# CONTAMINATION CONTROL BY UNIDIRECTIONAL FLOW VENTILATION IN A REFUSE DISPOSAL FACILITY

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**ABSTRACT**

A series of CFD and model experiments were carried out in order to find the most effective ventilation system in a separated refuse disposal facility. The ventilation system needed in the facility protects the working space from dust and odors generated by handling refuse. The desired ventilation system is to introduce the outdoor air from the one side of the working area and to exhausts the contaminated air through the opposite side of the refuse stock yard, so-called the unidirectional airflow ventilation.

Both of the experiments indicated that an air curtain system and a wind shield screen which were added to the basic system could improve the ventilation efficiency. System performance was measured at a newly built facility. The measurements proved that this system needs only an additional 3% of total flow rate to effectively protect the working space from contamination.

**KEYWORDS**
CFD, Model experiments, Full-scale experiments, Ventilation efficiency, Separated refuse disposal facility

## INTRODUCTION

Recently, the disposal of municipal refuse has caused huge problems. All the wastes are usually dumped at sea or are disposed off by means of incinerators. But the increasing mass of the waste requires a nearly infinite space. It is extremely necessary to overcome the problems of increasing waste by reducing the amount of waste and/or by reusing it. In some cities, a recycling system has been introduced. After being collected daily, salvageable materials such as cans and bottles are sorted and kept separate to be reused. To recycle as much waste as possible, a large separated refuse disposal facility must be built. In such a facility, collected city wastes are carried in by the containers and are then separated by machine and/or by hand to be reused. Usually there is no partition between the stock yard, where the waste is stored temporarily, and the working yard, where the waste is handled. The workers who carry waste and sort out the salvageable materials suffer terribly from the dust and odors if an effective ventilation system is not operated. The ventilation system is expected to prevent dust and odors which are generated in the stock yard from spreading and entering into the working yard. The best ventilation system will introduce outdoor air from the one side of the working yard and exhaust the contaminated air through the other side of the stock yard, which provides unidirectional airflow ventilation. The ideal unidirectional airflow ventilation system which is employed in the cleanroom needs a huge volume of airflow and is very uneconomical when applied to a large building. In this study, we investigate how a unidirectional airflow ventilation system can be improved in efficiency and economy.

## VENTILATION PRINCIPLE

Figure 1 shows the disposal facility and its ventilation system. It has two sets of the equipment. Each yard is divided into two parts with no partition. The recyclable waste is carried in by the container truck through the slope attached the west wall of the building and dumped at the stock yard, which occupies one half of the whole yard. The other half is the working yard where the vehicles pick up the waste and then transfer it to the next process. The main function of the ventilation is to prevent dusts and odors generated in the stock yard from spreading and entering into the working yard. The best way to achieve this successfully is to make the ventilation air flow in one direction. This ventilation principle is called unidirectional airflow ventilation and is applied to the cleanrooms which require high level of cleanliness. To determine the necessary velocity of the ventilation airflow accurately enough to prevent contaminants from spreading and reversing is most essential for designing the system. The theoretical method for solving this problem is accomplished by applying the continuity equation for diffusion with convection. The mathematical model of this ventilation system is as follows: The concentration of contaminants in the space is described with the continuity equation for diffusion with convection. This ventilation system can be modeled as a one dimensional convection diffusion problem as shown in figure 2. The continuity equation then reduces to a one dimensional equation:

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} = D\frac{\partial^2 C}{\partial x^2} \quad (1-1)$$

with boundary conditions:

$C = C_0$ at $x=0$

$C = C_l$ at $x=l$

In this case, we can assume that the system has reached a steady state. This allows the exact solution of C (x) which is the concentration of the contaminant between the working area and the stock yard to be found as:[1)]

$$C(x) = (C_l - C_0)\frac{\exp(ux/D) - 1}{\exp(ul/D) - 1} + C_0 \quad (1-2)$$

Where the terms and variables are defined as follows:

u : velocity of the ventilation air

D : diffusivity of the contaminant

$C_0$: concentration of the contaminant in the work yard

$C_l$: concentration of the contaminant in the stock yard

l : length of the transition between the work yard and the stock yard

Figure 2 shows the concentration curve derived from the equation (1-2). The better the ventilation system runs, the steeper the slope of the concentration curve must be and the shorter the length l. But

