Parameters Affecting Indoor Air Exposure to Volatile Organic Compounds

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Abstract

Volatile organic compounds(VOCs) present in the VOCs-contaminated water are released to air while showering and their air concentrations depend on the shower parameters, resulting in the variation of the VOCs breath concentration. The present study evaluated the key shower parameters(water temperature and inhalation duration) that affect the inhalation exposure to air chloroform while showering, by determining chloroform breath concentration. The chloroform breath concentrations increased with water temperature and inhalation duration increase. The two inhalation exposure conditions which resulted in the greatest chloroform breath concentration difference were a 5 min-inhalation exposure with warm water and a 15 min-inhalation exposure with hot water. The chloroform breath concentration was almost three times higher after later exposure. The mathematical model analyzing the relationship between two key shower parameters and breath concentration normalized to water concentration fits quite well with the experimental data at a probability of $p = 0.0001$.

KEY WORDS: VOCs, inhalation exposure, shower parameter, inhalation duration, breath concentration, chloroform

1. INTRODUCTION

Exposures to indoor volatile organic pollutants have been shown to exceed those from the ambient environment when indoor sources are suspected(Wallace et al., 1984; Wallace et al., 1987). One source of volatile organic compounds is the use of municipal tap water. Chlorinated water contains microgram per liter quantities of trihalomethanes(THMs), which are formed as by-products of the chlorination process(Krasner et al., 1989). Recently, several studies(Cothern et al., 1985; Andelman, 1985[a]; Andelman, 1985[b]; Weiss, 1985; Jo, et al., 1990[a]; Jo, et al., 1990[b]) indicated that exposure to VOC which are released from water to indoor air may be as large as or larger than exposure from ingestion alone.

Showering, the largest indoor source of chloroform for the typical daily human activities associated with the use of chlorinated water, exposes individuals to elevated concentrations of THMs in the air within the confined space of the shower. The elevated VOCs concentration in shower air depends on the shower parameters(Andelman et al., 1986; Weiss, 1985; Jo, et al., 1990[c]). These include: the mass transfer coefficient between shower water and shower air for each chemical, water temperature, contaminant concentration, shower duration, water flow rate, shower head spray setting, height of shower water drop path, and level of ventilation. Among these, the key parameters that can vary are: shower water temperature, shower duration, and shower water concentration. The present study evaluated the effects of two parameters(shower duration and water temperature) on shower air chloroform concentration by determining breath concentrations prior to and after inhalation exposure to shower air chloroform, with the variation of the water concentration.

2. METHODOLOGY

2.1. Sampling

Exhaled breath samples were collected from subjects by having them breathe through a non-rebreathing two-way valve attached to a Teflon sampling bag. The subjects were supplied with purified, humidified air through the valve from an inhalation bag. Breath from the collection bag was transferred to a Tenax-packed trap. Water samples were collected from the tap in the same room as the model shower using clean 50 mL vials, following EPA Method 502.1(1981).

2.2. Analysis

The breath samples were analyzed using a thermal desorbing system (furnace, Tekmar Co.) and a gas chromatograph(GC, Varian Model 3700) with electrolytic conductivity detector(Tracor Model 700) for halogen-specific compounds. The column used was a packed column with 100.8 inch long x 0.007 inch ID SS, SP-1000 and 60/80 Carbopak B). The flowrate of the carrier gas(helium) was adjusted to 32 cc/min. The GC oven temperature was programmed from 45 ℃ to 200 ℃ at a rate of 10 ℃/min. The column injection temperature was 90 ℃. The furnace temperature of the detector was fixed to 950 ℃. Propanol(Spectra grade, Fisher Scientific) was used as the electrolytic solution. The conductivity of the detector was set to 100.

2.3. Quality Assurance

A blank and an external standard were analyzed daily to monitor the response of the GC. Typically, the blank concentrations were below the detection limits thus any response indicated contamination in the system. The response of an external standard was compared with the value calculated from a calibration equation. If the response differed by more than 20%, a new calibration equation was determined. The precision of the desorption and water analytical systems for chloroform were 13% and 10%, respectively. The minimum detection limits(MDLs) of the breath and water analytical system were 13 ng and 0.65 ug/L, respectively.

2.4. Experiment

A model shower, constructed of SS, was used to evaluate the effect of water temperature and duration of inhalation exposure on the air concentration by measuring the breath concentration. Water was sprayed within the chamber using a standard shower head at two temperature, 34℃ and 41℃, and the subject breathed the air from chamber for 5, 10, or 15 minutes. All other controllable parameters were fixed for the experiment including: the water flowrate(8.7 L/min), shower head setting, ventilation system being off and post exposure delay prior to the collection of a breath sample(5 minutes). The chloroform water concentration was measured whenever a breath sample was collected.

Thirty inhalation exposures were taken through a model shower system. The exposures were taken by twelve subjects(ten males and two females). Five exposures were taken for each of six different shower conditions. The subjects were randomly selected for each exposure. All consecutive exposures taken on the same day were taken using different subjects with at least 3 hours separating an experiment. No subject took more than one inhalation exposure in a day. The subject was exposed only to gaseous chloroform vaporized from shower tap water in the model chamber through the mouthbit connected to the chamber.

Table 1. Breath concentrations normalized to tap water concentrations((ug/m3)/(ug/L)) obtained after inhalation exposures for warm water(33.6℃) and three inhalation durations.

Replicate Number	Inhalation Duration		
	5 min	10 min	15 min
1	0.25	0.35	0.58
2	0.25	0.46	0.66
3	0.32	0.47	0.76
4	0.33	0.54	0.76
5	0.38	0.58	0.93

Table 2. Breath concentrations normalized to tap water concentrations((ug/m^3)/(ug/L)) obtained after inhalation exposures for hot water(40.8℃) and three inhalation durations.

