A SCALE MODEL STUDY ON CONTAMINANT REMOVAL EFFECTIVENESS OF INDUSTRIAL FACILITY

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ABSTRACT

Effective ventilation systems for a factory where various kinds of contaminant are discharged from many point sources are investigated in this study. Two ventilation systems are examined by scale model experiment using tracer gas. One system supplies fresh air and exhausts indoor air through the ceiling; the other has the inlet in the floor and outlet in the ceiling. Each system has a hanging wall installed at the ceiling, a device for immediate removal of the contaminant before it diffuses into the whole space. The performance of these ventilation systems is evaluated by an index of contaminant removal effectiveness.

Results indicate that the hanging wall system can be very effective to ensure good indoor air quality if properly designed. The system with fresh air supply from the floor and a long hanging wall was the most effective. This system reduces the spatial averaged concentration in the occupied zone to 60% of the complete mixing concentration and therefore improves the air quality.

KEYWORDS

Model experiment, Invent, Contaminant removal effectiveness, Concentration distribution, Hanging wall

INTRODUCTION

Usually, various kinds of contaminant are discharged at many locations in manufacturing factory. It is therefore difficult to have clean air by ventilating the whole space. Local ventilation systems which remove the contaminant immediately after its release to the occupied zones are adopted in most factories. Such a system may consist of various devices for effective ventilation. The design of ventilation systems should take into account the origins of contaminant.

In this study, the effectiveness of ventilation systems for a factory manufacturing tires were examined by model experiments. In particular, the influence of the relative locations of the inlet and the outlet and the influence of hanging wall length from the ceiling were studied on six experimental models. The distribution of concentration was measured and the performance of the ventilation systems was evaluated with an effectiveness index[1],[2].

EXPERIMENTAL METHODS

Model and experimental apparatus

The geometric scale of the models of a factory space is 1/32. The models were made from plywood and transparent acrylic board. The three dimensions of the inside space of the models were 2.0 m (length), 2.3 m (width) and 0.31 m (height) as shown in Figure 1 and Figure 2. Twenty four machines out of the ninety six in the factory were assumed to emit contaminants. Ethylene tracer gas was discharged to a height of 3.75 cm in a rate of 0.25 cm³/s from each machines.

The sources of tracer gas remained the same for all experiments. Aluminum sheet is affixed to the inside wall of the models to prevent the absorption of the tracer gas. In
the models, twenty four vents (a diameter of 0.03 m) in total were arranged in the ceiling and two sheets of mesh were installed in the chamber so that the exhaust air velocity of each vent was equal (Figure 3).

The examined ventilation system

The performance of two kinds of ventilation systems was examined in Table 1 and Figure 4. One of the systems supplies fresh air and exhausts indoor air through the ceiling, the other supplies fresh air from the floor and exhausts indoor air through the ceiling. By using three different wall lengths, the effect of the hanging wall installed at the ceiling was also examined. The ventilation flow rate on the ceiling was 0.03 m$^3$/s for all experiments. This corresponded to an air change rate of 75 times/h.

Measurement points of tracer gas concentration

The measurement points of concentration were arranged at three planes

![Figure 1 Exhaust outlet, supply inlet and measurement points in the model (Scale: 1/32)](image1)

![Figure 2 Sectional view of model with a hanging wall and the measurement height of the plane](image2)

![Figure 3 Measuring system](image3)
of different heights: 1.5m (A-plane), 2.5m (B-plane) and 5.0m (C-plane) from the floor in the prototype, see Figure 2. There were seventy two points in each plane. The concentration at each point was measured by using the photoacoustic infra-red detection method after the exhaust air concentration and the concentration at a reference point were steady.

Normalization of concentration and evaluation of ventilation performance

The concentration measured can be normalized to yield a dimensionless concentration by using equation (1). This dimensionless concentration is defined as the ratio of the concentration at a measurement point to that of the exhaust; the concentration of the ambient supply air was removed from the calculation. Since the exhaust air concentration corresponds to the complete mixing situation, the dimensionless concentration means the ratio of the concentration to that of complete mixing. The dimensionless concentration, which is the proportional to the effectiveness index of contaminant removal described in literature [1], is an indicator for the efficiency of the ventilation system. A small dimensionless concentration means high efficiency.

\[ C'_p = \frac{C_p - C_x}{C_e - C_s} \]  

(1)

where

- \( C'_p \) = dimensionless concentration
- \( C_p \) = concentration at measurement point
- \( C_e \) = concentration of exhaust air
- \( C_s \) = concentration of supply air

The performance of each ventilation system is evaluated by the spatial averaged dimensionless concentration in the three planes as shown in equation (2). The averaged dimensionless concentrations in A-plane of the systems are compared for different systems.

