Nitter (corresponding author)

Kristin v. H. Svendsen

Department of Industrial Economics and Technology Management, Faculty of Economics and Management, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
E-mail: therese.nitter@ntnu.no

Wolfgang Kampel

Bjørn Aas

SIAT – Centre for Sport Facilities and Technology, Department for Civil and Environmental Engineering, Faculty of Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

INTRODUCTION

Chlorine-based water treatment is the most common disinfectant used in swimming pool water. The method reduces the risk of exposure to pathogens present in the water such as bacteria, parasites and fungi. If these pathogens are not removed, they can cause severe health effects (World Health Organization 2006). The reaction between chlorine and organic matter from the occupants such as hair, lotions, dirt, skin particles and urine creates disinfection by-products (DBPs). The presence of DBPs in the pool room has been linked to a variety of health issues (World Health Organization 2006; Kogevinas *et al.* 2010; Manasfi *et al.* 2017a, 2017b). Among the most important groups within DBPs are trihalomethanes (THMs), where chloroform (TCM), bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform (TBM) are

most abundant. Of the four THMs, TCM is the compound generally present in the greatest concentration (World Health Organization 2006). However, adding seawater to the pool increases the amount of brominated DBPs, making TBM the most dominant THM (Parinet *et al.* 2012; Ged & Boyer 2014; Chowdhury 2015; Manasfi *et al.* 2016). Studies show that increased formation of brominated THMs occurs in chlorinated bromide-rich waters (Hua *et al.* 2006; Ged & Boyer 2014). Another factor associated with an increased amount of brominated DBPs in swimming pool water is the use of sodium hypochlorite for water disinfection if the brine solution used for the production contain bromide ions (Bouland *et al.* 2005). The brominated THMs are in general more genotoxic compared to their chlorinated analogues (Kogevinas *et al.* 2010; Manasfi *et al.* 2017a, 2017b).

doi: 10.2166/ws.2017.201

Exposure to DBPs in pools can take place through inhalation, dermal contact, and to a lesser extent by accidental swallowing of water (Chen *et al.* 2011; Chowdhury 2015). Occupants in the pool inhale more concentrated air in comparison to employees and visitors staying by the poolside. Beside that, the employees and athletes will be more exposed due to longer exposure time. To determine health effects related to DBPs, it is crucial to measure the concentration of THMs directly above the surface of the water, meaning the breathing zone of the swimmer, as high activity provides high pulmonary ventilation (World Health Organization 2006). The aim of the present study was to measure the concentration of THMs 0.05 m, 0.60 m and 1.50 m above the pool water surface, representing the breathing zone of the swimmers, as well as children and adults standing by the pool side, and to compare the distribution of THMs from three freshwater pools and one seawater pool using different disinfection principles.

METHOD

Four swimming pools in Norway, located in two public indoor swimming facilities, were selected for this study. They were chosen to make a comparison between different disinfection methods possible, as facility 1 (S1) uses granulated calcium hypochlorite ($\text{Ca}(\text{OCl})_2$) while facility 2 (S2) uses liquid sodium hypochlorite (NaOCl). The latter also includes a pool where the water is a mixture of 67%

freshwater and 33% seawater. Samples were collected between 13 February, 2017 and 10 March, 2017. Above each pool, between 15 and 26 samples were collected. In Table 1, physicochemical parameters and number of bathers for the different swimming pools are listed. The two swimming facilities are referred to as S1 and S2.

In S1, pools 1 and 2 are in the same room. In addition, there is also a whirlpool and a small paddling pool. Approximately 130,000 visitors visit S1 per year. Both pool 1 and 2 use drinking water from the public water supply. The results are based on 41 air samples collected from S1 during the 4 weeks of sampling. In S2, pool 3 is in the same hall as four other swimming pools including a wave pool, a slide pool and several whirlpools and fountains. Pool 4 is in its own room with its own ventilation system, but is supplied with disinfected water from the same circulation system as pool 3. In total, approximately 360,000 people visit S2 per year. Besides 33% of seawater being used in pool 3, both pool 3 and 4 use drinking water from the public water supply. The results are based on 41 air samples collected from S2 during the 4 weeks of sampling.

