Size distributions of suspended fine particles during cleaning in an office

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Abstract

In this study, the concentration of fine dust particles and the size distribution of fine dust particles were analyzed by measuring the dust generated during the cleaning process of an indoor office. We measured PM₁₀, PM₂.₅, and PM₁.₀ and analyzed the size distributions of dust bigger than 0.3 μm in diameter during cleaning. The results showed that the concentration of PM₁₀ increased rapidly during cleaning, and PM₁.₀ did not increase. Before cleaning with a broom, the fine dust concentration was about 50 μg m⁻³, but increased to about 400 μg m⁻³ as cleaning progressed. In the case of indoor cleaning with a vacuum cleaner, the concentration of PM₁₀ increased during the cleaning process and the increase of PM₂.₅ was relatively small. PM₁.₀ did not increase as in the case of cleaning with the broom.

Keywords: indoor cleaning; broom; vacuum cleaner; PM₁₀; PM₂.₅; PM₁.₀

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INTRODUCTION

There are various reports that fine dust and ultrafine dust are severe health hazards. Recently, there is a great demand for air quality improvements worldwide. The annual average concentration of PM$_{10}$ in Seoul was 44 $\mu$g m$^{-3}$ in 2013, 46 $\mu$g m$^{-3}$ in 2014, 45 $\mu$g m$^{-3}$ in 2015, and 48 $\mu$g m$^{-3}$ in 2016 although it had decreased from 61 $\mu$g m$^{-3}$ in 2007 to 41 $\mu$g m$^{-3}$ in 2012. However, it is still higher than the developed countries and especially higher than twice the 20 $\mu$g m$^{-3}$ that is the annual mean PM$_{10}$ concentration of the World Health Organization (WHO) air quality guideline. It is difficult to reduce the human exposure to airborne particles only by control of domestic air pollution. Therefore, the short-term solution is to reduce the suspended particles indoor where people spend most of their time.

According to a recent study, Korean residents spend indoors more than 21 hours a day, and their residence time in a space differed depending on occupation, sex, and age (Yoon et al., 2017). However, there are a few data analyzed in detail on the exposure to suspended dusts according to the behavior patterns of various people in the indoor environment and on the characteristics of the sources (Bae and Kim, 2017). As a result of exposure studies for suspended dust indoor, it has been reported that aerosols can be released from vacuum cleaners during indoor cleaning (Ozturk, 2006; Knibbs et al., 2012; Wu et al., 2012; Lee et al., 2014). Wu et al. (2012) analyzed the amount of dust generated from a vacuum cleaner in a small chamber by measuring the number density and size distribution based on it. Knibbs et al. (2012) confirmed the emission
characteristics of dust generated by conducting duct tests of 21 kinds of vacuum cleaners. Lee et al. (2014) confirmed that fine dust could be released during the operation of the vacuum cleaner through the test, which drove a vacuum cleaner in the chamber. Nevertheless, there is a lack of research on concentration properties and size distribution of dust generated in actual cleaning process.

In this study, we investigated the characteristics of dust generated in the process of cleaning in an office where people wear shoes. PM$_{10}$, PM$_{2.5}$ and PM$_{1.0}$ were analyzed, and the particle size distributions of suspended dust larger than 0.25 $\mu$m was measured and analyzed in the cleaning process. In particular, the characteristics of dust that resuspended in the process of using broom or vacuum cleaner were analyzed.

METHODS

The measurements were carried out at an office having an area of 105.3 $m^2$ located on the 13th floor of the newly constructed building in Seoul. The office zones were divided only by partitions of about 1.5 m in height. As a first case, we measured the particles generated in the process of cleaning the office floor with a broom. There was a lot of dust on the floor because it was office moving day. At the second and third measurements, a vacuum cleaner was used for floor cleaning. Dust suctioned by the vacuum cleaner is collected in a large dust bag installed in the vacuum
cleaner, and the filtered air is discharged into air by passing through a filter equipped at the air outlet. Secondly, in three weeks after the moving, the characteristics of the fine particles in air were measured and analyzed during the cleaning process using the vacuum cleaner. It was a cloudy day with a rainfall of about 6 mm. In four weeks from the moving day, the 3rd measurement was performed. An optical particle counter (OPC, model 11A, GRIMM, Germany) was used in all three measurements. A condensational particle counter (CPC, model 5400, GRIMM, Germany) was additionally used at the third measurement. The number concentration of particles larger than 4 nm was measured. The interior structure including arrangement of desk, table, chair, and so on of the relocated office and the cleaning circulation line are shown in Fig. 1. Measurement instruments were located at the starting point of cleaning. The conditions for three cleaning cases using a broom and a vacuum cleaner in the office are summarized in Table 1.
door was opened to the corridor. As shown in Fig. 1, the cleaning with a broom started from where the measuring instrument was located.

