Effect of Particle Sizes on the Particle Restraint and Removal Efficiencies in a Laboratory Utilizing a Lagrangian Particle-Tracking Method

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Abstract: The effect of the different particle sizes on the efficiency of restraining particles from entering the laboratory and the efficiency of particle removal from the laboratory were investigated by simulating the flow conditions, accompanied by a Lagrangian particle-tracking method to calculate the trajectories of the particles in the laboratory. The cases containing particles with different particle size ranging from 10 to 30 μm and the case without gravity effect were used to investigate the restraint and removal effects in the study. The results indicate that the restraint rate decreases by the particle size enlarged and the restraint rate of particles is the best under without gravity condition. However, the removal rate increases by the particle size enlarged and the removal rate of particles is the worst under without gravity condition. It is also found that for the case with the particle size smaller than 10 μm, the gravitational effect is much smaller and can be neglected. Therefore, for the case with the size of the contaminant smaller than 10 μm, the distribution of pollution in an indoor space can be obtained by solving the gaseous concentration equation to simulate the dispersion and deposition of pollutant particles inside an indoor space. With the Lagrangian Particle-Tracking Method, the trajectories of micro-particles can be traced and calculated in the in time and the gravity effect can also be considered in the analysis. By tracing and calculating the trajectories of micro-particles in time, the particle restraint and removal effects can be explicitly indicated by calculating the amount of particles that enter or leave the laboratory.

Key words: Pollutant particle, gravity effect, particle size, restraint rate, removal rate

INTRODUCTION

Many people spend most of their lifetime in an indoor environment. The fine particulate matter can deposit in the lungs and cause respiratory diseases. It can be a great impact on human health (Klepeis et al., 2001). Thus, Indoor Air Quality (IAQ) and the prediction of indoor pollution levels have become more important subjects for health risks. With the development of technology, the aerospace, semiconductor, electro-optical, medicine and precision-manufacture industries, among others, want to precisely control any kind of pollution in their working spaces. Ventilation of indoor space may have serious influence on the precision of experimental results or the manufacture of products. Unsuitable ventilation can even change the risk level of surgery in an operation room. In an indoor environment, particles are regarded as pollutant sources. Particle deposition may damage the human body and equipment. Therefore, the behavior of pollutant particles and the design of ventilation systems must be further evaluated. A proper ventilation system can not only restrain the pollutant particles from entering the indoor space but also remove the pollutant particles from that space efficiently. Abades et al. (2001) investigated the experimental determination of deposition constants for several wall textures in order to predict indoor particles concentration. Bouilly et al. (2005) investigated the impact of ventilation strategies on the indoor particle concentration. Results show that the ventilation acts differently according to the particle size.

In the last decade, many particle studies have been conducted. Some researchers investigated using ventilation systems to remove pollution that studied the mean deposition velocity and the mean deposition rate of particles in the indoor environments. These velocities concern the indoor particle concentration and explain the predominant role of indoor particle pollution, subjects that are useful and suitable for study and analysis of indoor deposited particles (Howard-Reed et al., 2003; He et al., 2005). Nazaroff (2004) summarized the modeling techniques used to study indoor particle dynamics, the review was based on the assumption of a well mixed...
condition of room air and particles. Sippola and Nazaroff (2003) measured the particle deposition on the floors, walls and ceilings of experimental duct surfaces. The deposition rate on the floor is much greater than the deposition rates on walls or on the ceiling and these experimental results have been applied to understanding particle exposure evaluations. Gao and Niu (2007) used the drift-flux model to predict the distribution of particle concentration in the isothermal flow. It was shown that the larger the particle size, the lower the human exposure.