Both S1 and S2 use the same type of ventilation system and the ventilation flow rate is constant. The supplied amount of fresh air is controlled according to the humidity and the temperature in the rooms.

Sampling

Each sampling day, stationary air samples were collected during morning swimming (0630–0930 AM), baby swimming

Table 1 | Physicochemical parameters and number of bathers for the different swimming pools

| | S1 | | S2 | |
|-----------------------------------|---------------------------|---------------------------------------|----------------------------|----------------------------|
| | P1 | P2 | P3 | P4 |
| Water volume [in m ³] | 600 | 200 | 2,450 | 210 |
| Disinfectant | $\text{Ca}(\text{OCl})_2$ | $\text{Ca}(\text{OCl})_2 + \text{UV}$ | $\text{NaOCl} + \text{UV}$ | $\text{NaOCl} + \text{UV}$ |
| Water temperature [in °C] | 26.5–26.8 | 32.9–33.1 | 28.3–28.9 | 33.9–34.6 |
| Air temperature [in °C] | 27.0–28.5 | 27.5–29.0 | 28.0–30.3 | 29.6–32.3 |
| pH | 7.22–7.45 | 7.37–7.87 | 7.20–7.35 | 7.15–7.23 |
| Free chlorine [in mg/L] | 0.77–0.89 | 1.03–1.44 | 0.45–0.51 | 0.95–1.04 |
| Combined chlorine [in mg/L] | 0.15–0.25 | 0.02–0.42 | 0.02–0.06 | 0.11–0.31 |
| Number of users | 5–25 | 0–22 | 5–25 | 22–50 |
| Fresh/seawater ratio | 1/0 | 1/0 | 0.67/0.33 | 1/0 |

(1430–1730 PM) and public swimming (1730–1830 PM). Both the morning swimming and baby swimming took place in the therapy pools (pool 2 and 4) while public swimming occurred in the sport pools (pool 1 and 3) of the two facilities. Three samples were collected simultaneously using a test stand with three different heights, 0.05 m, 0.60 m and 1.50 m above the pool water. The test stand was placed by the pool side and in the middle of the long side of the pool, at the same place during all measurements.

Air samples were obtained by pulling air through stainless steel tubes containing 0.20 g of Tenax TA 35/60 (Markes International), using low flow pumps with an average flow rate of 50 ml/min for 20 min to obtain air volumes of 1 liter. The pumps were calibrated *in situ*, before and after each sample. The tubes were immediately recapped after collection using Swagelok caps with combined PTFE ferrules to avoid losses. After sampling, the tubes were wrapped in uncoated aluminum foil and placed in an airtight container with charcoal to avoid contamination. This is in accordance with recommendations of the standard US EPA Method TO-17 (United States Environmental Protection Agency 1999). Tube number and placement, pool, activity, free chlorine, combined chlorine, pH, air- and water temperature and number of bathers were recorded when the samples were collected. Information on water temperature, free and combined chlorine and pH were collected from the automatic logging system in the two pool facilities. The air temperature and relative humidity were measured *in situ* with a portable instrument (AirMeterTM TestT001, Fluke).

Laboratory analysis

The sampling and analysis of THM levels in air were based on the US EPA Method TO-17 (US EPA 1999) and ISO 16017 (International Organization for Standardization 2000). Determination of THMs in the air was performed by using a Unity thermal desorber (Markes International) coupled with Agilent Technologies 5975T Low Thermal Mass (LTM) Gas Chromatography/Mass Selective Detector (GC/MSD). Thermal desorption was carried out for 10 min at 284 °C with a flow rate of 30 ml/min and to a cold trap packed with Tenax TA. Secondary desorption was carried out with a carrier gas flow rate of 20 ml/min from the trap. The THMs were submitted to a 3.7:0.7 split ratio.

The separation was performed on a capillary column (DB-1; ID 0.25 mm and 0.25 µm film thickness). The oven temperature was running with a temperature program from 35 °C to 90 °C with 5 °C/min steps, with post run at 230 °C. Identification and quantification of THMs were performed in selection ion monitoring (SIM) mode. The results are based on 82 of 87 collected samples. Five samples were excluded due to tube leakage during the pressure test before desorption. The analysis of THM was performed in the laboratory of the Department of Health, Safety and Environment at the Institute of Industrial Economy and Technology Management at NTNU.