Fig. 2 shows the changes in the concentration of particles suspended in the cleaning process and after cleaning. Fig. 2(a) shows the changes of PM$_{10}$, PM$_{2.5}$, and PM$_{1.0}$ before, during, and after cleaning. The PM$_{10}$ concentration was about 50 $\mu$g m$^{-3}$ before cleaning, but it increased to about 400 $\mu$g m$^{-3}$ during cleaning with broom. Cleaning with a broom was performed for about 15 minutes. When cleaning around the measuring device, the concentration increased the most. As moving away from the measuring site, the indoor dust concentration decreased first and then increased. Total amounts of indoor suspended dust increased with sweeping using a broom. Dust concentration in air was increased with time because the suspended fine dust diffuses in the total office space. It took at least 1 hour for the indoor concentration decreasing to about 50 $\mu$g m$^{-3}$ even after cleaning. The air exchange by natural ventilation was little due to the structure of the office although the windows were opened during and after the cleaning. In Fig. 2(b), the mass concentrations of PM$_{2.5}$-PM$_{1.0}$, PM$_{10}$-PM$_{2.5}$, PM$_{1.0}$ were indicated which were calculated from PM$_{10}$, PM$_{2.5}$, and PM$_{1.0}$ data to analyze particle size characteristics. The concentration of PM$_{10}$, the relatively large dust of which particle size is in a region of 2.5-10 $\mu$m, increased sharply while that of PM$_{1.0}$ did not change much. The reason might be that the dust on the floor is resuspended in the air due to the physical force such as sweeping with broom, but the dust smaller than 1 $\mu$m
seems not falling well from the large dust. Fig. 2(c) shows the ratio of concentration after cleaning to before cleaning. For the before-cleaning concentration, 10 minutes average value was used. The particle having the size of 1 ~ 2.5 μm increased about 5 times whereas the relatively large dust having a diameter of 2.5 ~ 10 μm increased about 60 times than before cleaning. The particles smaller than 1 μm did not show a clear increase trend.

Fig. 3 shows the size distribution change of the dust suspended in the cleaning process using a broom. The basic data of the optical particle counter shows the number concentration of each size channel, but the measured size was expressed as an optically equivalent size in this study to qualitatively compare the change characteristics of a dust according to its relative size. Each dust was assumed to have a spherical shape and a density of 1.0 g cm$^{-3}$, and the particle size distribution was estimated. In order to express the optical equivalent size as an aerodynamic size, it is necessary to know the exact density. Since the particle density is assumed to be 1.0 g cm$^{-3}$, the particle size distribution must be shifted to the smaller side (Hinds, 1999). Dust smaller than 0.25 μm cannot be measured by OPC, it is conceivable that there is another peak near the 0.25 μm. The particle size distribution before cleaning was like that of particles in the atmosphere. Two peaks were found in the size distribution that one mainly caused by gas exhausted from automobile or thermal power plant was smaller than 1 μm, and the other resuspended from road or soil by wind is larger than 1 μm.
At the beginning of the cleaning, there is almost no change in the concentration of dust having size below 1 μm as shown in Fig. 2, but the concentration of particles in the range of 1 to 10 μm increases sharply. It indicates that the 1 ~ 10 μm particles were re-suspended into air from the floor by sweeping with a broom like that the dust is generated by the wind. Because there was a lot of dust on the floor during the moving process, the dust was re-suspended during the cleaning process and the concentration of particles suspended in air was greatly increased. It was confirmed that the particles larger than 10 μm, which are difficult to track merely from PM10, PM2.5, and PM1.0 data of Fig. 2, were suspended in the air by particle size distribution analysis.

Concentration and size distribution of dust suspended in cleaning with a vacuum cleaner

Fig. 4 shows the results of measuring the dust suspended during the vacuum cleaning. It was in three or four weeks after moving, there was not much dust on the floor due to steadily cleaning and mopping. It was a condition that only a certain amount of dust was on the floor due to dust shaken out of shoes. Fig. 4(a) shows the result of cloudy days with rainfall of about 6 mm at three weeks after moving. On the other hand, Fig. 4(b) shows the result of clear and dry day after 4 weeks after moving. The increase in indoor dust concentration was lower when using vacuum cleaner than when the floor was cleaned with a broom in the dusty condition on the moving day shown in Fig. 2. Compared with before cleaning, the mass concentration of the dust in the range of 2.5~10 μm was less than 5 times when using a vacuum cleaner with little dust on the floor. It
was unlike the case where it increased by 60 times when using a broom for cleaning. The cause of such a result is the difference between a broom and a vacuum cleaner, and a difference in the amount of floor dust. Particularly, in the Fig. 3, there was almost no resuspension of particles having size less than 1 μm as well as in the range of 1~2.5 μm. Those particles were hard to fall off from relatively large dusts because it was a wet weather day with rainfall. On a dry and sunny day, the increased concentration of 1~2.5 μm particles was about 2 times higher than before cleaning.

