韓國環境科學會誌 第3卷(第3號), 253~261, 1994
J. of the Korean Environmental Sciences Society

CHLOROFORM IN THE AIR OF INDOOR SWIMMING POOLS AND THE OUTDOOR AIR NEAR THE SWIMMING POOLS IN A CITY OF KOREA

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(Manuscript received 13 April 1994)

Abstract

Chloroform present in the swimming water disinfected with sodium hypochlorite is released to the air of swimming pools. The air chloroform concentrations were measured in two swimming pools A and B which applied both sodium hypochlorite and ozone. Their mean concentrations are 28.0 $\mu g/m^3$ and 33.6 $\mu g/m^3$ in the swimming pools A and B, respectively. On the other hand, the mean water chloroform concentrations in the swimming pools A and B were 23.9 $\mu g/\ell$ and 19.5 $\mu g/\ell$, respectively.

The air chloroform concentrations were lower in the swimming pools A and B than those reported by previous studies abroad employed the swimming pools which applied sodium hypochlorite only for water disinfection. The water chloroform concentrations were also lower in this study than in the previous studies. The relationship between the air and water chloroform concentrations measured in this study was significant with p=0.002 and R^2=0.42.

At similar time to the indoor air sampling, outdoor air samples were collected at two sites near each of the swimming pools A and B. The mean outdoor air chloroform concentrations near the swimming pools A and B were 0.41 $\mu g/m^3$ and 0.16 $\mu g/m^3$, respectively. The outdoor air chloroform concentrations measured in this study were equal to or lower than those reported by previous studies abroad.

The chloroform dose inhaled for a typical one-hour swim was estimated to be 25.9 μg per person, corresponding to a specific 0.37 μg/Kg body weight for a reference 70 Kg male adult, while the inhalation dose of chloroform from the outdoor air was estimated to be 5.6 μg per person per day, corresponding to a specific 0.08 μg/Kg/day for the same reference male adult.

Key word : Chloroform, swimming, sodium hypochlorite, inhalation, dose

1. Introduction

Volatile organic compounds(VOCs) in chlorinated water is released to air and is present at elevated levels in indoor air such as swimming pool and shower room air(Aggazzotti *et al.*, 1990; Andelman, 1985a; Andelman, 1985b; Andelman *et al.*, 1986; Jo *et al.*, 1990a; Jo *et al.*, 1990b; Jo *et al.*, 1990c; Lahl *et al.*, 1981; Wallace *et al.*, 1984; Wallace *et al.*, 1987). Swimmers can inhale VOCs released from chlorinated water to air of indoor swimming pools and then, have an elevated health risk from the VOCs(Aggazzotti *et al.*, 1990; Lahl *et al.*, 1981). Hence, inhalation exposure to VOCs in indoor swimming pools represents an additional source that must be accounted for when exposure levels to VOCs are considered.

The VOCs release depends on water temperature, air temperature, concentration in water, the number of swimmers, the time spent for swimming, and the intensity of air circulation in the pools(Lahl *et al.*, 1981; Aggazzotti *et al.*, 1990). Particularly, Aggazzotti *et al.*(1990) found some correlations in indoor swimming pools between the water and the air chloroform concentrations, and between the air chloroform concentrations and the number of swimmers. However, Lahl *et al.*(1981) found no significant relationships in swimming pools between the trihalomethanes(THMs) and the water THMs concentrations, indicating that other parameters like variance in ventilation hid this effect.

A recent concern with the health risks from exposure to VOCs has been increased(Wallace, 1982; Shah and Singh, 1988; Summerhays, 1991; Berkley *et al.*, 1991; Hisham and Grosjean, 1991). VOCs have been measured in ambient air throughout the United States(Hisham and Grosjean, 1991; Wallace, 1982; Wallace *et al.*, 1984; Wallace *et al.*, 1985; Wallace *et al.*, 1987; Wallace *et al.*, 1991) and the data have been systematically organized(Shah and Singh, 1988; Edgerton *et al.*, 1989). However, there are very limited data for the VOCs in urban air of Korea, mainly because National Ambient Air Quality Standards of Korea are nonexistent for VOCs.