Method validation and quality assurance

Both external and internal calibration methods were performed. For internal calibration, the sorbent tubes were spiked with 250 ng 8260 Internal Standard Mix 2 (Supelco) containing fluorobenzene, chlorobenzene-d5, and 1,4-dichlorobenzene-d4 in methanol. For external calibration, a five-point calibration curve was made, ranging from 0.5 ng to 500 ng, for each of the four THMs, using Trihalomethanes Calibration Mix (Supelco) diluted with methanol ($n = 30$). Using this method, a limit of quantification (LOQ) of 0.5 µg/m³ and a linear range from 0.5 µg/m³ to 500 µg/m³ was obtained for all four THMs. In accordance with US EPA Method TO-17, all duplicate measures and volume pairs of tubes have been within the precision of 5%. The test for breakthrough was carried out weekly to verify that less than 5% of the target analytes were observed on any of the back-up tubes (US EPA 1999). The calibration check was performed during and after the measuring campaign was finished.

Statistical analysis

For descriptive purposes, the arithmetic mean (AM) and standard deviation (SD) were calculated for the THM concentrations using Statistical Package for Social Sciences (SPSS) 24.00. Spearman rank correlation was used to estimate the correlation between the various variables, and a one-way analysis of variance (ANOVA) model was used to estimate the swimming pool variance components. Independent T-tests were used to investigate whether the two facilities were significantly ($p \leq 0.05$) different from each other.

RESULTS AND DISCUSSION

A summary of the measured parameters is shown in Table 2. The measured THM concentrations in $\mu\text{g}/\text{m}^3$ for the different pools and different heights are listed in Table 3. The concentration of combined chlorine was always in agreement with the Norwegian guidelines (<0.50 mg/L). On the final day of sampling, the measured level of pH in S1 exceeded the required value in the Norwegian guideline (7.20–7.60). In pool 3, one sample of free chlorine showed 0.45 mg/L, which is lower than the limit value of 0.50 mg/L (Norwegian Ministry of Health 1996).

Concentration of THM 0.05 m, 0.60 m and 1.5 m above water surface

Figure 1 shows that significantly higher levels of tTHM were measured in pool 3 and 4 located in S2. Only TCM and BDCM were quantified in all samples in S1 (pool 1 and 2), while DBCM and TBM was either not detected or under the LOQ. In S1, at 0.05 m above the water surface, the concentration of tTHM was in the range of $162.5 \mu\text{g}/\text{m}^3$ – $316.4 \mu\text{g}/\text{m}^3$ and $95.4 \mu\text{g}/\text{m}^3$ – $202.7 \mu\text{g}/\text{m}^3$ for pools 1 and 2 respectively. For S2, the concentration of tTHM was in the range of $448.3 \mu\text{g}/\text{m}^3$ – $781.7 \mu\text{g}/\text{m}^3$ and $210.6 \mu\text{g}/\text{m}^3$ – $638.7 \mu\text{g}/\text{m}^3$ for pools 3 and 4 respectively.

For both S1 and S2, the concentrations measured at 0.60 m and 1.50 m above the water surface were almost identical. In S1, the concentrations were measured from $89.2 \mu\text{g}/\text{m}^3$ – $199.7 \mu\text{g}/\text{m}^3$. Former studies that measured the concentration of tTHM at the same heights found values between $44.0 \mu\text{g}/\text{m}^3$ – $260.8 \mu\text{g}/\text{m}^3$ (Fantuzzi *et al.* 2010; Richardson *et al.* 2010; Lourencetti *et al.* 2012; Chowdhury 2015; Marco *et al.* 2015; Manasfi *et al.* 2017a, 2017b). In S2, higher values

were found, ranging from $205.0 \mu\text{g}/\text{m}^3$ – $676.1 \mu\text{g}/\text{m}^3$. High concentrations were also measured in other studies (Bessonneau *et al.* 2011; Tardif *et al.* 2016). However, the mean concentrations of tTHM obtained in these studies were lower compared to the mean concentrations measured in S2. As shown in Figure 1, the average concentrations of tTHM measured at 0.05 m above the water surface showed, above pool 1, 71%, and above pool 3, 25% higher values than the corresponding value measured 1.50 m above the water surface. The samples collected 0.05 m and 1.5 m above pool 2 and pool 4 did not vary as much, probably because these pools are located closer to the air supply channels in the pool room.