Computational Fluid Dynamics (CFD) can be used to study particle dispersion and spatial distribution with either the Eulerian or Lagrangian method. The Eulerian method treats particles as a continuum and it is widely used to predict particle concentration distributions in rooms (Holmberg and Chen, 2003; Zhao et al., 2004b). The Lagrangian method emphasizes the individual behavior of each particle. For the particle motion and dispersion condition, the Lagrangian method is more attractive. Lai (2002), Zhao et al. (2004a) and Chen et al. (2006) investigated the particle deposition and particle distribution indoors with numerical methods and the numerical results were compared with experimentally measured data. It was shown that the particle deposition velocity varies under different indoor environments in their results. Zhang and Chen (2006) and Narayanan et al. (2003) studied the problem of the Euler and Lagrange approaches to calculate the particle contaminant distribution in a room using numerical simulation. They used a CFD program with a Lagrangian particle tracking method to predict the particle dispersion and concentration distribution in ventilated rooms. Zhao and Wu (2007) investigated some factors that can affect particle deposition in indoor environments. They indicated that as the particle size grows larger, the particle deposition velocity first grows smaller and then becomes larger. The deposited particle flux is very different for different particle spatial distributions. Chow et al. (2006), Zhao and Guan (2007) and Yongson et al. (2007) investigated the influence of the particle dispersion characteristics. They indicated that the factors of particle sizes, air supply volume and ventilation modes have significant influence on particle dispersion in personalized ventilated rooms. Memarzadeh and Jiang (2000) and Qian et al. (2008) used ventilation systems in hospital rooms to reduce the risk of airborne transmissible diseases. Cases with high exhaust grilles vent out more particles than low exhaust systems for the particle release points considered in low to medium air changes per hour (ACH) values. Cheng et al. (2010) investigated the effect of air supply and air exhaust locations on the efficiencies of restraining particles from entering the laboratory and particle removal from the laboratory. They calculated the trajectories of the particles in the laboratory to simulate the flow conditions by a Lagrangian particle-tracking method. Their results indicate that for the case with air supplied from the air supply located on the ceiling near the door, the efficiency of restraining particles from entering the laboratory is the best among the cases in their study. However, for the particle removal efficiency, the case with the air supplied from the air supply located on the ceiling in the center of the laboratory possesses the best removal performance (Cheng et al., 2010).

Most of the studies investigated the distribution of pollution in an indoor space by calculating the distribution of the gaseous concentration to simulate the dispersion and deposition of pollutant particles inside an indoor space. For smaller pollutant particles, the distribution of the pollution is similar to the distribution of the gaseous concentration inside the indoor space. However, for larger pollutant particles, due to the gravitational effects on the particles, calculating the distribution of the gaseous concentration cannot directly simulate the dispersion and deposition of the particles. For larger pollutant particles, the materials and the sizes of the particles can seriously affect the distribution of the pollutant particles (Loomans and Lemaire, 2002). These effects cannot be investigated by directly solving the mass transport equation and calculating the distribution of the gaseous concentration. The Lagrangian approach method is to describe the motion of individual particle. The positions of the individual particle are a function of time through the study of a way to keep track the motion. Generally, the Lagrangian method may be ensure statistically stable results. The Lagrangian method is attractive if interests are in the particle dispersion. In this study, a Lagrangian particle-tracking method, which solves the particle motion equation was used to analyze the particle dispersion and deposition in a laboratory with a negative pressure gradient in order to investigate the effects of the different particle sizes on the efficiency of restraining particles from entering the laboratory and the efficiency of particle removal from the laboratory.

This study investigated the restraint efficiency for the particles entering the laboratory and the removal efficiency of the particles from the laboratory under the influence of the different particle sizes and the door open and close periods. Due to lower air pressure in the laboratory in comparison with that in the front room, while the door was open, some particles in the front room were brought into the laboratory by the airstream flowing from the front room to the laboratory. The airflow conditions and sizes of the particles affected the amount of particles passing through the door. Otherwise, the particles
existing in the laboratory could also be removed from the laboratory by the air exhausts installed in the four corners of the laboratory. The amount of particles that could be removed from the laboratory was also dependent on the air flow conditions in the laboratory and the particle sizes.

**MATERIALS AND METHODS**

**Geometry of the physical model:** In traditional research, the removal efficiency of pollutant is investigated by the gaseous concentration. By this method, the influence of removal rate on different particle size is uncertain. In this study, the distribution of pollutant is investigated by the gas particle sizes, it can be calculated not only the removal rate of pollutant but also the accurate restraint rate of pollutant. Therefore, this method is better closer to the practical condition.