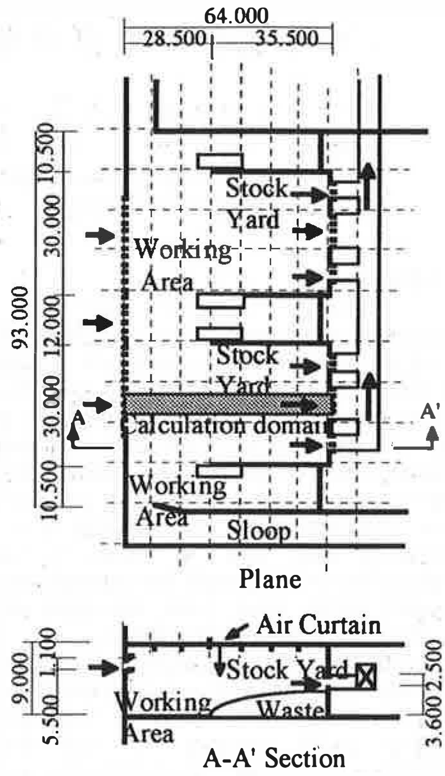


Fig. 1 Plane and Section of the Facility

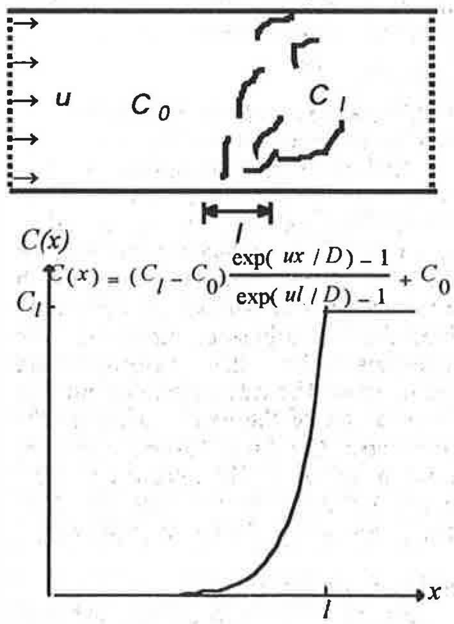


Fig. 2 Principle of Ventilation System

| Table 1 Calculation Conditions | | | | | |
|---|---|---|---|---|---|
| | Boundary Condition | | | Wind shield screen | Waste |
| | Inlet Velocity | Outlet Velocity | Air Curtain | | |
| Case1 | free | 2.0 m/s | without | without | without |
| Case2 | free | 2.0 m/s | without | without | with |
| Case3 | free | 2.0 m/s | 6.0 m/s | without | without |
| Case4 | free | 2.0 m/s | 6.0 m/s | with | with |

the influx of the contamination will be a function of not only diffusion and convection, but also turbulence. The theoretical solution cannot give an accurate velocity, and it is necessary to combine the theoretical solution with the experimental results. In addition, the inlet opening cannot extend from end to end, and one cannot assume a one dimension model. This leads us to the difficulty that the air does not flow unidirectional and the contaminants drawn into the vortex turn around. To overcome this difficulty without a fully opened inlet, it is necessary to increase the ventilation rate. The very high ventilation rate is not only expensive but also noisy. It is expected that the air curtain can separate the yard into two parts and prevent the contaminants from entering the work area with a small amount of ventilation air. To verify the effects of the air curtain, it is necessary to carry out further experiments.

## NUMERICAL SIMULATION[2)]

### Description of Simulation

At first, a numerical simulation was carried out to predict the effects of the air curtain. The existing computational fluid dynamics (CFD) software was used to compared the ventilation system both with the air curtain and without it. CFD code solved the k-ε turbulence model in three dimensions for the velocity and concentration. The calculation domain was defined a part of the entire facility as the hatched area (L=64m × W=6m × H=9m) shown in figure 1. The calculation model has 131,610 cells (107L× 30W × 41H ). Table 1 shows the calculation conditions.

