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A Case Report on Fungal Contamination and Remediation in a Leakage-water Damaged Apartment

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요 약

이 사례연구는 누수가 있었던 고층 아파트의 공기중 진균 오염 실태를 조사하고, 이를 개선하기 위해 취해진 복원방법의 효과를 평가하기 위해 실시하였다. 공기중 진균은 주로 엔더슨 샘플러를 사용하여 측정하였다. 누수가 있었던 아파트의 복원 전 공기중 진균 농도는 매우 높았다(평균: 51,000 cfu/m^3, 기하평균: 40,163 cfu/m^3). 고농도의 오존처리와 오염된 벽체 철거 후 공기중 진균 농도는 상대적으로 매우 낮아졌으며(평균: 1,118 cfu/m^3, 기하평균: 899 cfu/m^3), 제거효율은 96.3%로 나타났다. 철거되지 않고 남아 있던 인근 벽체의 벽지를 제거하고 살진균제 처리를 실시한 결과, 공기중 진균 농도는 상대적으로 안전한 수준까지 낮아졌으며(평균: 95 cfu/m^3, 기하평균: 88 cfu/m^3), 제거효율은 99.7 %로 나타났다. 결론적으로, 누수가 있었던 아파트의 공기중 진균 농도는 매우 높은 상태로 오염이 심한 상태이었으나, 본 연구에서 적용한 복원방법들은 공기중 진균 농도 저감에 있어서 매우 높은 효율을 나타냈다.

Keywords: water-leakage, apartment, fungi, ozone treatment, biocide

I. Introduction

In modern times, lots of people live in an apartment in urbane area. According to the housing status in Korea, the percentage of apartments showed 52.7% of all the types of houses in Korea in 2005.[1] Thus, the environment of apartment is very important including indoor air quality.[2,3] One of the most complaints of the apartment problems was a leakage of water, or 32.6% in Korea.[4] Generally, the leakage of water gives environmental fungi a favorable habitat for growth, and the fungal growth aggravates the indoor air quality.[5] The health effects of environmental fungi were infectious diseases of skin, nails, and mucous membranes, and hypersensitivity diseases of immediate type allergic reactions and hypersensitivity pneumonitis.[6] There were many studies on the status of fungal contaminations and health effects.[7] However, the studies on remediation process comprehending both physical and chemical treatment against fungi were very limited. There were few studies on biocide treatment for fungal contamination, especially in an apartment.

The purpose of this case report was (1) to investigate the status of fungal contamination in a leakage-water damaged apartment, and (2) to evaluate the effectiveness of physical and chemical remediation methods such as ozone treatment, removal of water-damaged walls, ripping off wallpapers, and biocide treatment.

II. Materials and Methods

1. Sampling Place and Remediation Phase

The apartment was built in Seoul, Korea in 1976. It was at 10th floor of 15 floors. It consisted of three bed rooms, one living room, and one kitchen (see Fig. 1). The ceiling of toilet was damaged by the leakage of water from the upper floor, the 11th floor. The leakage water from the

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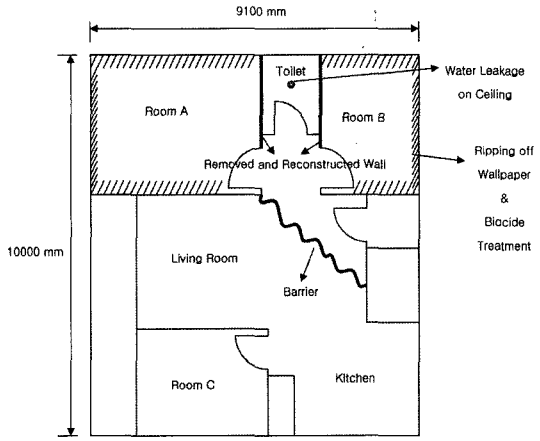

Fig. 1. Plane figure of a leakage-water-damaged apartment.

ceiling penetrated to the walls near to the toilet ceiling. Occupants in the apartment made a complaint of uneasiness like irritation of nose and throat. One of occupants was diagnosed as dermatophytosis.

Totally, 24 indoor air samples were collected in the water-damaged apartment (see Table 1). 6 indoor air samples were collected by filtration method in the initial step and 18 indoor air samples were collected by two-stage Anderson sampler in the phase I and phase II, 12 and 6 samples respectively. 4 outdoor air samples were collected for reference. 1 outdoor air sample was collected by filtration method in the initial step and 3 outdoor air samples were collected by two-stage Anderson sampler in the phase I and phase II, 2 and 1 sample respectively.