Chloroform is one of ubiquitous toxic VOCs measured in the air of the United States (Wallace, 1982; Wallace, 1984; Wallace, 1985; Wallace, 1987). Chloroform is carcinogenic to rats and mice(Bethesda, 1976; Roe *et al.*, 1979; Jorgenson *et al.*, 1985) and the International Agency for Research on Cancer(IARC) has classified chloroform as a probable human carcinogen(Group 2B)(IARC, 1979). Similarly, the United States Environmental Protection Agency(USEPA) has placed chloroform in Group B2 in their classification scheme, based on sufficient evidence of carcinogenicity in animals, but inadequate epidemiologic evidence.

This study is designed to examine chloroform levels in the air of swimming pools and the outdoor air at the residential areas near the swimming pools in a city of Korea, to estimate corresponding inhalation exposures to the chloroform levels, and to examine the relationships of the air chloroform concentrations with the water chloroform concentrations in swimming pools.

2. Methodology

2.1. Study Design

For this study, two indoor swimming pools(A and B) which used both sodium hypochlorite and ozone for water disinfection were selected in a city of Korea. Table 1 summarizes the number of indoor and outdoor air, and water samples taken between February 19, 1994 and March 26, 1994. The air samples were collected at 15 to 20 cm in height above the water surface at the edge of the pool.

Outdoor air samples were collected at a residential site near each pool(70 m to 100 m distance from the swimming pool) for two purposes. One is to examine chloroform levels in outdoor air at the residential areas near the

Table 1. The numbers of indoor and outdoor air, and water samples collected in two swimming pools.

Swimming Pool	No. of Indoor Air Samples	No. of outdoor Air Samples	No. of of Water Samples Prior to^a	No. of Water Samples after^b
A	10	10	10	6
B	10	9	10	7

* Superscripts a and b represent prior to and after air sampling, respectively.

swimming pools. The other is to estimate background chloroform levels in the air of the swimming pools. The ambient air samples were collected at the human breathing zone.

Prior to and right after the indoor air sampling, water samples were collected to understand the effects of water chloroform concentration on indoor air chloroform concentrations of the swimming pools. The water chloroform concentrations were averaged for the two water samples collected prior to and after air sampling, and the average was used for the regression analysis on the indoor air and water chloroform concentrations. If only one of the two water samples was available, the one was used for the same purpose. At about the same time, the water temperatures were measured in the pools.

2.2. Sampling

The water samples were collected applying EPA method 502.1 (USEPA, 1981). Detailed sampling method is described in Jo's study(Jo, 1994).

Air samples were collected by drawing air through 1/4 inch(in.) outside diameter(O.D.) by 7 in. long stainless steel tubes with Tenax-GC adsorbent, using personal air samplers(AMTEK MG-4). Flowrates for outdoor air samples were set between 225 ml/min and 290 ml/min for an hour, and the volumes collected ranged from 13.5 liter to 15.9 liter, which were determined by considering the sensitivity of the analytical system and the breakthrough volumes of chloroform. Indoor air samples were collected for 20 minutes at the flowrate set between 12.4 ml/min and 14.7 ml/min, and the volumes collected ranged from 248 ml to 294 ml.

2.3. Analysis

The air analytical system used in this study includes a thermal desorbing system(furnace, Tekmar Co.) and a gas chromatograph(GC, Hewlett Packard 5890 II) with an electron capture detector(ECD, Hewlett Packard) for halogen-specific compounds. A purge and trap system was added to the air analytical system for water analysis. Water samples were purged and trapped in the 1/4 in. O.D.-7 in. length Tenax-filled stainless steel(SS) tubes. Detailed analytical method for water sample is described in Jo's study(Jo, 1994).