As shown in Table 2, TCM was found to be the dominant compound in S1 (between 97% and 99%), followed by BDCM. In S2, all four THMs were present in all samples and as for S1, TCM was found to be the dominant compound. However, in pool 4 (100% freshwater pool), tTHM in the air comprised 25% brominated THMs. Higher fractions of brominated THMs in the air above pool 3 were anticipated, due to the source water quality (mixture of 33% seawater and 67% freshwater). For this seawater pool (pool 3), the fraction of brominated THM in air samples was 55.6% (0.05 m), 40.9% (0.60 m) and 39.0% (1.50 m). Past studies have reported approximately 95% brominated THMs in seawater pools (Parinet *et al.* 2012; Chowdhury 2015). In a former study where THMs above one pool containing seawater were measured, TBM was found to account for 85% (0.60 m) of tTHM (Chowdhury 2015). In pool 3, a smaller amount of brominated THMs was found to be possible due to there being only 33% seawater in the pool. A former study found that even small amounts of salt can increase the amount of bromide present in the water significantly (Ged & Boyer 2014). As brominated THMs were found to represent approximately 25% of

Table 2 | Average chemical-physical parameters and number of bathers of swimming pool waters for each activity in S1 and S2

| Pool, Facility | Activity | n | RH (%) | pH | F _{chlorine} (mg/L) | B _{chlorine} (mg/L) | No. of bathers | T _{air} (°C) | T _{water} (°C) | tTHM, ($\mu\text{g}/\text{m}^3$) |
|----------------|------------------|----|--------|-----|------------------------------|------------------------------|----------------|-----------------------|-------------------------|------------------------------------|
| Pool 2, S1 | Morning swimming | 11 | 66.4 | 7.5 | 1.26 | 0.20 | 2.2 | 27.5 | 33.0 | 145.8 |
| Pool 2, S1 | Baby swimming | 12 | 60.3 | 7.5 | 1.15 | 0.23 | 14.3 | 28.3 | 33.1 | 122.4 |
| Pool 1, S1 | Public swimming | 18 | 57.2 | 7.3 | 0.82 | 0.21 | 13.4 | 27.9 | 26.7 | 168.4 |
| Pool 4, S2 | Morning swimming | 14 | 57.5 | 7.2 | 0.99 | 0.20 | 25.2 | 31.8 | 34.2 | 435.5 |
| Pool 4, S2 | Baby swimming | 12 | 58.8 | 7.2 | 0.99 | 0.20 | 41.4 | 31.2 | 34.1 | 267.3 |
| Pool 3, S2 | Public swimming | 15 | 66.8 | 7.3 | 0.49 | 0.04 | 15.6 | 29.0 | 28.6 | 528.1 |

n: samples of tTHM, RH: relative humidity, F_{chlorine}: free chlorine, B_{chlorine}: combined chlorine, T_{air}: air temperature, T_{water}: water temperature, tTHM: average concentration (all heights).

Table 3 | THM concentrations in $\mu\text{g}/\text{m}^3$ for the different swimming pools and different heights