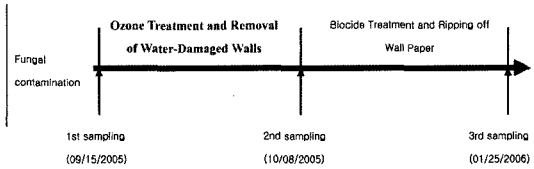

Fig. 2. Remediation and sampling date.

Fig. 2 showed the remediation process and sampling dates. The initial process was performed to investigate the status of environmental fungi in the water-damaged apartment. After that, ozone treatment was performed for lessening the level of the airborne fungi in Room C, living room, kitchen, and toilet by the engineer at working in the private environmental remediation company. The high concentrations of ozone (195 ppm) were treated through the 4 indoor spaces for 18 hours, except for Room A and Room B (Ozones Korea Co., LTD Class.1.5. SLW-80). After that, the two toilet walls, which were affected by leakage water, had been destructed in the apartment. The next remediation was to rip wallpaper off remained walls before chemical treatment in Room A, Room B, and toilet. Ripping-off and chemical treatment were performed to root out the source of airborne fungi. About 50,000-100,000 ppm sodium hypochlorite (NaClO) as a biocide had been sprayed on the surface of remained walls in Room A, Room B, and toilet. Barrier made of PVC (Polyvinyl chloride) had been constructed between direct contamination area (Room A, Room B, and toilet)

Table 1. Average fungal concentrations and removal efficiency of remedial method

Location	Initial		Ozone Treatment & Removal of Water-Damaged Walls			Removal of Whole Wall Paper and Biocide Treatment		
	No.	Conc. (cfu/m^3)	No.	Conc. (cfu/m^3)	Removal Efficiency (%)	No.	Conc. (cfu/m^3)	Removal Efficiency (%)
Room A	1	21,000	3	2,899	86.2	1	83	99.6
Room B	1	48,000	3	653	98.6	1	70	99.8
Room C	1	27,000	1	486	98.2	1	107	99.6
Living Room	1	17,000	1	481	97.2	1	59	99.7
Kitchen	1	81,000	1	1,054	98.7	1	72	99.9
Toilet	1	112,000	3	1,132	99.0	1	181	99.8
Mean (Geomean)		51,000 (40,163)		1,118 (899)	96.3		95 (88)	99.7
Outdoor	1	1,053	2	696	*Not Applicable*	1	102	*Not Applicable*

No.; Number of samples.

and indirect contamination area (Room C, Riving room, and kitchen) from the removal of wall to the biocide treatment (see Fig. 1). The workers and engineers at remediation wore PPE (Personal Protective Equipment) such as N-95 respirator and globe. The sampling was started in September 15, 2005 and was end up in January 25, 2006.

2. Air Sampling

Two-stage 200-hole Anderson sampler was mainly used. Only in the first phase filtration method was additionally used accompanying with two-stage 200-hole Anderson sampler, because it was known that filtration method was more suitable than impactor method for the sampling of airborne fungi in high concentrations.

The guidelines of the American Conference of Governmental Industrial Hygienists for air sampling in the indoor environment were followed.[6] Two-stage 200-hole Anderson sampler (Anderson serial # 1447, USA) was used. The median particle diameter (D_{50}) of the particles collected on the top stage of the impactor was more than 4.7 um (the "less"-respirable fraction), while the D_{50} of particles from the bottom stage was less than 4.7 um (the "more"-respirable fraction). Before sampling, the impactor stages were swabbed with 70% ethanol and allowed to air dry. A constant flow of 28.3 *l*/min was supplied by a Becker air pump. The air-sampling unit was placed at a height of approximately 1.0 m from the floor. In order to collect airborne fungi, MEA (malt extract agar) with chloramphenicol was used as a culture media. Fungal concentrations were adjusted by positive-hole-collection table.[6]

Air samples before the remediation process were also collected on polycarbonate membrane filters (diameter 37 mm, pore size 0.4 μm (Nuclepore Corp., Cambridge, Mass.)) at a flow rate of 3 *l*/ min for 60 minutes Samples were delivered to the laboratory within 24 hours after sampling and analyzed immediately on arrival. To extract the fungi from the filter samples, 1.5 m*l* of sterile peptone water (0.1%, w/v, containing 0.01% Tween 80) were inoculated onto the support pad through the outlet of the cassette, after which the connection was plugged up. Five m*l* of the sterile peptone water were transferred through the inlet hole, and the cassette was re-plugged and vigorously shaken for more than 30 minutes (at approximately 400 rpm on a shaker table). The cassette was unplugged and the suspension was pulled with a syringe. A portion of the suspension was utilized for the determination of viable fungi by a plate count technique (Palmgren *et al.*, 1986).[8] As for the culture media, MEA (malt extract agar) with chloramphenicol was used as a culture media. The total culturable fungi were measured as an arithmetic mean of counts. The rest fungi on the filter surface were counted by culturing the filter on MEA media plates. The plates were incubated at room temperature (25°C) for seven days. Concentrations of airborne fungi were presented as colony forming units per cubic meter (cfu/m^3). Fungi were classified by spore morphology or colonial mophology. Lactophenol cotton blue was used as a stain. The light microscopy, magnifying from 100 X to 400 X, was employed to classify the fungi.[9,10] Samples were analyzed by an industrial hygienist, highly experienced in the area of microbiological examination, of Industrial Hygiene group, School of Public Health, Seoul National University.

