Measurement and Analysis of Dust Spatial Distribution in a Mechanically Ventilated Pig Building

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Dust has been implicated as a major contributor to the increased incidence of respiratory disorders among pig workers. Unlike gaseous contaminants, dust is not uniformly distributed within pig buildings. Dust spatial distribution is an important variable in the understanding of dust transportation and the implementation of appropriate control strategies. There is a lack of data on dust spatial distribution in livestock confinement buildings because of a lack of adequate sampling techniques. In this project, a multi-point sampler was used to measure the dust spatial distribution in a mechanically ventilated pig building. Experimental results show that there was a high variation in the dust spatial distribution within the mechanically ventilated pig building. Ventilation rate and diurnal change of weather affect the dust spatial distribution. It was shown that dust source control such as oil sprinkling at regular frequencies was an effective measure to control the dust levels. Room air cleaning such as dedusters can be used to reduce dust concentration and change dust spatial distribution.

1. Introduction

Confinement livestock housing at high animal density causes many problems such as poor indoor air quality (Carpenter, 1986), especially for cold climate buildings, in which the ventilation rate is low during winter. Many studies confirm the adverse effects of high contaminant concentration in livestock buildings on humans working in these contaminated environments (Dosman et al., 1988; Donham et al., 1989; Senthilselvan et al., 1997). Air quality has been an increasing concern for confinement livestock buildings.

Dust in enclosed pig buildings is primarily generated from feed grains, faecal materials, animal skin and hair, insects, and dead microorganisms. They are comprised of viable organic compounds, fungi, endotoxins, absorbed toxic gases, and other hazardous agents. It has been proven that dust adversely affects animal health and productivity (DeBoer et al., 1991). A considerable amount of data from the literature has shown that dust along with viable microorganisms, fungi and absorbed toxic gases within airspaces of pig buildings, have been implicated as major contributors to the increased incidence of respiratory disorders among pig producers compared to nonfarm workers (Donham et al., 1989).

Unlike gaseous contaminants, the trajectories of the dust particles differ from the air streamlines within an airspace. Dust concentration depends largely on air distribution, relative locations of the dust sources, and the level of animal activity in the building. Consequently, dust is not likely to be uniformly distributed within a ventilated airspace, i.e., it can be expected that there are spatial gradients of dust concentration within a ventilated airspace. Dust spatial concentrations in livestock buildings have been studied by Barber et al. (1991). They found that there is a significant spatial variability of dust within pig buildings. However, more research on dust spatial distribution is needed to characterize the dust within livestock buildings.
The dust transport behaviour is very complicated in a ventilated airspace, because of the combined effects of airflow patterns, animal and human activities, gravitational sedimentation, diffusion, coagulation, adhesion and resuspension. One of the challenges in indoor air quality studies is to measure the dust spatial distribution so that the nature of dust transportation can be better understood and appropriate control strategies can be implemented. A clear understanding of the dust spatial distribution will provide useful information to control dust sources, improve the design of ventilation systems and implement the control technologies. The first objective of this project was to measure the dust mass spatial distribution within a typical mechanically ventilated pig building at different conditions to study the dust transport behaviour. The second objective was to evaluate dust control techniques (oil sprinkling and deduster) in the field, using multiple point measurements.

2. Material and methods

2.1. Multi-point dust sampler

A common method of dust measurement has been based on monitoring dust concentration at only one representative location or on ‘grab’ samples collected at two or three sites within the animal buildings. To study the dust spatial distribution and transport behaviour, it is critical to measure dust concentrations across an airspace at multiple points during the same time period. Otherwise, the time required for each measurement point (typically of the order of hours or days for mass concentration) will introduce large errors in dust distribution patterns which are highly time dependent.