### Results of Simulation

Figure 3 shows the calculated results for case 1. The velocity vector distribution in an x-y plane through the center of the enclosure shows the flow pattern. The outdoor air entering through the supply slot along the wall flows in an offset and plane jet

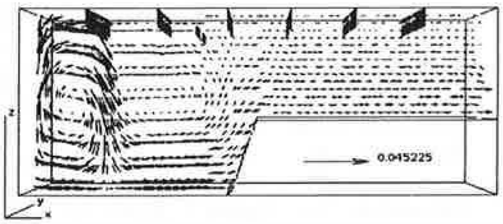


Fig. 3 Calculated Velocity (Case1 Proto type)

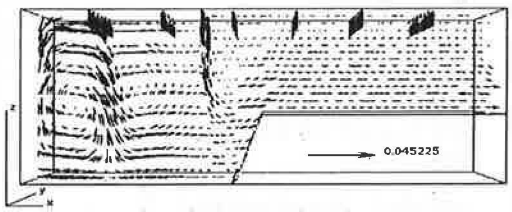


Fig.4 Calculated Velocity (Case4 Alternative)

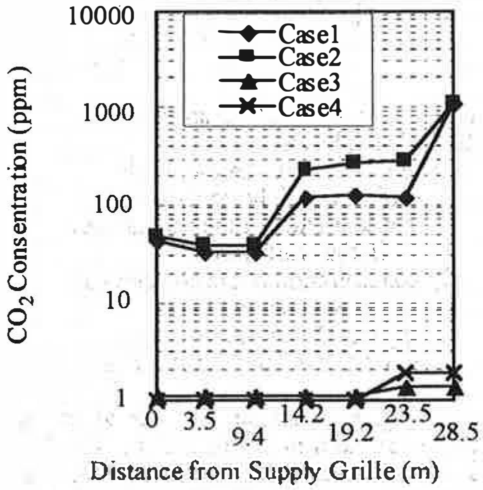


Fig. 5 Calculated $CO_2$ Concentration

along the surface of the ceiling as a result of Coanda effect and then turns down to the floor. After impinging on the floor, the flow separates into two directions. Part of the flow returns back and is entrained by the supply jet, which resulting a strong recirculation. The other part ascends the slope of the dummy waste and again separates into two flows. The major one flows toward the extract opening. The rest turns to the windward and forms another recirculation flow which unfortunately reverses the contaminant from the stock yard to the working area. The main reason why this undesirable flow pattern occurs is due to the offset supply aperture, which is near the ceiling. Because of the building design, the supply aperture cannot be placed at the desired position. It is expected that the air curtain can prevent the reverse flux of the contaminants. Figure 4 shows the calculation results for case 4. As the figure clearly shows, the air curtain reaches the floor and effectively prevents the reverse flux. Figure 5 shows the $CO_2$ concentration which was calculated under conditions where $CO_2$ was generated from the top edge of the dummy waste at a concentration of 1000 ppm. The $CO_2$ concentration curves for case 3 and 4 descend sharply toward the working area. This reconfirms that the air curtain is fairly effective.

## MODEL EXPERIMENT[3)]

Description of Experimental Set-up

Figure 6 shows the experimental set-up and the one-tenth scale model for one half of the whole facility shown in Figure 1. The reduced similarity rules were applied, which allows a similarity between the actual object and the model when the eddy viscosity is proportional to the product of the characteristic length and velocity. [4)] This is satisfied for flows having a large Reynolds number. Table 2 shows the dimensions of the model and the scale factor. The velocity vectors and the $CO_2$ concentration were measured under the conditions shown in table 3, as the numerical simulation. The velocity was measured by a 3-dimensional ultrasonic anemometer. $CO_2$ was emitted at the top of the dummy waste slope and its concentration was measured by a CO-$CO_2$ meter. A smoke generator was used to visualize the airflow. Figure 7 shows the measurement points.

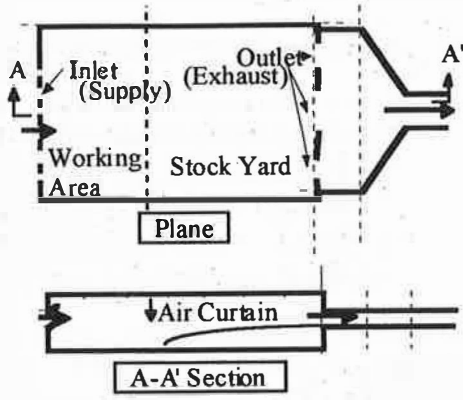


Figure 6 Experimental Set-up ( 1/10 Scale Model)