Replicate Number	Inhalation Duration		
	5 min	10 min	15 min
1	0.33	0.57	0.65
2	0.39	0.58	0.82
3	0.41	0.62	0.84
4	0.46	0.65	0.99
5	0.47	0.69	1.03

3. RESULTS

As shown in Tables 1 and 2, the breath concentrations normalized to tap water concentrations were calculated for six shower concentrations based on the inhalation duration and water temperature. Chloroform was not detected in any of the breath samples prior to the inhalation only exposures.

Using analysis of Variance(ANOVA) and Duncan's Multiple Range Test, comparisons were made for the normalized breath concentrations obtained from the six shower conditions. Two-way ANOVA compared inhalation duration and water temperature effects on chloroform breath concentration. The F-test from two-way ANOVA indicates that the difference of chloroform breath concentrations obtained after inhalation exposures using warm water and hot water was significant at a probability of $p=0.0017$. Inhalation duration effect on chloroform breath concentration from the exposure was also significant at a probability of $p=0.0001$.

Once the duration and temperature effects were found to be significant with chloroform breath concentration from two-way ANOVA, Duncan's Multiple Range Test was used to compare the six shower conditions separately. The test grouped the six shower conditions differently. The two inhalation exposure conditions which resulted in the greatest chloroform breath concentration difference were a 5 min-inhalation exposure with warm water and a 15 min-inhalation exposure with hot water. The chloroform breath concentration was almost three times higher than after later exposure.

A linear model was developed to establish the relationship between the shower parameters and breath concentration normalized to water concentration using the data shown in Table 1 and Table 2. The R-square value obtained from the model indicates that there is a strong relationship between the shower factors and the normalized breath concentration. The model is:

Warm Water Temperature

$C_{bw}=0.076+0.043\times T$ with $R^2=0.80$ for $p=0.0001$ (3.1)

Hot Water Temperature

$C_{bh}=0.18+0.045\times T$ with $R^2=0.81$ for $p=0.0001$ (3.2)

where C_{bw} = breath concentration normalized to water concentration after inhalation exposure with warm water((ug/m3)/(ug/L)),

C_{bh} = breath concentration normalized to water concentration after inhalation exposure

with hot water((ug/m3)/(ug/L)),
T =inhalation duration(min)

4. DISCUSSION

The results of this study comfirm that chloroform released from water to air during showering enters human body. This entrance can be described by a hypothesis that there is a net absorption of chloroform by the body during showering since the exchange of chloroform between alveolar air and blood across the lung/capillary interface is based on an equilibrium process.

As shown in Tables 1 and 2, breath concentration obtained after inhalation exposure increased with water temperature and inhalation duration. The effect of water temperature on the chloroform breath concentration is explained based on the increase of shower air concentration with water temperature. Since the mass transfer coefficient for chloroform increases as temperature increases, the volatilization will increase (Andelman et al., 1986), resulting in an elevation of the chloroform concentration in the shower air with higher water temperature(Andelman et al., 1986; Weiss, 1985). The resulting chloroform breath concentration will be higher at higher water temperature than at lower water temperature.

Inhalation duration effects on chloroform breath concentration from inhalation exposure can be explained based on the increase of shower air concentration and the increase of the amount of shower air inhaled with the longer duration.

While the present study considerd the maximum shower duration as 15 minutes, some old people are believed to take shower more than 15 minutes. Extrapolating the equation 3.1 to 30 minute showers, the chloroform breath concentration normalized to water concentration after inhalation exposure was estimated to be 1.53 (ug/m^3)/(ug/L). The estimate is 3.7 times higher than the normalized breath concentration obtained for a 5 minutes inhalation exposure at the same water temperature. This estimate implies that the old who take longer daily showers may have more cancer risk from showers with VOC contaminated water due to the higher shower air concentration and their physiological state.

5. CONCLUSIONS

Individuals are exposed to chloroform from daily showers when using chlorine-treated municipal tap water, due to the increased chloroform in air resulting from the release of chloroform from water to air. Lower water temperature, shorter shower duration, and less contaminated water use are suggested to minimize the exposure to VOC in air resulting from showers.

The mathematical model, between two key shower parameters and breath concentration normalized to water concentration, fits quite well with the data at a probability of $p = 0.0001$. Thus this model is considered useful to estimate the chloroform breath concentration by only measuring environmental parameters rather than a person.

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휘발성 유기화합물에 대한 실내공기노출에 영향을 미치는 인자

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수중에 존재하는 휘발성 유기화합물은 샤워를 하는동안 공기로 방출되고 공기농도는 샤워변수에 따라 달라지는데, 이는 휘발성 유기화합물의 호기농도의 변화를 야기 시킨다. 본 연구에서는 샤워를 하는 동안 공기중의 클로로포름 노출에 영향을 미치는 주요한 샤워변수(물온도 및 노출시간)를 클로로포름 호기농도를 측정하여 검토 하였다. 클로로포름 호기농도는 물의 온도와 노출 시간이 증가함에 따라 증가 하였다. 가장 큰 클로로포름 호기농도 차이를 나타내는 두개의 흡기 노출 조건은 미지근한 물을 이용한 5분 동안의 노출과 더운 물을 이용한 15분 동안의 노출이었다. 클로로포름 호기농도는 후자의 노출후에 전자의 경우보다 거의 3배 정도 높았다. 주요 샤워변수와 수중농도로 조정된 호기농도 사이의 수학모델은 0.0001의 확률에서 데이타와 훌륭한 일치되는 결과를 나타내었다.