A multi-point dust sampler has been developed by the authors using an array of critical venturis (Wang et al., 1999). A conceptual design of the multi-point sampler is shown in Fig. 1. It consists of a commercially available vacuum pump, a pressure monitor, a pressure regulator, and an array of critical venturis with air filters. When the air is drawn through a filter, the volumetric flow rate remains constant for all venturis as long as the pressure across the venturi is higher than the critical pressure drop. Since the critical pressure drop of the venturi is below 11 kPa, the pump is operated at a sufficiently high vacuum and a constant flow through the filters is maintained. This multi-point sampler is used in this study to measure the dust mass concentration in a cross-section of a typical pig building.

2.2. Experimental arrangement

The building used in this experiment is shown in Fig. 2. This building comprised two identical rooms, each housing 72 pigs. Fresh air entered each room through slotted air inlets. Each room had two exhaust fans with a total capacity of $4.3 \times 10^{-3} \text{m}^3 \text{s}^{-1}$. During winter operation, the room air temperature was approximately 18–22°C. A thermostat control system was used to activate the fans or heater to control air temperature in the rooms. The fan duty cycles were recorded using timers connected to the fans so that the ventilation rate could be calculated.
Temperature and relative humidity were recorded continuously in each room using an Oakton hygrothermograph, which was calibrated inside the pig building by measuring the dry-bulb temperature and the wet-bulb temperature.

Each room consisted of 11 pens; each pen is equipped with one two-hole feeder and a nipple drinker. Two pens in the middle of the room were kept empty to set up the multi-point sampler. Partially slotted floors were used in both rooms. The animals housed in this building weighed between 70 and 110 kg each and were fed with mashed dry maize meal.

Air velocities were measured prior to the dust sampling tests to ensure that the sampling efficiency was close to 100%. Air velocities were also measured at the same points that the dust samples were measured plus seven extra points along the ceiling (35 points total, Fig. 3). An air velocity meter (Model 8330, TSI Inc.) was calibrated in the factory. The accuracy is ±50% of reading or ±0.025 m s⁻¹, whichever is greater in the range of 0.13–20 m s⁻¹. The measured velocity distribution is shown in Fig. 4. Figure 4 shows that the room air velocity at most of the sampling points was less than 1.0 m s⁻¹, except some points near the ceiling next to the inlet. According to still air sampling criteria for negligible sampling error due to particle inertia (Vincent, 1989; Hinds, 1999; Wang, 2000), the maximum air velocity is 1.3 m s⁻¹ for 10 μm, and 0.5 m s⁻¹ for 20 μm particles. That means that the sampling errors caused by particle inertia are negligible if the air velocity is less than 1.3 m s⁻¹ for 10 μm particles or the air velocity is less than 0.5 m s⁻¹ for 20 μm particles in a close still air sampling. Since the room air velocity at most of the sampling points was less than 0.5 m s⁻¹, the dust sampling inlet was oriented perpendicular to airflow to keep the sampling efficiency at all sampling points close to 100%. The sampling efficiency was less than 1 for particles larger than 20 μm in a few sampling points next to the ceiling due to particle inertia because the air velocity was greater than 0.5 m s⁻¹. The sampling error
was considered to be small because there were very few particles larger than 20 µm in the upper level of the pig building.

The dust mass concentrations of 27 points at the central cross-section were measured using a multi-point sampler, as shown in Fig. 5. The dust collector located upstream of each critical venturi was a 37 mm diameter (0·8 µm porosity, Millipore Co.) filter housed in a holding cassette. Filters were dried in a desiccant drier for 24 h and weighed on a precision electronic balance (Model AG245, Mettler-Toledo AG) prior to the dust collection. The accuracy of the balance is 0·02 mg in the range of 0–41 g. This balance was calibrated with an internal calibration weight. In the pig building measurements, the start time and the stop time of dust sampling were recorded. Each measurement was over an approximate 24 h period except for the daytime and nighttime sampling (diurnal effect study). The samplers were dried in a desiccant drier for 24 h after sampling and immediately weighed again on the precision electronic balance. The dust mass in each filter was calculated and recorded.

2.3. Error analysis

2.3.1. Standard deviations

The dust mass concentration in each point was calculated using the following equation.

\[
C_m = \frac{1000m}{Qt}
\]  

where: 
- \(C_m\) is the dust mass concentration in mg m\(^{-3}\); 
- \(m\) is the net mass increase of the filter after sampling in mg; 
- \(Q\) is the sampling rate of each filter in l min\(^{-1}\); and 
- \(t\) is the sampling period in min.