| Height (m) | THM | n | AM ($\mu\text{g}/\text{m}^3$) | SD ($\mu\text{g}/\text{m}^3$) | Min ($\mu\text{g}/\text{m}^3$) | Max ($\mu\text{g}/\text{m}^3$) |
|----------------------------------|------|----|------------------------------------|------------------------------------|-------------------------------------|-------------------------------------|
| Pool 1, S1 (sports pool) | | | | | | |
| 0.05 | tTHM | 6 | 230.9 | 57.7 | 162.5 | 316.4 |
| | TCM | 6 | 224.3 | 55.0 | 160.0 | 306.6 |
| | BDCM | 6 | 6.6 | 2.8 | 2.5 | 9.7 |
| 0.60 | tTHM | 6 | 139.5 | 36.9 | 99.7 | 199.7 |
| | TCM | 6 | 137.5 | 36.2 | 98.4 | 196.5 |
| | BDCM | 6 | 2.1 | 0.7 | 1.4 | 3.2 |
| 1.50 | tTHM | 6 | 134.9 | 28.1 | 99.4 | 179.4 |
| | TCM | 6 | 133.2 | 28.5 | 97.9 | 179.4 |
| | BDCM | 6 | 2.2 | 0.8 | 1.4 | 3.4 |
| Pool 2, S1 (therapy pool) | | | | | | |
| 0.05 | tTHM | 8 | 141.9 | 39.5 | 95.9 | 202.7 |
| | TCM | 8 | 139.4 | 38.6 | 94.8 | 198.8 |
| | BDCM | 8 | 2.4 | 1.2 | 1.1 | 3.9 |
| 0.60 | tTHM | 7 | 129.3 | 27.7 | 96.7 | 173.2 |
| | TCM | 7 | 127.1 | 27.3 | 95.1 | 171.2 |
| | BDCM | 7 | 2.2 | 1.9 | 0.6 | 6.2 |
| 1.50 | tTHM | 8 | 129.1 | 39.5 | 89.2 | 170.4 |
| | TCM | 8 | 127.2 | 29.6 | 89.2 | 168.4 |
| | BDCM | 8 | 1.9 | 1.4 | <LOQ | 4.3 |
| Pool 3, S2 (sports pool) | | | | | | |
| 0.05 | tTHM | 5 | 606.0 | 128.5 | 448.3 | 781.7 |
| | TCM | 5 | 268.4 | 96.5 | 158.8 | 415.7 |
| | BDCM | 5 | 55.3 | 12.7 | 38.4 | 70.4 |
| | DBC | 5 | 30.4 | 6.1 | 24.4 | 38.4 |
| | TBM | 5 | 251.9 | 54.8 | 174.0 | 318.9 |
| 0.60 | tTHM | 5 | 492.5 | 114.2 | 366.5 | 676.1 |
| | TCM | 5 | 290.7 | 108.4 | 201.7 | 476.2 |
| | BDCM | 5 | 58.1 | 14.8 | 42.0 | 77.4 |
| | DBC | 5 | 19.9 | 3.6 | 15.3 | 24.4 |
| | TBM | 5 | 123.8 | 25.8 | 101.0 | 165.2 |
| 1.50 | tTHM | 5 | 485.9 | 112.5 | 372.4 | 657.4 |
| | TCM | 5 | 296.1 | 103.2 | 205.8 | 468.6 |
| | BDCM | 5 | 59.5 | 12.9 | 46.5 | 75.8 |
| | DBC | 5 | 18.9 | 3.2 | 15.5 | 22.5 |
| | TBM | 5 | 111.3 | 23.3 | 92.5 | 318.9 |
| Pool 4, S2 (therapy pool) | | | | | | |
| 0.05 | tTHM | 8 | 397.3 | 145.5 | 210.6 | 638.4 |
| | TCM | 8 | 296.7 | 113.2 | 153.5 | 476.6 |
| | BDCM | 8 | 58.9 | 21.6 | 31.4 | 94.1 |
| | DBC | 8 | 10.6 | 4.1 | 4.6 | 16.8 |
| | TBM | 8 | 31.2 | 11.0 | 21.1 | 51.1 |
| 0.60 | tTHM | 10 | 338.4 | 107.4 | 205.0 | 508.8 |
| | TCM | 10 | 251.5 | 86.0 | 140.7 | 400.0 |
| | BDCM | 10 | 47.5 | 11.8 | 32.8 | 69.3 |
| | DBC | 10 | 8.7 | 3.0 | 4.9 | 12.9 |
| | TBM | 10 | 30.6 | 10.7 | 17.9 | 50.4 |
| 1.50 | tTHM | 8 | 342.9 | 109.8 | 210.9 | 492.9 |
| | TCM | 8 | 258.4 | 86.9 | 152.9 | 372.6 |
| | BDCM | 8 | 46.0 | 13.5 | 28.0 | 68.8 |
| | DBC | 8 | 8.5 | 3.4 | 4.0 | 16.8 |
| | TBM | 8 | 31.2 | 11.3 | 21.1 | 49.9 |

tTHMs in pool 4 (a freshwater pool), brominated THMs seem to be associated with the use of sodium hypochlorite for water treatment, possibly due to bromide ions in the brine used to produce sodium hypochlorite.