Initial concentrations of airborne fungi in a fungal contaminated apartment were calculated by the data from the filtration method, because the data of Anderson sampler's exceeded the upper limit of detection. According to *NIOSH Manual of Analytical Method*, Anderson 6-Stage and Anderson 2-stage samplers for culturable bioaerosols will overload sample in case of concentrations greater than 5,000-7,000 cfu/m^3 and filter samplers are good for very low to very high concentrations.[11] The other concentrations were calculated by the data from Anderson sampler's measurements. Removal efficiency of airborne fungi by remedial method calculated as follows;

$$\text{Removal efficiency (\%)} = \frac{(\text{Initial concentration} - \text{Concentration after treatment})}{\text{Initial concentration}} \times 100$$

3. Statistical Analysis

A W-test (Shapiro and Wilk test) was performed to determine if the type of distribution of airborne fungi concentrations in an apartment was lognormal. A Mann-Whitney test was used to investigate the

Table 2. Fungal concentrations in bulk samples by type of material

Type of Sample	Sample Location	Fungi	
		No.	Concentration (cfu/g)
Settled dusts	Room B	1	1,275,289
	Room C	1	57,628
Wall plaster	Toilet	1	162,932
Wall paper	Room A	2	Overloaded
	Room B	2	Overloaded

No.; Number of samples.

significant variation of indoor fungi concentrations by remediation phase. All statistical analyses were conducted using the statistical package SPSS 10.0.

III. Results

1. Environmental Fungal Concentrations in a Leakage-water Damaged Apartment

The airborne fungal concentrations in an apartment were log-normally distributed. Table 1 presents results of investigation into environmental fungi in a leakage-water damaged apartment. Airborne fungal concentrations ranged from 17,000 to 112,000 cfu/m^3. The maximum concentration was shown in toilet, where the fungal contamination was firstly started by the leakage-water over the ceiling. The mean of fungal concentrations was 51,000 cfu/m^3, and geometric mean was 40,163 cfu/m^3. I/O ratio (indoor concentrations/outdoor concentrations) ranged from 16.1 to 106.4. The relative humidity was 71% and temperature was 28.5°C in the apartment. *Aspergillus*, *Penicillium*, *Cladosporium*, *Mucour*, *Yeast*, others were identified, and *Aspergillus* was most frequently identified.

Fungal concentrations in settled dust showed 1,275,289 cfu/g in the Room B and 57,628 cfu/g in Room C (see Table 2). Room B was close to the toilet. Fungal concentration in the grain chiseled from wall plaster inside toilet wall was 162,932 cfu/g. The fungi on the wallpaper were visible, and they were too many to count on culture agar plates and overloaded.

2. Effect of Ozone Treatment and Removal of Wall

After the ozone treatment and removal of wall,

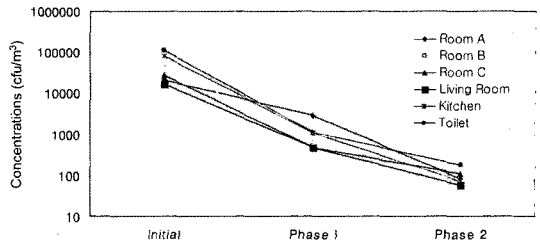

Fig. 3. Change of airborne fungi level by remedial phase.

airborne fungal concentrations averaged 1,118 cfu/m^3, and ranged from 481 to 2,899 cfu/m^3 (see Table 1). Mann-Whitney test showed significant variation between initial fungal concentrations and fungal concentrations after the ozone treatment and removal of wall ($p<0.05$). The removal efficiencies (%) of airborne fungi averaged 96.3%, and ranged from 86.2 to 99.0%. I/O ratios averaged 1.6 ranging from 0.7 to 4.2. The proportions of respirable fungi averaged 78%, ranging from 67 to 90%. The relative humidity was 87% and temperature was 22.0°C during the sampling in the apartment.