The standard deviation can be calculated using the following equation (Bevington, 1969):

\[
\sigma_C^2 = \sigma_m^2 \left(\frac{C}{m}\right)^2 + \sigma_Q^2 \left(\frac{C}{Q}\right)^2 + \sigma_t^2 \left(\frac{C}{t}\right)^2
\]  

where: 
- \(\sigma_C\) is the dust mass concentration standard deviation in mg m\(^{-3}\); 
- \(\sigma_m\) is the dust mass standard deviation in mg; 
- \(\sigma_Q\) is the air flow standard deviation in l min\(^{-1}\); and 
- \(\sigma_t\) is the time standard deviation in min.
2.3.2. **Estimation of standard deviations**

The maximum error of time measurement in this test was 2 min. The maximum error of mass measurement in this test was 0.2 mg. The error of flow rate was the most difficult to estimate. The real mass flow rate of a critical venturi is dependent on its upstream pressure even though the volume flow rate at the upstream condition is constant. Therefore, when a critical venturi is used in air sampling to measure and control the flow rate, its flow rate under operating conditions should be calibrated. If the critical venturi is used downstream of the filter, the critical venturi can be calibrated under actual operating conditions using a calibrated flow meter (e.g., a rotameter) since different types of filters and sampling set-up have different pressure drops across them. In this case, the flow rate of the critical venturi was calibrated with a rotameter. The effect of the filter and dust loading on the flow rate of the critical venturis was checked. Before sampling, the sampling rate of each filter was checked with a calibrated rotameter (Dwyer Rate-Master Flowmeter, accuracy within ±3% of full-scale reading), the average sampling rate of all the filters was 19.2 ± 0.2 l min⁻¹ (at temperature T = 21.5°C and pressure P = 739 mm Hg). The flow rate after dust loading was also checked. The calibration results show that the pig barn dust loading on the filter did not have a significant effect on the flow rate. The maximum standard deviation of flow caused by dust loading was 0.24 l min⁻¹. According to the calibration of the critical venturi in the laboratory, the standard deviation of flow for the critical venturi in the multi-point sampler was 0.2 l min⁻¹. So the maximum error of flow was 0.44 l min⁻¹. Then the standard deviation of dust mass concentration can be calculated using Eqn (2).

The standard deviation of the overall average mass concentration of 27-point measurements was calculated using the equation:

$$\sigma_{om}^2 = \left(\frac{1}{27}\right)^2 (\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \cdots + \sigma_{27}^2)$$  \hspace{1cm} (3)$$

where: \(\sigma_{om}\) is the standard deviation of overall average mass concentration of 27-point measurements in mg m⁻³; \(\sigma_i\) is the mass standard deviation in mg m⁻³ calculated using Eqn (2) for each point measurement \(i = 1, 2, \ldots, 27\).

3. **Results and discussion**

The dust mass concentrations of 27 points at the central section of the building were measured at different conditions between 20 November 1998 and 2 April 1999. The dust mass concentration spatial distributions were plotted using a surface mapping software SURFER (Golden Software, CO 80401, USA). The SURFER software plots a contour map based on scattered point data. In this case, the scattered point data are 27 dust concentrations across the experimental room (Fig. 5). Typical experimental cases and results are summarized in Table 1. Each test had only one replicate because the test conditions such as ventilation rate, animal activities and pen