The distribution of THMs

Table 2 shows the average concentration of combined chlorine in pool 3 (seawater pool) was measured to be 0.04 mg/L, which is lower compared to the concentration of combined chlorine measured in the other pools. In pool 3, UV treatment is used as a secondary disinfectant, and it is well known that UV treatment lamps might reduce the concentration of combined chlorine in the pool water (Cassan *et al.* 2006). This could, to some extent, explain the low concentration of combined chlorine in pool 3, but UV treatment is also used in pool 2 and 4 where the level of combined chlorine was much greater (0.20 mg/L–0.23 mg/L). Since pool 3 contains 33% seawater, it is likely that high concentrations of bromide are present in the water. When chlorine is added to bromide-rich waters, bromide ions oxidise, yielding hypobromous acid (Taylor 2006). If hypobromous acid reacts with ammonia in the water, this might form bromamines. Most European guidelines only regulate the concentration of free and combined chlorine in the water; it may be questioned whether brominated compounds should also be regulated in bromide-rich waters.

For pool 3, little difference between the concentrations of TCM was measured between the three heights, while the concentration of TBM was measured to be 226% higher at 0.05 m compared to 1.50 m above the water surface. TBM is less volatile than TCM (Beech *et al.* 1980), and it was therefore expected that higher concentrations of TBM would be found directly above the pool water surface. These findings emphasize how important it is to measure as close to the water surface as possible, especially considering the increased genotoxicity related to brominated compounds (Manasfi *et al.* 2017a, 2017b). As stated above, significantly higher concentrations of tTHM were measured in S2 compared to S1 (on average 282%). In a former study, a strong correlation was found between the number of users in the swimming pool and the concentration of tTHM (Chu & Nieuwenhuisen 2002). However, for S2, the correlation was found to be significantly negative. In S1, no correlation was obtained. Presence of brominated compounds is found

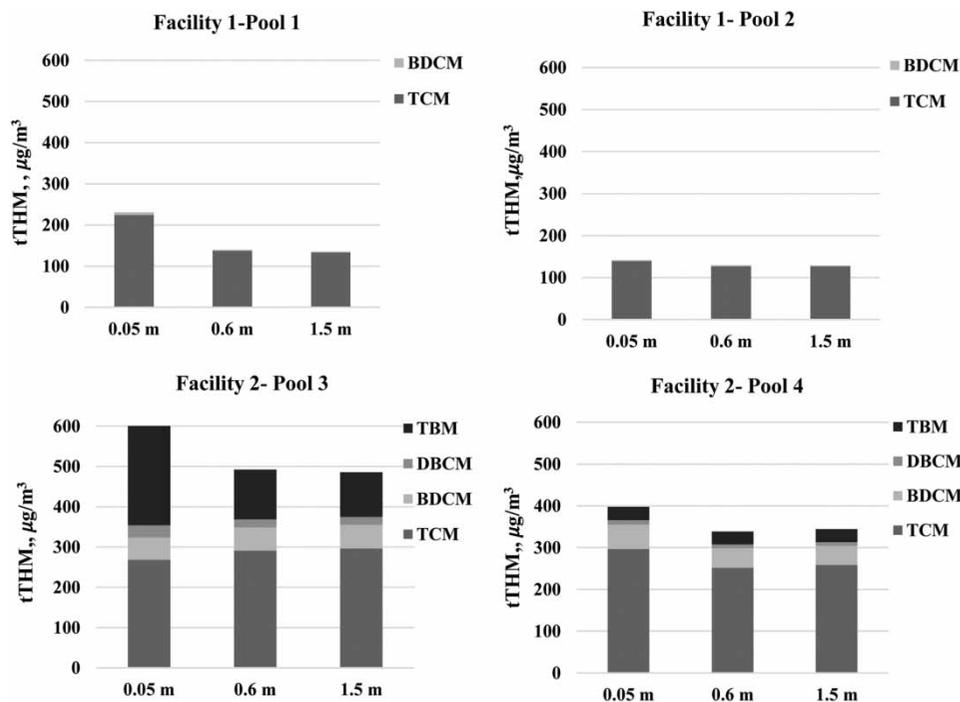


Figure 1 | The average concentration of tTHM measured at the different heights above the four swimming pools.