2.4. Quality Assurance

Instrument performance was checked the same way as done in Jo's study(Jo, 1994). The precision of the water analytical system for chloroform based on the analyses of standards was estimated to be 15.9 %. The minimum detection limit(MDL) and recovery of the water analytical system were estimated to be 0.08 ug/L and 90.4 %, respectively. The precision of the air analytical system for chloroform based on the analyses of standards was estimated to be 10.6 %. The MDL and recovery of the air analytical system were 0.02 ug/m^3 and 88.7 %, respectively.

2.5. Statistical analyses

Using analysis of variance(ANOVA) and Duncan's Multiple Range test, comparisons were made for the water and the indoor air temperatures between in the swimming pool A and the swimming pool B, and for the air chloroform concentrations between in the two swimming pools. Another comparison was made for the outdoor air chloroform concentrations between in the two areas. A regression analysis was conducted on the indoor air and the water chloroform concentrations.

3. Results

Table 2 includes the summaries of chloroform levels in the air of swimming pools, and in the outdoor air near the pools. Based on the distribution of indoor air chloroform concentrations which were shown in Figure 1, a F-test was conducted and showed no significant difference of the chloroform levels between in the air of the swimming pools A(28.0$\pm$5.7 $\mu g/m^3$) and B(33.6$\pm$12.8)$\mu g/m^3$. However, a F-test used the data which were shown in Figure 2 indicated the outdoor air chloroform level(0.41$\pm$0.15 $\mu g/m^3$) near the swimming pool A was significantly (p=0.0001) different from that(0.16$\pm$0.05 $\mu g/m^3$) near the swimming pool B. The indoor air chloroform levels were about 70 folds and 240 folds higher than the corresponding outdoor air chloroform levels in the two areas, respectively.

The chloroform levels in the water of the swimming pools A and B are summarized in Table 2. A F-test used the water chloroform levels which were shown in Figure 3 showed that the chloroform level(23.9$\pm$6.6 $\mu g/\ell$) in the swimming pools A was not significantly different from that(19.5$\pm$7.5 $\mu g/\ell$) in the swimming pool B.

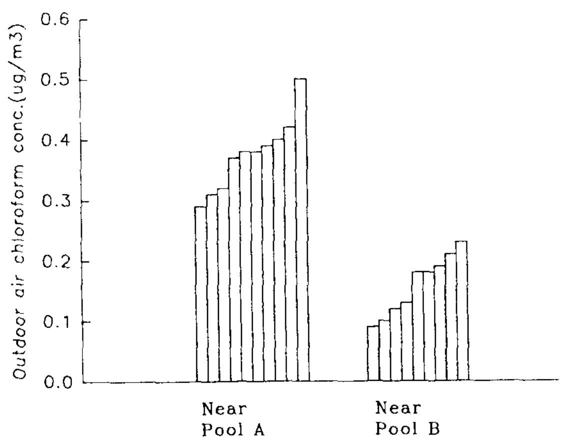

Fig. 2. Distribution of ten and nine outdoor air chloroform concentrations near swimming pools A and B, respectively.

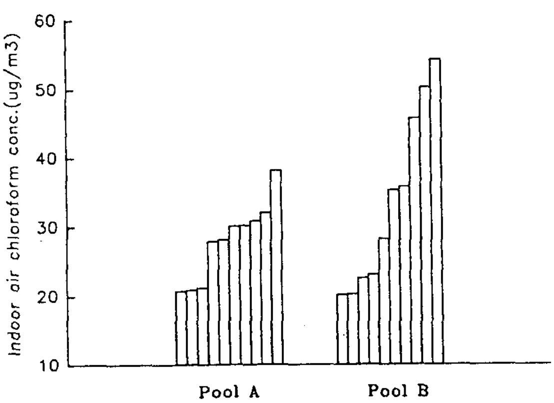

Fig. 1. Distribution of ten air chloroform concentrations measured in each of swimming pools A and B.