<table>
<thead>
<tr>
<th>Tests</th>
<th>Indoor</th>
<th>Outdoor</th>
<th>Sampling</th>
<th>Fan duty</th>
<th>Overall average dust mass concentration (C₀m), mg m⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temp., °C</td>
<td>Relative humidity, %</td>
<td>Temp., °C</td>
<td>time, minute</td>
<td>cycle*, %</td>
</tr>
<tr>
<td>Low ventilation</td>
<td>20–22</td>
<td>58 ~ 73</td>
<td>1 ~ 11</td>
<td>1375</td>
<td>26</td>
</tr>
<tr>
<td>Middle ventilation</td>
<td>20–23</td>
<td>40 ~ 60</td>
<td>-3 ~ 9</td>
<td>1385</td>
<td>68</td>
</tr>
<tr>
<td>High ventilation</td>
<td>20–23</td>
<td>67 ~ 80</td>
<td>8 ~ 19</td>
<td>1254</td>
<td>99</td>
</tr>
<tr>
<td>Nighttime</td>
<td>15–18</td>
<td>51 ~ 69</td>
<td>-2 ~ 1</td>
<td>971</td>
<td>11</td>
</tr>
<tr>
<td>Daytime</td>
<td>16–19</td>
<td>51 ~ 70</td>
<td>-5 ~ 0</td>
<td>480</td>
<td>30</td>
</tr>
<tr>
<td>Control roomicky</td>
<td>20–22</td>
<td>53 ~ 74</td>
<td>-5 ~ 0</td>
<td>1405</td>
<td>11</td>
</tr>
<tr>
<td>Air cleaning with dedusters</td>
<td>19–24</td>
<td>51 ~ 66</td>
<td>4 ~ 21</td>
<td>1425</td>
<td>19</td>
</tr>
<tr>
<td>Control room()</td>
<td>16–19</td>
<td>53 ~ 74</td>
<td>-3 ~ 7</td>
<td>1410</td>
<td>N/A</td>
</tr>
<tr>
<td>Oil sprinkling</td>
<td>16–19</td>
<td>48 ~ 80</td>
<td>-2 ~ 14</td>
<td>1330</td>
<td>N/A</td>
</tr>
</tbody>
</table>

1 Control room, refers to the reference room which runs in the regular practice without any treatments.

2 Fan duty cycle is a percentage of time when both fans were on during the sampling period. Fan capacities are 4.3 m³ s⁻¹.

3 Overall average mass concentration is the average mass concentration of 27 points in the entire room.

4 The error is calculated according to the standard deviations of 27-point measurements.

5 N/A—the data are not available.
floor conditions were difficult to keep consistent in different tests over the time period of the experiment.

3.1. Effect of ventilation rate on dust spatial distribution

Ventilation is effective in the control and dilution of gaseous contaminants. It is also widely believed that ventilation has a direct effect on dust spatial distribution. Ventilation will remove dust from the airspace, but at the same time ventilation may increase air movement and stir up dust and keep much of it airborne. Physical disturbances are especially involved in pig buildings, such as the movement of pigs (Shaw, 1994).

Dust spatial distributions at different ventilation rates were measured in the same room. However, the ventilation rate was regulated by a thermostatically controlled system based on weather changes, rather than controlled by experimental design. So, the measurement of dust spatial distributions at the required ventilation rates had to be carried out on different days. As a result, there was a difference in the experimental conditions in the pig building on the different days. Variations in pig behaviour, floor cleanliness and relative humidity were recorded. However, the largest difference occurred with the average ventilation rate: case (a) was at low ventilation rate, case (b) was at middle ventilation rate, and case (c) was at high ventilation rate. The fans in case (a) were running only 26% of the time (average ventilation rate 1.1 m$^3$ s$^{-1}$). The fans in case (b) were running 68% of the time (average ventilation rate 2.9 m$^3$ s$^{-1}$) and the fans in case (c) were running 99% of the time (average ventilation rate 4.2 m$^3$ s$^{-1}$).

The dust spatial distributions at three different ventilation rates are shown in Fig. 6. All results show that there is a high variation in the dust spatial distribution within the mechanically ventilated pig building. At 1.1 m$^3$ s$^{-1}$ ventilation, there was a high dust concentration zone close to the centre and dust was more symmetrically distributed across the building section. The higher ventilation rate caused a zone of high dust concentration near the air inlet side. This could be a local zone that had less air exchange, as shown in the velocity distribution in Fig. 4. The dust spatial distribution is similar to the airflow pattern. It appears that the ventilation rate has a direct effect on the dust spatial distribution. However, the measured overall average dust mass concentrations [4.56 mg m$^{-3}$ in case (a) and 4.05 mg m$^{-3}$ in case (b)] indicated little difference between cases (a) and (b) even though the ventilation rate in case (b) was 2.6 times higher than in case (a). The possible reason for this is that the dust production rate increases with the increase of the ventilation rate. This indicates that the ventilation rate has an effect on the overall dust removal, but not as much as expected.