to increase the amount of tTHMs (Hua *et al.* 2006; Ged & Boyer 2014), this could, to some extent, explain the high concentration of tTHM in S2. However, this hypothesis should be further tested before any conclusions are made. Differences in ventilation are another possible explanation for this wide range of tTHM concentrations. S1 and S2 use the same type of ventilation system, and the air changes per hour of fresh air are almost equal for both facilities. However, slides, fountains, the wave pool and higher air- and water temperature in S2 are activities likely to promote the dispersion of tTHMs to the air. A higher amount of fresh air may be needed to compensate for the increased disturbance in the water surface and increased air and water temperature.

In S1 and S2, samples collected during morning swimming showed on average 19% and 60% higher values of tTHM compared to corresponding values measured during baby swimming in the afternoon. These values are calculated based on the days where no samples were excluded. This finding can be associated with the use of a night mode in the ventilation system. Night mode ventilation equals approximately 70% of day mode air flow ventilation, and during the night less fresh air is supplied. Measurements carried out on Mondays were found to be higher compared

to Wednesdays and Fridays. This is associated with high occupancy during weekends and constant ventilation flow-rate, regardless of the number of visitors. This underlines the importance of a flexible and good ventilation strategy.

CONCLUSION

In this study, concentrations of brominated THMs in the air appear to be much higher when sodium hypochlorite is used for water treatment. Regardless of whether calcium hypochlorite or sodium hypochlorite is used for water treatment, the concentration of tTHMs was measured to be higher in the breathing zone of the swimmers in the pool compared to 1.50 m above the floor. The levels of TBM above the pool with 33% seawater were measured to be much higher (226%) at 0.05 m compared to 1.50 m. Considering the increased genotoxicity of this compound, it is crucial to measure as close to the water surface as possible, especially when brominated THMs are present. More attention should be paid to TBM in swimming pool air, as this compound could potentially cause severe effects to human health. Increased attention should also be paid to the

effect of the supplied amount of fresh air and air distribution to reduce the concentration of the volatile DBPs.