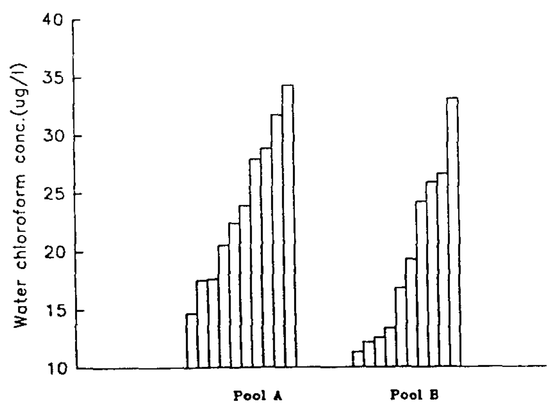

Fig. 3. Distribution of ten water chloroform concentrations measured in each of swimming pools A and B.

Table 2. Chloroform concentrations measured in the water and indoor air of swimming pools, and in the outdoor air near the pools.

Swimming Pool	Indoor Air Conc.(μg/m3)a	Outdoor Air Conc.(μg/m3)a	Water conc. (μg/ℓ)a	Water Temp.(oC)a
A	28.0+5.7	0.41+0.15	23.9+6.6	30.3+0.5
B	33.6+12.8	0.16+0.05	19.5+7.5	28.4+0.1

* Superscript, a, means arithmetic mean $\pm$ standard deviation.

A summary of water temperatures is shown in Table 2. The water temperatures were different with p=0.0001 between in the two swimming pools, with the difference of about 2 °C.

Figure 4 shows the relationships between the indoor air and the water chloroform concentrations. A regression analysis was conducted based on the data which were shown in the Figure 4. The analysis indicated significant correlations between the indoor air and the water chloroform concentrations with p=0.002 and R^2=0.42.

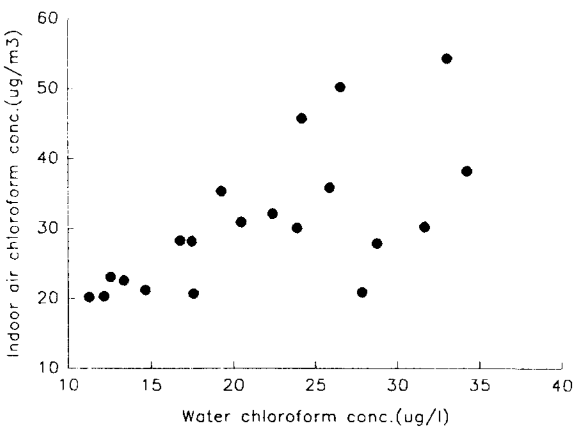

Fig. 4. Variation of air chloroform concentrations with the change of water chloroform concentrations in two swimming pools.

4. Discussion

The indoor air chloroform levels measured in two swimming pools in Korea were much less than those reported by the previous studies abroad(Aggazzotti *et al.*, 1990; Lahl *et al.*, 1981). The air chloroform levels in swimming pools A and B are 28.0±5.7 μg/m^3 and 33.6±12.8 μg/m^3, respectively. Recalculating Aggazzoti *et al.*'s results(1990), the air chloroform concentrations ranged from 66.1 μg/m^3 to 665 μg/m^3 directly above the water surface of swimming pools. In addition, Lahl(1981) reported that the typical air chloroform concentrations was a few 100 μg/m^3 directly above the water surface of swimming pools. The difference of air chloroform levels between in this study and the previous studies abroad can be explained by several swimming parameters which were described in the "Introduction" section. Practically, it is not easy to control and examine every swimming parameters in the real swimming pools. Hence, it was best tried using the limited information available to explain the difference above.