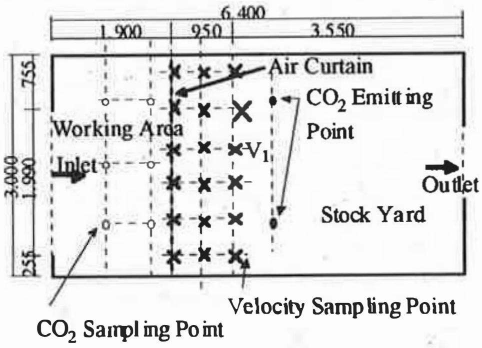


Figure 7 Measuring Point

Table 2 Model Dimension And Scale Factor

| | Actual | Model | |
|---|---|---|---|
| | Dimension | Scale Factor | Dimension |
| Volume ($m^3$) | 17,280 | 0.001 | 17.28 |
| Exhaust Opening ($m^2$) | 16.67 | 0.01 | 0.167 |
| Exhaust Velocity (m/s) | 2.00 | 1.00 | 2.00 |
| Ventilation Rate ($m^3$/h) | 120,000 | 0.01 | 1,200 |
| Air Change Rate (1/h) | 6.94 | 10.00 | 69.4 |

Experimental Results

Air flow

As shown in Figure 8, for any case, the bulk air flow in the model is very similar to the numerical simulations, i.e. the outdoor air entering through the supply opening deflects upward to the ceiling and then turns downward. Figure 9 shows the vertical distribution of the velocity ( x-component ) at the point $V_1$ shown in Figure 7. In the lower half, the air flows toward the exit opening, but in the upper half it goes in the opposite direction.

$CO_2$ concentration

Table 4 shows the results of the $CO_2$ concentration measurements. The $CO_2$ concentration in the working area for case 2 is greater than that for any other case. This is because only case 2 does not have the dummy waste, and its cross section area is larger than the others so the velocity across the y-z plane becomes smaller than in the other cases. It is supposed that the reverse flux of $CO_2$ can be easily produced. To evaluate the performance of the ventilation system, a Reach Rate ( R.R.) is used. The R.R. was defined as shown below in Table 4. At any point, a low $CO_2$ concentration indicates that $CO_2$ can reach few and the reverse flux of $CO_2$ is small. Therefore a small R.R. indicates the system has a very high level of performance. The air curtain system ( Case 3) has one-third the R.R. of the non-curtain system ( Case 1). The air curtain + wind shield screen system ( Case 5 ) reduces the R.R. by one-fifth from the air curtain only. This indicates clearly the effect of the wind shield screen which could not be proved by the numerical simulation.

## MEASUREMENT on FACILITY[5)]

Description of measurements

Measurements were carried out in the newly built facility before it was put into use in order to evaluate the performance of the ventilation system and the availability of the experiments. The measurements included air flow rate, velocity, and pattern, and the concentration of air borne particles. The air flow was measured by the 3-dimensional ultrasonic anemometer and visualized by a smoke candle. Figure 10 shows the measurement points and Table 5 shows the measurement cases.

Results of measurements

Air flow rate

Table 3 Experimental Condition

| Case | Dummy Waste | Velocity of Air Curtain | Wind Shield Screen | Notes |
|---|---|---|---|---|
| Case1 | with | - | - | Prt. |
| Case2 | without | - | - | Prt. |
| Case3 | with | 6.0 m/s | without | Alt. |
| Case4 | with | 3.0 m/s | with | Alt. |
| Case5 | with | 6.0 m/s | with | Alt. |
| Case6 | with | 9.0 m/s | with | Alt. |

Prt.:Prototype, Alt.:Alternative

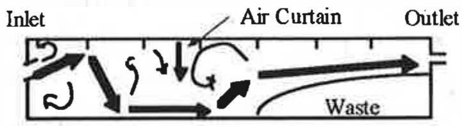


Fig. 8 Bulk air flow in the model (Case5)