REFERENCES

- Beech, J. A., Dia, Z. R., Ordaz, C. & Palomeque, B. 1980 Nitrates, chlorates and trihalomethanes in swimming pool water. *American Journal of Public Health* **70** (1), 79–82.
- Bessonneau, V., Derbez, M., Clément, M. & Thomas, O. 2011 Determinants of chlorination by-products in indoor swimming pools. *International Journal of Hygiene and Environmental Health* **215** (1), 76–85.
- Bouland, S., Duguet, J. P. & Montiel, A. 2005 Evaluation of bromate ions level introduced by sodium hypochlorite during post-disinfection of drinking water. *Environmental Technology* **26** (2), 121–126.
- Cassan, D., Mercier, B., Castex, F. & Rambaud, A. 2006 Effects of medium-pressure UV lamps radiation on water quality in a chlorinated indoor swimming pool. *Chemosphere* **62** (9), 1507–1513.
- Chen, M.-J., Lin, C.-H., Duh, J.-M., Chou, W.-S. & Hsu, H.-T. 2011 Development of a multi-pathway probabilistic health risk assessment model for swimmers exposed to chloroform in indoor swimming pools. *Journal of Hazardous Materials* **185** (2–3), 1037–1044.
- Chowdhury, S. 2015 Predicting human exposure and risk from chlorinated indoor swimming pool: a case study. *Environmental Monitoring and Assessment* **187** (8), 502.
- Chu, H. & Nieuwenhuijsen, M. J. 2002 Distribution and determinants of trihalomethane concentrations in indoor swimming pools. *Occupational and Environmental Medicine* **59**, 243–247.
- Fantuzzi, G., Righi, E., Predieri, G., Giacobazzi, P., Mastroianni, K. & Aggazzotti, G. 2010 Prevalence of ocular, respiratory and cutaneous symptoms in indoor swimming pool workers and exposure to disinfection by-products (DBPs). *International Journal of Environmental Research and Public Health* **7** (4), 1379–1391.
- Ged, E. C. & Boyer, T. H. 2014 Effect of seawater intrusion on formation of bromine-containing trihalomethanes and haloacetic acids during chlorination. *Desalination* **345**, 85–95.
- Hua, G., Reckhow, D. A. & Kim, J. 2006 Effect of bromide and iodide ions on the formation and speciation of disinfection byproducts during chlorination. *Environmental Science & Technology* **40** (9), 3050–3056.
- International Organization for Standardization 2000 ISO 16017-1:2000(E) indoor, ambient and workplace air – Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography (Vol. ISO 16017-1:2000(E)).
- Kogevinas, M., Villanueva, C. M., Font-Ribera, L., Liviach, D., Bustamante, M., Espinoza, F., Nieuwenhuijsen, J., Espinosa, A., Fernandez, P., DeMarini, D. M., Grimalt, J. O., Grummt, T. & Marcos, R. 2010 Genotoxic effects in swimmers exposed to disinfection by-products in indoor swimming pools. *Environmental Health Perspectives* **118** (11), 1531–1537.
- Lourencetti, C., Grimalt, J. O., Marco, E., Fernandez, P., Font-Ribera, L., Villanueva, C. M. & Kogevinas, M. 2012 Trihalomethanes in chlorine and bromine disinfected swimming pools: air-water distributions and human exposure. *Environment International* **45**, 59–67.
- Manasfi, T., De Méo, M., Coulomb, B., Di Giorgio, C. & Boudenne, J.-L. 2016 Identification of disinfection by-products in freshwater and seawater swimming pools and evaluation of genotoxicity. *Environment International* **88**, 94–102.
- Manasfi, T., Coulomb, B. & Boudenne, J.-L. 2017a Occurrence, origin, and toxicity of disinfection byproducts in chlorinated swimming pools: an overview. *International Journal of Hygiene and Environmental Health* **220** (3), 591–603.
- Manasfi, T., Temime-Roussel, B., Coulomb, B., Vassalo, L. & Boudenne, J.-L. 2017b Occurrence of brominated disinfection byproducts in the air and water of chlorinated seawater swimming pools. *International Journal of Hygiene and Environmental Health* **220** (3), 583–590.
- Marco, E., Lourencetti, C., Grimalt, J. O., Gari, M., Fernández, P., Font-Ribera, L. & Kogevinas, M. 2015 Influence of physical activity in the intake of trihalomethanes in indoor swimming pools. *Environmental Research* **140**, 292–299.
- Norwegian Ministry of Health 1996 Regulations for swimming facilities, swimming pools and sauna.
- Parinet, J., Tabaries, S., Coulomb, B., Vassalo, L. & Boudenne, J.-L. 2012 Exposure levels to brominated compounds in seawater swimming pools treated with chlorine. *Water Research* **46** (3), 828–836.
- Richardson, S. D., DeMarini, D. M., Kogevinas, M., Fernandez, P., Marco, E., Lourencetti, C., Ballesté, C., Heederik, D., Meliefste, K., McKague, A. B., Marcos, R., Font-Ribera, L., Grimalt, J. O. & Villanueva, C. M. 2010 What's in the pool? A comprehensive identification of disinfection by-products and assessment of mutagenicity of chlorinated and brominated swimming pool water. *Environmental Health Perspectives* **118** (11), 1523–1530.
- Tardif, R., Catto, C., Haddad, S., Simard, S. & Rodriguez, M. 2016 Assessment of air and water contamination by disinfection by-products at 41 indoor swimming pools. *Environmental Research* **148**, 411–420.
- Taylor, C. J. L. 2006 The effects of biological fouling control at coastal and estuarine power stations. *Marine Pollution Bulletin* **53**, 30–48.
- United States Environmental Protection Agency 1999 Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air.
- World Health Organization 2006 Guidelines for safe recreational water environments. Volume 2: swimming pools and similar environments.