Water chloroform concentration is one of the most important parameters which influence the air chloroform concentration in swimming pools(Aggazzotti *et al.*, 1990; Lahl, 1981), and affected by the types of water disinfectants (Aggazzotti and Predieri, 1986). The water chloroform concentrations in the two swimming pools A and B(from 10.9 to 35.4 μg/ℓ) were lower than Lahl *et al.*'s(from 56 to 880 μg/ℓ) and Aggazzotti *et al.*'s(1990, from 16.9 to 47.1 μg/ℓ). The swimming pools used in the present study applied both sodium hypochlorite and ozone, while the swimming pools used in the two studies abroad applied sodium hypochlorite only for water disinfection. Based on the above, it was indicated that the types of water disinfectants caused at least partially the difference of air chloroform levels between in the present study and the two previous studies abroad.

A regression analysis showed that the air chloroform concentrations were significantly correlated with the water chloroform concentrations in the swimming pools, which was consistent with Aggazzotti *et al.*(1990)'s finding (R^2=0.55 and p was not reported). This supports the above, in that water chloroform concentration is one of most important parameters which influence the air chloroform concentration in swimming pools. However, the correlation intensity was not strong between the two data sets(R^2=0.42), implying that other parameters like variance in ventilation, water temperature, air temperature, would hid this effect.

The indoor air chloroform level measured in the swimming pool A was not statistically different from that of the swimming pool B for all sampling days. Three swimming parameters examined in the present study are used to explain the statistical result. First, the water chloroform concentrations were not different between in the two swimming pools. Second, both the swimming pools applied very similar disinfection processes. Lastly, water temperatures measured in the swimming pool A were higher than those in the swimming pool B, implying that more chloroform would be transferred from water to air(Andelman, 1986; Weiss, 1985) and then, higher air chloroform concentration would be caused in the pool A than in the pool B, which is not consistent with the statistical result. This indicates that the other parameters also should be examined to completely understand the statistical result.

Since the sampling sites were located at 70 m to 100 m far away from the swimming pools, it was assumed that the indoor air chloroform does not influence the outdoor air chloroform concentration. The assumption is supported by that even though the air chloroform levels were not significantly different between in the swimming pools A and B, the outdoor air chloroform levels were different between near the two pools. This indicates that other sources for chloroform influenced the outdoor air chloroform levels at the sampling areas. Hence, the outdoor air chloroform levels to be representative ones in the corresponding sampling areas and to be a background levels in the air of each swimming pools for the sampling days.

The outdoor air chloroform concentrations measured in the present study were almost equal to or lower than those measured in New Jersey and Los Angeles. The outdoor air chloroform levels measured near the swimming pools A and B were 0.41 ± 0.15 $\mu g/m^3$ and 0.16 ± 0.05 $\mu g/m^3$, respectively. Wallace *et al.*(1985) reported that the outdoor air chloroform level was 1.6 ± 0.3 $\mu g/m^3$ for daytime and 1.2 ± 0.2 $\mu g/m^3$ for night-time in New Jersey, in the fall of 1981. Another study done by Wallace *et al.*(1991) showed that the mean outdoor air chloroform levels were 0.47 $\mu g/m^3$ and 0.9 $\mu g/m^3$ for 24-hour air samples measured in Los Angeles in the winter and the summer of 1987, respectively. Using the mean outdoor air chloroform concentration(0.28 $\mu g/m^3$) in the present study, the inhalation dose to chloroform from the outdoor air was estimated to be 5.6 μg per person per day, corresponding to a specific 0.08 μg/Kg body weight for a reference 70 Kg male adult(Snyder *et al.,* 1984). For the estimation, a breathing rate of 20 m^3/day (Syneder *et al.,* 1984) and a chloroform absorption efficiency of 0.77(USEPA, 1980) were applied.