3. Effect of Ripping Wallpapers off the Remained Walls and Biocide Treatment

After the wallpaper ripping off remained walls and biocide treatment in Room A, Room B, and toilet, airborne fungal concentrations averaged 95 cfu/m^3 and ranged from 59 to 181 cfu/m^3 (see Table 1). Though Room C, living room, and kitchen were not remedied by the methods, fungal concentrations in those spaces were lower than the previous step, after the adjacent fungal sources removed. Mann-Whitney test showed significant variation between fungal concentrations after the ozone treatment and removal of wall and those after the wallpaper ripping off and biocide treatment ($p<0.05$). The removal efficiencies (%) of airborne fungi averaged 99.7%, and ranged from 99.6 to 99.9%. I/O ratios averaged 0.9 ranging from 0.7 to 1.8. The proportions of respirable fungi averaged 61%, ranging from 43 to 81%.

The relative humidity was 19% and temperature was 23.0°C during the sampling in the apartment. Fig. 3 showed the variation of airborne fungal concentrations at each space in a leakage-water damaged apartment by remediation phase.

IV. Discussion

The residential apartment considered to be severely contaminated by environmental fungi from the water-damaged ceiling and walls indoors. The hypothesis is supported by the results that the airborne fungal concentrations averaged 51,000 cfu/m^3, and that one of the occupants was diagnosed as a dermatophytosis. The IAQA (Indoor Air Quality Association) has recommended a level of 300 cfu/m^3 for total fungal species.[12] The USOSHA (US Occupational Safety and Health Administration) regarded a level of 1,000 cfu/m^3 as a contamination indicator.[13] In this study, the airborne fungal concentrations in the apartment exceeded 1,000 cfu/m^3. Furthermore, the average of airborne fungal concentration also exceeded 13,000 cfu/m^3. It was reported that levels exceeding 13,000 cfu/m^3 were related to adverse respiratory conditions in humans.[14] Additionally, this assumption was proved by the high relative humidity and temperature in the apartment, and by the high level of I/O ratios of airborne fungi (I/O ratio: 16.1-106.4). This is also supported by the previous study, which reported 17.4 of I/O ratio and 18,900 cfu/m^3 in a water-damaged drawing room.[15]

Ozone treatment and removal of contaminated wall could be a powerful process to abate the high concentrations of airborne fungi in a residential building like an apartment. The ozone treatment and removal of contaminated wall indicated a remarkable decrement of airborne fungi to the water-damaged residential building. Gas-phase ozone was recognized as a poor biocide for a long time.[16] In 1997, Foarde *et al.* reported that to achieve a significant kill for some microorganism, ozone gas of 6 to 10 ppm were required.[6,17] However, our remediation was successfully performed with the high level of gas-phase ozone about 195 ppm for 18 hours. This study could not investigate the level of airborne fungi during the removal of contaminated walls. However, previous report indicated that in the construction zone, the concentrations of microorganisms were 4~25 times higher during remediation than before it.[18] After the completion of removal of the contaminated walls, the airborne fungi concentrations came down near the normal condition. Furthermore, although the relative humidity was higher than that of the previous step, the indoor fungal concentrations were lower than those of previous step. This result supports the fact that the remediation was effective in the water-damaged apartment.

However, the air quality after ozone treatment and removal of wall might still be unsafe, because the average concentration of airborne fungi showed to exceed 1,000 cfu/m^3.

Sodium hypochlorite was frequently used to treat microbial growth because of broad spectrum effectiveness.[6] This case report suggests that the effects of sodium hypochlorite (NaClO) be good enough to lessen the high level of airborne fungi to the relatively safe level in a leakage-water-damaged apartment. The level of airborne fungal concentrations after ripping off wallpaper and chemical treatment on the contaminated wall did not exceed 300 cfu/m^3, or guideline of IAQA. In addition, the average of I/O ratios was 0.9, which was similar to 1.0, or normal condition.[6] Our data also suggest that for decreasing the percentage of respirable fungi, the ripping-off wall paper and sodium hypochlorite treatment against the wall be more effective than the ozone treatment and removal of a contaminated wall.

V. Conclusions

This case study was performed to investigate the status of fungal contaminations in one leakage-water-damaged apartment, and to evaluate the effectiveness of the remediation methods. The level of airborne fungi in the water-damaged apartment was severely high, however, the level of airborne fungi after the remediation actions decreased to the relatively safe level. The remediation process like ozone treatment, removal of water-damaged wall, ripping off wallpaper of remained walls, and biocide treatment were very effective in the fungal contaminated apartment. The ozone treatment and removal of water-damaged wall indicated a remarkable decrement of airborne fungi, and after the ripping off wallpaper and biocide treatment on the walls the airborne fungi concentrations came down to the relatively safe level.

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