In case (c), the ventilation rate increased by 45% from case (b). The dust spatial distribution was similar to that in case (b). The difference is that the dust spatial distribution in case (c) is more influenced by airflow pattern. On comparing the measured overall average dust mass concentrations [4.05 mg m$^{-3}$ in case (b) and 2.86 mg m$^{-3}$ in case (c)] between cases (b) and (c), it is found that the measured overall average dust mass concentrations decreased by about 42%. It seems that the ventilation rate in the (c) and (b) range has a significant effect on the overall dust removal and the dust reduction is approximately proportional to the increase of the ventilation rate. This is in conflict to the conclusion drawn from the comparison of cases (a) and (b). After checking the recording of the conditions of the pen floor in cases (b) and (c), it was found that there was a difference in the cleanliness of the floor. Compared to case (b), the pen floor was more messy and wet in case (c) during the test period because of warmer weather. This indicates that there was a difference in the dust production rate. Another possible reason could be the difference in relative humidity. Due to more manure on the floor and warmer weather, case (c) has higher relative humidity. This could affect the resuspension rate inside room. Since it is difficult to control the experimental conditions in the pig building, it seems necessary to carry out further study under controllable experimental conditions to verify the effect of the ventilation rate on the overall average dust level.

3.2. Effect of diurnal change on dust spatial distribution

The dust concentrations were measured during the day and at night to study the effect of diurnal change on dust spatial distribution during winter operation. The nighttime measurements were taken between 5:00 pm to 9:00 am the next day, and the daytime measurements were taken between 9:00 am to 5:00 pm during the same day. The lights were on for 24 h. Figure 7 shows that the dust spatial distribution changes with the diurnal change.

The measured spatial dust concentrations showed that the overall dust level during the daytime was much higher than that during the nighttime even though the daytime had a higher ventilation rate. One explanation for this phenomenon is the animal activity. Compared with nighttime, pigs are usually more active during the daytime. They are eating, walking and playing, and disturbing more dust into the air. The activities of farm workers might also affect the dust production during the daytime. Comparing the dust spatial distribution patterns, the dust was more symmetrically distributed across the
section during nighttime because of the low ventilation rate.

3.3. Effect of dust source control on dust spatial distribution

Dust spatial distribution and dust level are very closely related to the dust source and dust production rate. It has been proven that oil sprinkling can control the dust source and reduce the dust production rate (Zhang et al., 1996). A field test was conducted in a typical pig building to evaluate the effectiveness of oil sprinkling during winter operation. A pig finishing building was divided into two identical rooms with a solid, airtight partition between the two rooms (Fig. 2). Soya bean oil was sprinkled on the floor surface and pigs, once a day with a manual sprayer, in the treatment room. The schedule of oil

![Dust concentration, mg m⁻³](image)

![Dust concentration, mg m⁻³](image)

![Dust concentration, mg m⁻³](image)

Fig. 6. Effect of the ventilation rate on dust spatial distribution in mg m⁻³: (a) low ventilation rate at 26% fan duty cycle, average dust concentration $C_{ave} = 4.56$ mg m⁻³; (b) medium ventilation rate at 68% fan duty cycle, $C_{ave} = 4.05$ mg m⁻³; (c) high ventilation rate at 99% fan duty cycle, $C_{ave} = 2.86$ mg m⁻³
sprinkling was as follows: days 1 to 2 with 40 ml m\(^{-2}\); days 3 to 4 with 20 ml m\(^{-2}\); and days 5 to end of study with 15 ml m\(^{-2}\). Dust size distribution was measured using a laser particle counter (CLIMET, Model CI-7350) 1.5 m above the floor in the middle of the hallway after oil sprinkling treatments for 4 weeks. A comparison of dust size distribution between the oil sprinkled room and the control room is shown in Fig. 8. This data are the mean of five samples. The control room refers to the room which is managed based on the normal practice without any treatments.