Fig. 5 shows the size distribution of dust suspended in air in the process of vacuum cleaning. The data shown in Fig. 5(a) was obtained on a cloudy day with about 6 mm of rainfall, and the data shown in Fig. 5(b) was measured on a clear day that was after four weeks from the moving day. As shown in Fig. 5(a), dusts larger than 2 μm in diameter were mainly suspended in the air on a rainy and cloudy day. Meanwhile, the dust larger than 1 μm in diameter resuspended in air on a sunny day as shown in Fig. 5(b). When using a vacuum cleaner, the concentration of dust larger than 10 μm in diameter was not high in comparison with the condition that a broom was used to clean a dusty floor on the moving day.

Fig. 6 shows the changes in the suspended dust concentration before cleaning, on cleaning, and after cleaning with a vacuum cleaner on a clean day that is 4 weeks after the moving day. The PM_{10-2.5}, PM_{2.5-1.0} and PM_{1.0} obtained by OPC are expressed as a ratio of mass concentration, and
the values measured by CPC are represented as the ratio \(\frac{N}{N_0}\) of the number concentrations (N).

It was confirmed that dust larger than 1 μm in diameter were suspended in the air. They floated for about 40 minutes despite the opening of the windows. The decrease in it was observed when natural ventilation was active. The number concentration measured by CPC increased rapidly at the beginning of the operation of the vacuum cleaner as shown in Fig. 6. As the production of particles in the vacuum cleaner sharply decreased, the particle concentration in the air decreased sharply.

Fig. 7 shows the change of the total number concentration variation of particles larger than 250 nm in diameter and 4 nm in diameter. They are measured by OPC and CPC, respectively. Most number of particles are smaller than 250 nm in diameter. When the sampling probe of the CPC is placed near to the air outlet of the vacuum cleaner, the higher number concentration of dusts was measured. It is estimated that this vacuum cleaner was not equipped with a HEPA filter at the outlet. The generation of high concentrated particles shows a possibility that evaporation, nucleation and condensation were made from the adhered organic substances on the motor surface of vacuum cleaner. It is assumed that the heat generated by the motor of the vacuum cleaner has caused the nanoparticle formation. Further research is needed in the future.

CONCLUSIONS
In this study, we investigated the characteristics of dust generated in the process of cleaning in an office where people wear shoes. The mass concentrations of PM$_{10}$, PM$_{2.5}$, and PM$_{1.0}$ and the size distributions of dust larger than 0.3 μm in diameter were measured and analyzed in the cleaning process. Particularly, the resuspension characteristics of fine dust on the floor during the use of a broom and a vacuum cleaner were analyzed. The concentration of PM$_{2.5}$ and PM$_{10}$ increased with the start of cleaning, and they could float indoors for a long time after cleaning. On the other hand, the PM$_{1.0}$ concentration did not show a tendency to increase during the cleaning process. Especially, in cleaning with a broom the dust having the size of 1 ~ 2.5 μm increased about 5 times whereas the dust of 2.5 ~ 10 μm in diameter increased about 60 times with too much dust on the floor. The dust larger than 2.5 ~ 10 μm in diameter increased in the case of cleaning using a vacuum cleaner, but the concentration was 5 times below the initial concentration. During the operation of the vacuum cleaner equipped with an exhaust filter, the total particle number concentration measured by the CPC rapidly increased at the initial stage of vacuum cleaner operation and then decreased. The size of most particles produced during cleaning using a vacuum cleaner were smaller than 250 nm in size.

It is known that the exposure of particles suspended indoor to inhabitants is affected by the incoming particles from the outside atmosphere and the particles generated in indoor. However, it is necessary to systematically measure and analyze fine dusts generated by indoor activities. In
addition to the studies on the various atmospheric fine dusts already in progress, it is necessary to systematically study the characteristics of the particles suspended in air from indoor activities in the future.

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REFERENCES


Table 1. Indoor cleaning conditions and cleaning tools.

<table>
<thead>
<tr>
<th>Case</th>
<th>Cleaning method</th>
<th>Cleaning activity</th>
<th>Dust amounts on the floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Broom</td>
<td>Office cleaning after moving</td>
<td>Much</td>
</tr>
<tr>
<td>2</td>
<td>Vacuum cleaner</td>
<td>Vacuum cleaning</td>
<td>Little (rainy day)</td>
</tr>
<tr>
<td>3</td>
<td>Vacuum cleaner</td>
<td>Vacuum cleaning</td>
<td>Little</td>
</tr>
</tbody>
</table>
Figure Captions

Fig. 1. Office indoor structure and cleaning moving line.

Fig. 2. Mass concentrations and ratios of mass concentration of particles resuspended during cleaning with a broom.

Fig. 3. Particle size distributions of resuspended dust during cleaning with a broom.

Fig. 4. Mass concentrations of particles resuspended during cleaning with a vacuum cleaner (a) rainy day, (b) sunny day.

Fig. 5. Particle size distributions of resuspended dust during cleaning with a vacuum cleaner (a) rainy day, (b) sunny day.

Fig. 6. Mass or number concentration ratios with time of particles during cleaning with a vacuum cleaner.

Fig. 7. Particle number concentrations with time during cleaning with a vacuum cleaner.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.