<table>
<thead>
<tr>
<th>Type of the model</th>
<th>Supply air</th>
<th>Exhaust air</th>
<th>length of the hanging wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1-1</td>
<td>from the ceiling</td>
<td>from the ceiling</td>
<td>without hanging wall</td>
</tr>
<tr>
<td>Type 1-2</td>
<td>from the ceiling</td>
<td>from the ceiling</td>
<td>15.6cm (to the center of the room height)</td>
</tr>
<tr>
<td>Type 1-3</td>
<td>from the ceiling</td>
<td>from the ceiling</td>
<td>22.3cm (to the center of the room height)</td>
</tr>
<tr>
<td>Type 2-1</td>
<td>from the ceiling</td>
<td>from the ceiling</td>
<td>without hanging wall</td>
</tr>
<tr>
<td>Type 2-2</td>
<td>from the ceiling</td>
<td>from the ceiling</td>
<td>15.6cm (to the center of the room height)</td>
</tr>
<tr>
<td>Type 2-3</td>
<td>from the ceiling</td>
<td>from the ceiling</td>
<td>22.3cm (to the center of the room height)</td>
</tr>
</tbody>
</table>

Table 1 Ventilation system examined in the experiment

Figure 4 Sectional view of the model types
\[
\overline{C} = \frac{\sum(C_p \times A_p)}{\sum A_p}
\]

where \( \overline{C} \) = spatial averaged concentration
\( A_p \) = the area each measurement point represents

RESULTS AND CONSIDERATION

Distribution of dimensionless concentration

1. Exhaust-ceiling supply system

The distributions of the dimensionless concentration in each plane for the system supplying air from the ceiling are shown in Figure 5, 6 and 7, representing three different hanging walls. Figure 5 shows the concentration of Type 1-1 without hanging wall. Figure 6 gives the concentration of Type 1-2 having the hanging wall extended to the center of the wall height. Figure 7 shows the concentration of Type 1-3 which has the hanging wall to the top of the machines. For Type 1-3, the region having dimensionless concentration of less than 0.5 exists a little broader in each plane, and the region having dimensionless concentration higher than 1.5 was limited to the immediate neighborhood of the contaminant sources, contrast to Type 1-1 and Type 1-2. The A-plane is within the occupied zone, and Type 1-3 had the lowest concentration. There was no distinct difference in the dimensionless concentrations in A-plane between Type 1-1 and Type 1-2.

2. Exhaust-floor supply system

The distributions of the dimensionless concentration in each plane for the system supplying air from the floor are shown in Figure 8, 9 and 10 for different hanging walls. For Type 2-1, dimensionless concentration of less than 0.5 was not detected and the region having concentration higher than 1.5 was in the lower portion of Figure 8. The region having concentration of less than 1.0 in A-plane was about 40% of the whole area. For Type 2-2, dimensionless concentration of less than 0.5 was found near the wall in each plane and regions having concentration higher than 1.5 were small. The region having concentration of less than 1.0 in the A-plane was about 80% of the whole area. For Type 2-3, dimensionless concentration of less than 0.5 appeared not only near the wall but also in the center part of the space. Concentration higher than 1.5 was rare. The region having concentration of less than 1.0 in A-plane was about 80% of the whole area.

Comparison of the averaged dimensionless concentration in each plane

The spatial averaged dimensionless concentration in each plane of the six models examined in the experiments were calculated and listed in Table 2. In the case of the ventilation system with air supply from the ceiling, no big difference in the averaged dimensionless concentration in A-plane was found between Type 1-1 and Type 1-2, and the concentrations were close to that of the complete mixing. The dimensionless concentration in Type 1-3 was smaller than that of the complete mixing. In other words, the hanging wall was useful for the removal of contaminant when it reached the height of the machines. Short hanging walls, such as Type 1-2, were not so effective. In the case of the ventilation system with air supply from the floor, the averaged dimensionless concentration of Type 2-1 exceeded the

<table>
<thead>
<tr>
<th>Supply from air</th>
<th>Type of model</th>
<th>A-plane</th>
<th>B-plane</th>
<th>C-plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>from the ceiling</td>
<td>Type 1-1</td>
<td>1.04</td>
<td>1.04</td>
<td>1.01</td>
</tr>
<tr>
<td></td>
<td>Type 1-2</td>
<td>1.03</td>
<td>1.02</td>
<td>0.96</td>
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<td>Type 1-3</td>
<td>0.97</td>
<td>0.98</td>
<td>0.95</td>
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<tr>
<td>from the floor</td>
<td>Type 2-1</td>
<td>1.14</td>
<td>1.18</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>Type 2-2</td>
<td>0.72</td>
<td>0.77</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Type 2-3</td>
<td>0.60</td>
<td>0.56</td>
<td>0.56</td>
</tr>
</tbody>
</table>
Figure 5  Dimensionless concentration distribution in each plane of Type 1-1

Figure 6  Dimensionless concentration distribution in each plane of Type 1-2

Figure 7  Dimensionless concentration distribution in each plane of Type 1-3
Figure 8  Dimensionless concentration distribution in each plane of Type 2-1

Figure 9  Dimensionless concentration distribution in each plane of Type 2-2

Figure 10  Dimensionless concentration distribution in each plane of Type 2-3
concentration of the complete mixing (1.0), and the concentrations for Type 2-2 and Type 2-3 were lower than that of the complete mixing (1.0). The concentration of Type 2-3 was the lowest, 0.60 times the complete mixing concentration.

CONCLUDING REMARKS
The performance of ventilation systems for occupied zones in an industrial facility can be adequately evaluated by the index of contaminant removal effectiveness. The ventilation system exhausting air from a ceiling with hanging wall to reduce the diffusion by removing the contaminant immediately after its release was effective for air supply from either the ceiling or the floor. The effectiveness of the system was marginal when the hanging wall was too short. The ventilation system with air supply from the floor was the most effective to remove the contaminant in the occupied zone when the hanging wall reached the top of the machines.

REFERENCES