Swimmers inhale chloroform in the swimming pools disinfected with chlorine or other chlorine-containing disinfectants. In the present study, the resulting dose from a typical one-hour swim was estimated to be 25.9 μg per person, corresponding to a specific 0.37 μg/Kg body weight for a reference 70 Kg male adult(Snyder *et al.,* 1984). For this estimation, the 77% absorption efficiency was used for chloroform, which is the same value as used above. The typical swim takes account the respiration rate of 1 m^3/h for swimming(Lahl *et al.,* 1981), and the mean chloroform concentration(33.6 $\mu g/m^3$) of two swimming pools A and B. The estimated dose from a swim lies about 45-fold above the ingestion dose of chloroform estimated in Jo's study(Jo, 1994) for the same swim, and about 110-fold above the inhalation dose of outdoor air chloroform for the same exposure period.

5. Conclusions

The swimming parameters described in the previous section compensate each other, and determine the air chloroform levels in swimming pools. The disinfection of water with both sodium hypochlorite and ozone can lower the water chloroform concentrations in swimming pools and then, lower the indoor air chloroform concentrations, compared to the disinfection of water with sodium hypochlorite only.

There was a significant relationship between the water and air chloroform concentrations of the swimming pools. This confirms that water chloroform concentration is one of the most important parameters which influence the air chloroform concentration in swimming pools.

The inhalation exposure to chloroform from a swim in indoor swimming pool was estimated to be significantly higher than that from outdoor air for the same exposure period. This indicates that for the individuals who spend their time in similar environments, swimmers may have more health risk from the inhalation exposure, compared to non-swimmers.

Acknowledgements

It is my pleasure to express my thanks to the managers of the swimming pools for their cooperation. I also want to thank to Miss Gee H. Kang, a graduate student in the Departmet of Environmental Health Science, Hyosung Women's University, for outdoor air sample collection.

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국내 한 도시의 실내 수영장 공기 및 수영장 인근의 실외 공기에서의 클로로포름

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(1994년 4월 13일 접수)

차아염소산 나트륨으로 살균된 수영장 물에 존재하는 클로로포름은 수영장 내의 공기로 방출된다. 차아염소산 나트륨과 오존 모두를 이용하는 두개의 수영장에서 실내공기내에 존재하는 클로로포름 평균농도를 측정하였다: 수영장 A에서는 28.0±5.7 μg/m^3 그리고 수영장 B 에서는 33.6±12.8 μg/m^3. 덧붙여, 수영장 A 및 B의 물에서 측정된 클로로포름 평균농도는 각각 23.9±6.6 μg/ℓ 및 19.5±7.5 μg/ℓ 이었다.

수영장 A 및 B 의 실내공기내에 존재하는 클로로포름 농도들은 살균제로서 차아염소산 나트륨만을 사용한 수영장을 대상으로 측정한 외국의 이전 연구에서 보고된 결과보다 낮았다. 본 연구에서 측정된 물속의 클로로포름 농도도 외국의 이전 연구의 결과보다 낮게 나타났다. 수영장 물과 공기에 존재하는 클로로포름 농도는 서로 유의한 상관관계를 나타내었다($p=0.002$ and $R^2=0.42$).

실내 공기 시료채취와 유사한 시간에 실외 공기 시료가 각각 수영장 A와 B에 가까운 두개의 장소에서 채취되었다. 수영장 A 및 B 근처에서 측정된 실외 공기에서의 클로로포름 평균농도는 각각 0.41±0.15 μg/m^3 및 0.16±0.05 μg/m^3 이었다. 본 연구에서 측정된 실외 공기 내의 클로로포름 농도는 해외의 이전 연구들에서 보고된 값들과 동등하거나 작게 나타났다.

전형적인 한 시간 수영동안 흡기되는 클로로포름 흡취량은 일인당 25.9 μg 으로 추산되었고, 이는 70 Kg의 성인 남자를 기준으로 하여 0.37 μg/Kg 에 해당되는 흡취량이다. 반면에, 일인이 하루에, 실외 공기 흡입으로 인한 클로로포름의 흡취량은 5.6 μg 으로 추산되었고, 이는 동일한 성인 남자를 기준으로 할 때, 0.08 μg/Kg/day 에 해당한다.