This study investigated the particle restraint and removal effects under the influence of the different particle size. The physical model used in the study possesses a front room and a laboratory, as shown in Fig. 1. The geometry of the physical model shown in Fig. 1 has realistic dimensions of a laboratory similar to the national laboratory animal center in Taiwan. Between the front room and the laboratory, there is a door for incoming and outgoing researchers. The length, width and height of the front room are 4, 5 and 5 m, respectively. The length, width and height of the laboratory are 6, 5 and 5 m, respectively. The width and height of the door are 1 and 2.2 m, respectively. In the front room, there is an air supply and an air exhaust. The length and width of air supply and air exhaust in the front room are 0.6 and 0.1 m, respectively. In the laboratory, the air supplies located near the door, in the center of the laboratory and far away from the door. The length and width of the air supply in the laboratory are 1.6 and 0.6 m. In the laboratory, there are also four air exhausts located in the four corners of the laboratory. The length and width of the air exhausts in the laboratory are 1.2 and 0.4 m, respectively.

The particles are release from the air supply of the front room to simulate the pollution distribution in the rooms. The values of the physical parameters in the study are an air density of 1.225 kg m$^{-3}$, a particle diameter of 10 μm, a viscosity of 1.789×10$^{-5}$ kg (m.s)$^{-1}$ and a particle density of 1550 kg m$^{-3}$.

The door opening and closing sequence and the corresponding period are shown in Fig. 2. During period I (from t = 0 to 240 sec), the particles were ejected from the air supply of the front room and were uniformly distributed over the front room. During period II (from t = 240 to 270 sec), the door was opened for 30 sec. Then, the door was closed during period III (from t = 270 to 300 sec). During period IV (from t = 300 to 360 sec) and period V (from t = 360 to 420 sec), the door was, respectively reopened and closed again. During period VI (from t = 420 to 510 sec), the door was reopened for 90 sec and at t = 510 sec, the door was closed again one more.

**Assumption of the physical model:** In order to simplify the physical characteristics considered in this study, the following assumptions are made.

![Fig. 1: Geometry of the physical model (Cheng et al., 2010)](image)
Fig. 2: The door opening and closing sequence and the corresponding period (Cheng et al., 2010)

- The fluid in the front room and laboratory is incompressible.
- There is no heat source in the physical domain. The temperature and buoyancy effects can be neglected but the gravity on the pollutant particles is considered.
- The equipment in the front room and the laboratory do not affect the airflow in the physical domain.
- The door between the front room and the laboratory is airtight. The air cannot leak out from the door while the door is closed.

In order to investigate the influence of the different particle size on the particle restraint and removal effects, the particle size 30, 25, 20, 15, 10, 15+30 μm and the without gravity condition are investigated in this study. Due to the character of the flow conditions within the physical domain, a k-ω turbulent model was used in the simulation. The governing equations used in this study are listed as follows:

- Continuity equation:
  \[ \nabla \cdot \vec{V} = 0 \]  

- Momentum equation:
  \[ \frac{d\vec{V}}{dt} = -\frac{1}{\rho} \nabla P + \frac{1}{\mu} \nabla \cdot \vec{V} + \vec{g} \]  

- Standard k-ω turbulent kinetic energy equation:
  \[ \frac{\partial}{\partial t} (\rho k) + \nabla \cdot (\rho k \vec{V}) = \nabla \cdot \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \nabla k \right] + G_k - \rho \varepsilon \]  

- Dissipation equation:
  \[ \frac{\partial}{\partial t} (\rho \varepsilon) + \nabla \cdot (\rho \varepsilon \vec{V}) = \nabla \cdot \left( \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \nabla \varepsilon \right) + C_{\mu} \frac{\varepsilon}{k} G_k - C_{\mu} \frac{\varepsilon^2}{k} \]  

Particle motion equation:
  \[ m_p \frac{d\vec{V}_p}{dt} = \frac{1}{2} C_{D_p} A_p \rho \vec{V} \left( \vec{V} - \vec{V}_p \right) \left( \vec{V} - \vec{V}_p \right) + m_p \vec{g} \]  

where,
  \[ \rho_1 = \rho C_u \frac{k^3}{\varepsilon} \]  

and
  \[ \begin{align*}
  C_u &= 24 \left( \frac{1 + 3.7 \text{ Re}}{16} \right)^{0.5} \text{ Re} \leq 1000 \\
  C_u &= 0.44 \text{ Re} > 1000
  \end{align*} \]

The physical definitions of the variables in the equations are shown in Table 1.