With oil sprinkling, there was an approximate 80% reduction in particles larger than 1 µm, as shown in Table 2. However, the concentration of small particles

![Dust concentration, mg m\(^{-3}\)](image)

**Fig. 7.** Effect of diurnal change on dust spatial distribution in mg m\(^{-3}\): (a) nighttime in control room, ventilation rate = 0.473 m\(^3\) s\(^{-1}\), average dust concentration \(C_{ave} = 4.23\) mg m\(^{-3}\); (b) daytime in control room, ventilation rate = 1.29 m\(^3\) s\(^{-1}\), \(C_{ave} = 7.14\) mg m\(^{-3}\)

![Dust concentration, mg m\(^{-3}\)](image)

**Fig. 8.** Dust size distribution in various locations: ■, control room; □, oil-sprinkling treatment room; □, outdoor air

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**Fig. 8.** Dust size distribution in various locations: ■, control room; □, oil-sprinkling treatment room; □, outdoor air

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**Table 2.** Dust concentration in various locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Dust concentration, mg m(^{-3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control room</td>
<td>4.23</td>
</tr>
<tr>
<td>Oil-sprinkling room</td>
<td>7.14</td>
</tr>
<tr>
<td>Outdoor air</td>
<td>2.0</td>
</tr>
</tbody>
</table>
(< 1 μm) was higher in the oil sprinkling room. According to the size distribution of outdoor dust, the small particle concentration was very high in the outdoor air. Thus, it is assumed that the small particles inside the pig building are mainly entering with fresh air from outside (Zhang et al., 1994). In the control room, because there was a large number of larger particles, the small particles had more chance to collide with large particles and agglomerate to form even larger particles. In the treatment room, the small particles had less opportunity to collide with larger particles because of the low concentration of large particles.

After sprinkling oil for 4 weeks, the dust spatial concentrations at 27 points across the central section in the treatment room were measured using a multi-points sampler (Fig. 5). Figure 9 shows the dust spatial distributions in the treatment room (with oil sprinkling) compared to the control room (without oil sprinkling). The measured dust spatial concentration in the treatment room shows that the overall mass dust level (0.82 mg m⁻³) was 70% lower than the control room (2.75 mg m⁻³). As oil sprinkling reduces most of the larger size particles, the dust spatial distribution pattern after treatment was similar to the airflow pattern because the small size particles are more likely to follow the air streamline (Fig. 9b).

Table 2. Particle size distributions in the control room and the treatment room

<table>
<thead>
<tr>
<th>Particle size, μm</th>
<th>Outdoor</th>
<th>Control room</th>
<th>Treatment room</th>
<th>Dust reduction, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3–0.5</td>
<td>10.86</td>
<td>—</td>
<td>2.84</td>
<td>—</td>
</tr>
<tr>
<td>0.5–0.7</td>
<td>1.69</td>
<td>—</td>
<td>2.50</td>
<td>—</td>
</tr>
<tr>
<td>0.7–1</td>
<td>0.26</td>
<td>0.00</td>
<td>1.27</td>
<td>—</td>
</tr>
<tr>
<td>1–5</td>
<td>0.19</td>
<td>5.82</td>
<td>1.51</td>
<td>74</td>
</tr>
<tr>
<td>5–10</td>
<td>0.03</td>
<td>3.12</td>
<td>0.40</td>
<td>87</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>0.01</td>
<td>3.03</td>
<td>0.47</td>
<td>84</td>
</tr>
</tbody>
</table>