The boundary conditions of the physical model are as follows:

- At each air exhaust, the boundary condition of \( \partial P/\partial n = 0 \) was used, where \( n \) is a unit normal vector to the surface of each air exhaust. The gauge pressures of air exhaust in the front room and air exhausts in the laboratory were 0 and -15 Pa, respectively. This pressure difference caused negative pressure gradients to exist between the laboratory and the ambient environment and between the front room and the laboratory. The negative pressure gradient between the laboratory and the ambient environment could prevent pollution infiltration and the pressure gradient between the front room and the laboratory caused the air to pass through the door and flow into the laboratory while the door was open.
- The no-slip boundary condition was applied to the surface of the door and the walls of the rooms.
- The slip grid boundary condition was applied to the door while the door was opening.
- In order to reach the air change rate, the air velocity from the air supply in the front room and in the laboratory should be set at 0.5 and 0.54 m sec\(^{-1}\). These flow velocities can result in 12 ACH (air changes per hour).
• In order to understand the particle restraint and removal effect, a mass flow rate of particles (6×10^{-13} kg sec^{-1}) is assumed to be full in the front room.

**RESULTS AND DISCUSSION**

The sequential and alternating door opening and closing sequences were applied to investigate the amount of particles brought into the laboratory and removed from the laboratory, respectively, under the influence of the different particle sizes.

**The flowing state of the airflow:** The different particle sizes were used to investigate the particle restraint and removal efficiency. The distributions of particles and the flow conditions of the airflow in the physical domain when the door is open or closed are shown in Fig. 3-4. The air was supplied from the air supply in the center of the laboratory on the ceiling and a jet flow moving from the air supply on the ceiling to the ground was formed in the center of the laboratory. When the air hits the ground, the air was induced to symmetrically move in radial directions and formed symmetrical circulations rotating in the counter-clockwise direction moving from the jet flow to the surrounding walls. While the door was open, due to the lack of horizontal rotating circulation moving in the x-direction near the door, most of particles removed from air exhaust 1. The rest of the particles were gradually blown upwards with the symmetrical circulations and gradually disperse to fill the entire space of the laboratory. While the door was closed, the particles could move with the airflow in the laboratory and be effectively removed by the four air exhausts in the corners.

In airflow analysis, Yongson et al. (2007) investigated temperature and velocity distribution over various virtual planes for different locations of the air conditioner blower was analyzed to achieve the maximum comfort for the occupant. Their results show the removal efficiency is better in the air conditioner closer to the outlet; however, they could not analyze the influence of the pollutant particle size on the restraint efficiencies. In this study, the effects of different single particle sizes and mixed particle sizes on the restraint efficiency of pollutant are investigated. Therefore, the results in this study are much closer to the practical flow conditions in the laboratory.

**Effect of particle sizes on restraint rates:** The restraint rate of particles (R_e,%) is defined as; (1-N_e/N_0)×100%,
Table 2: The statistics of the restraint rates for different particle sizes

<table>
<thead>
<tr>
<th>Period (sec)</th>
<th>30</th>
<th>25</th>
<th>20</th>
<th>15</th>
<th>10</th>
<th>15+30</th>
<th>Without</th>
<th>Amount of particles passing through the door $N_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (0-240)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2623</td>
</tr>
<tr>
<td>II (240-270)</td>
<td>221</td>
<td>142</td>
<td>58</td>
<td>168</td>
<td>211</td>
<td>174</td>
<td>345</td>
<td>2761</td>
</tr>
<tr>
<td>III (270-300)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2779</td>
</tr>
<tr>
<td>IV (300-360)</td>
<td>618</td>
<td>605</td>
<td>547</td>
<td>482</td>
<td>331</td>
<td>596</td>
<td>320</td>
<td>3356</td>
</tr>
<tr>
<td>V (360-420)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3226</td>
</tr>
<tr>
<td>VI (420-510)</td>
<td>1184</td>
<td>1184</td>
<td>1087</td>
<td>912</td>
<td>816</td>
<td>1152</td>
<td>666</td>
<td>4213</td>
</tr>
<tr>
<td>VII (510-600)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3907</td>
</tr>
<tr>
<td>Total</td>
<td>2023</td>
<td>1931</td>
<td>1692</td>
<td>1562</td>
<td>1358</td>
<td>1992</td>
<td>1331</td>
<td>5052</td>
</tr>
</tbody>
</table>

Table 3: The statistics of the removal rates for different particle sizes

<table>
<thead>
<tr>
<th>Period (sec)</th>
<th>30</th>
<th>25</th>
<th>20</th>
<th>15</th>
<th>10</th>
<th>15+30</th>
<th>Without</th>
<th>Amount of removed particles $N_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (0-240)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>221</td>
</tr>
<tr>
<td>II (240-270)</td>
<td>174</td>
<td>104</td>
<td>42</td>
<td>123</td>
<td>75</td>
<td>123</td>
<td>120</td>
<td>211</td>
</tr>
<tr>
<td>III (270-300)</td>
<td>47</td>
<td>35</td>
<td>10</td>
<td>24</td>
<td>29</td>
<td>37</td>
<td>38</td>
<td>47</td>
</tr>
<tr>
<td>IV (300-360)</td>
<td>459</td>
<td>401</td>
<td>357</td>
<td>250</td>
<td>198</td>
<td>384</td>
<td>167</td>
<td>618</td>
</tr>
<tr>
<td>V (360-420)</td>
<td>138</td>
<td>180</td>
<td>161</td>
<td>139</td>
<td>92</td>
<td>174</td>
<td>109</td>
<td>159</td>
</tr>
<tr>
<td>VI (420-510)</td>
<td>914</td>
<td>816</td>
<td>742</td>
<td>600</td>
<td>469</td>
<td>866</td>
<td>426</td>
<td>1205</td>
</tr>
<tr>
<td>VII (510-600)</td>
<td>256</td>
<td>348</td>
<td>306</td>
<td>239</td>
<td>260</td>
<td>265</td>
<td>210</td>
<td>291</td>
</tr>
<tr>
<td>Total</td>
<td>1688</td>
<td>1884</td>
<td>1618</td>
<td>1425</td>
<td>1123</td>
<td>1849</td>
<td>1070</td>
<td>2023</td>
</tr>
</tbody>
</table>

where $N_2$ is the amount of particles passing through the door and $N_1$ is the amount of particles in the front room. The statistics of the restraint rates for different particle sizes are listed in Table 2. From the Table 2, it can be seen that while the door was opened in period II, the amount of particles entering the laboratory and the restraint rates for different particle sizes have not regular tendency due to the shorter door opening time. While the door was opened in period IV and VI, due to the gravity effect of the particles, the larger size particles tend to deposit at the bottom of the front room. Thus, the amount of particles entering the laboratory for the case with the larger size particles is greater than that for the case with the smaller particles. In other words, the amount of the particles entering the laboratory increases with the increase in the particle size. Hence, the particle restraint rate is getting worse with the increase in the particle size. Furthermore, the case without gravity effect can obtain the best particle restraint rate among the cases. For the case containing both 15 and 30 μm particles, the restraint rate is between the restraint rates of the two cases with only 15 μm particles and with only 30 μm particles and it is closer to the particle restraint rate of the case with only 30 μm particles due to the gravity effect.

In the complete process, for the cases with particle sizes of 30, 25, 20, 15, 10, 15 and 30 μm and the case without gravity effect, the total $N_2$ are 5052, 5017, 4913, 4920, 4720, 5160 and 4825, respectively and the total $N_1$ are 2023, 1931, 1692, 1562, 1358, 1992 and 1331. Thus, the total $R_\text{rem}$ for the cases are 60.0, 61.5, 65.5, 68.4, 71.2, 62.8 and 72.4%, respectively. The comparison of restraint rates of particles for the cases with different particle sizes is shown in Fig. 5.