3.4. Effect of air cleaning on dust spatial distribution

Internal air cleaning can effectively improve indoor air quality. The dust removal effectiveness of air cleaning using aerodynamic dedusters was evaluated in a typical pig building during winter operation. An aerodynamic deduster is an air cleaning device which creates a spiral airflow at very high speed, thus separating particles from the airflow using centrifugal force. This deduster had a dust removal efficiency of 85% (Zhang et al., 1998). The pig finishing building was divided into two identical rooms using a solid, airtight partition (Fig. 2). In the treatment room, two aerodynamic dedusters were installed to remove dust in an air recirculation system. The air in the treatment room was recirculated through the dedusters to clean the room air using an air inlet and outlet duct system. The air inlet duct was placed where the highest dust concentration was expected, while the outlet duct was placed above the centre alley [Fig. 10(b)].

The total airflow rate of the two dedusters was 0.264 m³ s⁻¹. The ratio of the airflow rate through the dedusters to the average room ventilation rate was 32%. The dust spatial concentrations at 27 points across the central section in the control room and the treatment room were measured using a multi-point sampler. Before the measurements, the dedusters were cleaned using water to remove the dust that settled on the inner walls, fans and flexible ducts. The measured spatial dust concentrations with dedusters showed that the overall average dust level (3.82 mg m⁻³) is approximately 20% lower than the control room (5.02 mg m⁻³)[Fig. 10(b)]. This agrees well with the predicted dust reduction efficiency using the following equation:

\[ \frac{\eta J Q_f}{Q_r + \eta J Q_f} \]

where: \( \xi_r \) is the dust reduction efficiency of the room measured by percentage; \( J \eta \) is the dust removal efficiency of air cleaner; \( Q_r \) is the room ventilation rate in m³ s⁻¹; and \( Q_f \) is the airflow rate of air cleaner in m³ s⁻¹.

In this test, \( Q_f \) has a value of 0.32 \( Q_r \), \( J \eta \) is 0.85, and \( \xi_r \) is 21%. Apparently, a large flow rate for the deduster is required to improve the room air cleaning efficiency. The high dust concentration zone near the air inlet side disappeared in the treatment room. This indicates that some dust was removed from the dusty air by the air cleaning recirculation system. On the other hand, as the air recirculation system affected the airflow pattern, the dust spatial distribution was different from the control room. Additionally, it was observed during the test that the dedusters required frequent cleaning to maintain the high removal efficiency.
4. Conclusions

Dust spatial distributions at different conditions (ventilation rate, daytime and night-time, dust source control and air cleaning) were measured using a multi-point sampler in a typical pig building. Dust concentration depends largely on air distribution, relative locations to the dust sources, animal and human activity level in the building, and air cleaning technologies. Based on the experimental results, the following conclusions are summarized.

(1) Unlike gaseous contaminants, the trajectories of the dust particles may differ from the air streamlines within an airspace. There was a high variation in the dust spatial distribution within the mechanically ventilated pig building.

(2) Air distribution has a direct effect on the dust spatial distribution. But increasing the ventilation rate may not effectively reduce the overall dust level because the dust production rate increased with an increase of the ventilation rate as a result of interaction of air movement and mechanical disturbance, such as animal activities.

(3) There is a large variation in the overall dust concentration with the diurnal change. The overall dust concentration during the daytime is approximately 70% higher than the nighttime, likely due to the animal activities which increased the airborne dust production.

(4) Measured dust spatial distribution shows that air cleaning with dedusters can reduce the dust level. To improve the overall dust removal efficiency, a large flow rate through the dedusters is required.

(5) Oil sprinkling at regular frequencies is an effective measure to control the dust level. The overall dust mass concentration was reduced by 70% in this study.
(6) The variation of experimental results indicates that further study at controllable experimental conditions is necessary to study the effects of the ventilation rate and ventilation system on the dust spatial distribution.

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Fig. 10. Comparison of dust spatial distribution in mg m$^{-3}$ between control room and treatment room with air cleaning: (a) control room: without air cleaning, average dust concentration $C_{ave} = 5.02$ mg m$^{-3}$; (b) treatment room: air cleaning with dedusters, $C_{ave} = 3.82$ mg m$^{-3}$


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