Effect of particle sizes on removal rates: The remove rate of particles ($R_\text{rem}$ %) is defined as $N_1/N_2\times 100\%$, where, $N_1$ is the amount of particles removed and $N_2$ is the amount of particles in the laboratory. The statistics of the removal rates for different particle sizes are listed in Table 3. From the Table 3, it can be seen that while the door was opened in period II, the amount of particles removed and the removal rate for different particle sizes also have not regular tendency due to the shorter door opening time. While the door was opened in period IV and VI, due to the gravity effect, larger size particles tend to deposit at the bottom of the laboratory and easily be removed through the air exhausts in the corners. Thus, the removal efficiencies for the cases with larger particle sizes are greater than those for the cases with smaller particle sizes. In other words, the removal rates increases with the increase in the particle size. For the case without gravity effect, the removal rate is the worst among the cases. For the cases while the particle sizes are smaller than 15 μm, the removal rate reduces obviously. For the cases while the particle sizes are smaller than 10 μm, the removal rates converge toward a value almost equal to the removal rate.
The particle removal rate by each air exhaust: The comparison of removal rates from each air exhaust for the cases with different particle sizes is shown in Fig. 7 (from 0 to 600 sec). From the figure, due to the air exhaust 1 locating very close to the door, the particles passing through the door could be easily removed through air exhaust 1 by the airflow in the laboratory. Thus, the amount of particles removed from air exhaust 1 is greater than those from the other air exhausts and the removal rates from air exhaust 1 increase with the increase in the particle size. Furthermore, for the case without gravity effect, the removal rate from air exhaust 1 is the worst among the cases. The magnitudes of removal rates from the other air exhausts are air exhaust 2, air exhaust 3 and air exhaust 4 in order. For the case containing both 15 and 30 μm particles, the removal rate from air exhaust 1 is between the removal rates from air exhaust 1 for the two cases with only 15 and 30 μm particles but it is closer to that of the case with only 30 μm particles. With the
increase in the particle size, the diffuse efficiency of the particle decreases. Thus, the removal rates from each air exhaust increase with the increase in the particle size. The removal rates from each air exhaust for the case without gravity effect are the least among the cases. For the cases with the particle size equal or larger than 25 μm, there is no particle removed from the air exhaust 4.

The clearance time is defined as the required time for the particles can be entirely removed from laboratory from the time at \( t = 510 \) sec while the door is closed. Fig. 8 is the comparison of clearance time for the cases with different particle sizes. From the Fig. 8, it can be seen that the clearance time decreases with the increase in the particle size. The clearance time of the case without gravity effect is the longest among the cases. For the case containing both 15 and 30 μm particles, the clearance time is between the clearance times of the cases with only 15 and only 30 μm particles and it is closer to that of the case with only 15 μm particles.

Figure 9 is the comparison of the total removal rate by each air exhaust for the different particle sizes while the particles in the laboratory are entirely removed. The tendency of the particle restraint and removal rates in Fig. 9 is similar to those in Fig. 7.

For the analysis of the pollutant restraint and removal rates, Loomans and Lemaire (2002) investigated the distribution of pollution in an indoor space by calculating the distribution of the gaseous concentration. Their results show the removal rate is better while the particles deposit at the bottom of the room, which well agree with our results. However, in their study, they could not describe the effect of different particle sizes on the particle restraint rate.

**CONCLUSION**

The effects of particle sizes on the efficiency of restraining particles entering from the door to the laboratory and the efficiency of particle removal from the laboratory were investigated by simulating the flow conditions accompanied by a Lagrangian particle-tracking method. Utilizing the Lagrangian particle-tracking method can explicitly and precisely indicate the particle restraint and removal effects in the laboratory and the gravity effect of the particles can also be taken into account in the analysis. The numerical results present obvious differences in the restraint rate and the removal rate of particles for the cases with various particle sizes. Due to the gravity effect, the larger size particles tend to deposit at the bottom of the front room and the laboratory. While the door is open, the larger depositing particles can be brought into the laboratory by the airflow causing of the pressure gradient between the front room and the laboratory. Thus, the amount of particles entering the laboratory for the case with the larger size particles is greater than that for the case with the smaller particles. Therefore, the restraint rate decreases with the increase in the particle size and the case without the gravity effect possesses the best performance of the restraint rate among the cases in the study.
In the laboratory, due to the larger particles tend to deposit at the bottom of the laboratory and can be easily removed through the air exhausts in the corners by the airflows moving from the air supply on the ceiling. Thus, the removal efficiencies for the cases with larger size particles are greater than those for the cases with smaller size particles. Therefore, the removal rate increases with the increase in the particle size and the case without the gravity effect possesses the worst performance of the removal rate among the cases in the study. Similarly, due to the diffusion efficiency for the cases with smaller size particles are greater then those for the cases with larger size particles, the longer clearance time is required for the case with larger size particles. Finally, it is also found that for the case with the particle size smaller than 10 μm, the gravitational effect is much smaller and can be neglected. Therefore, for the case with the size of the contaminant smaller than 10 μm, the distribution of pollution in an indoor space can be obtained by solving the gaseous concentration equation to simulate the dispersion and deposition of pollutant particles inside an indoor space. However, for the case with the size of the contaminant greater than 10 μm, the gravity effect of the particles become more significant and can not be neglected in the analysis.

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