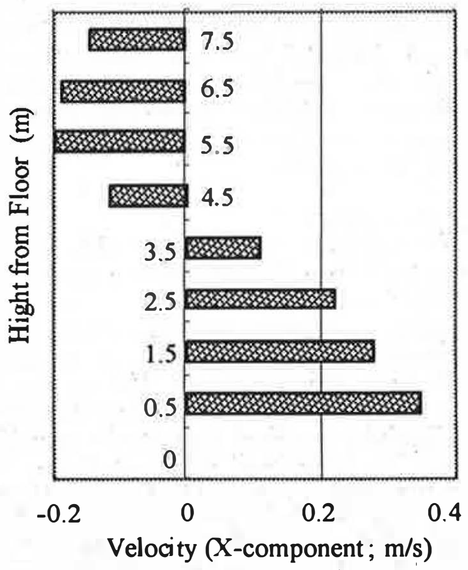


Fig. 9 Vertical Distribution of Velocity

The volume flow rates through the supply and/or the exhaust opening were measured and their balance was examined. The volume flow rate is obtained from the product of the face velocity and the total area of the opening. Table 6 shows the air flow rate of the ventilation openings. The supply air volume rate measured is far less than that of the design condition, but for the exhaust volume there is a good agreement between the measurement results and the design conditions. Not only the total rate of supply

Table 4 $CO_2$ Concentration (ppm) and R.R.

| | Supply | Exhaust | W1 | W2 | W3 | W4 | W5 | W6 | Ave. | R.R (%)*1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Case1 | 465 | 1600 | 570 | 550 | 530 | 500 | 480 | 475 | 517.5 | 4.6 |
| Case2 | 500 | 1500 | 1700 | 1600 | 1300 | 1000 | 750 | 700 | 1175.0 | 67.5 |
| Case3 | 485 | 1600 | 520 | 530 | 500 | 490 | 480 | 480 | 500.0 | 1.3 |
| Case4 | 425 | 1500 | 450 | 460 | 450 | 500 | 550 | 440 | 475.0 | 4.7 |
| Case5 | 520 | 1500 | 525 | 530 | 520 | 520 | 520 | 520 | 522.5 | 0.3 |
| Case6 | 540 | 1500 | 550 | 570 | 550 | 550 | 550 | 560 | 555.5 | 1.6 |

*1 R.R (Reach Rate ): R.R=( Ave.- Supply)/(Exhaust - Supply)

but also the rate from the original route (supply grille ) are less than that of the design. The reason that the measurement rate of total supply does not agree with the exhaust rate may be explained by the fact that it is very difficult to accurately measure the supply volume rates of both sides. The actual amounts of supply from the west and east sides are more than likely larger than what is indicated by the measurements. The actual supply conditions are rather different from both the numerical and the model experiments but these experiments were not found to be fruitless in investigating the ventilation system.

Air flow pattern

Figure 11 shows the air flow pattern for case 3 drawn from the velocity vector and the flow visualization. Figure 12 shows the velocity vector of the numerical simulation to compare with figure 11. The patterns agree with each other very well. The air curtain can keep out the reverse flow and prevent the contaminant air from entering the working area. The magnitude of the measured air velocity at the supply grille is rather smaller than that of the calculation because the measured amount of air volume through the supply grille was reduced by being divided from the other supply opening.

Table 6 The Airflow Rate of Ventilation Opening ($m^3$/h)

| | Measurement | Design |
|---|---|---|
| Supply | | |
| Grill(wall) | 34,410 | 120,000 |
| West Side | 7,480 | 0 |
| East Side | 42,270 | 0 |
| Total | 89,160 | 120,000 |
| Exhaust | 117,830 | 120,000 |

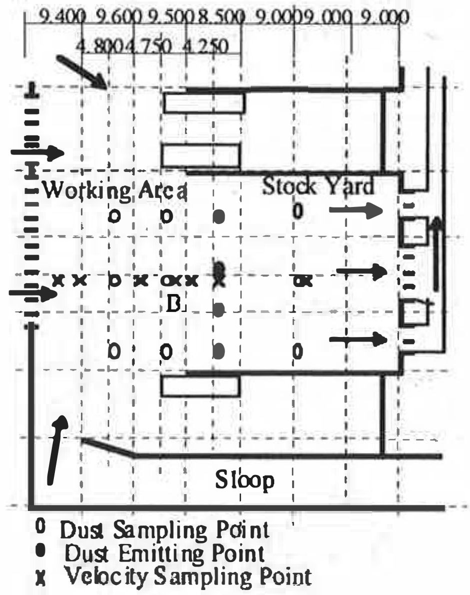


Fig 10 Measurement Point

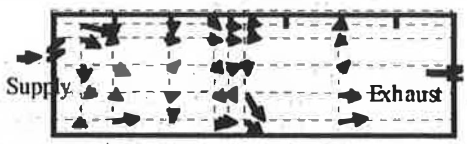


Fig 11 Measured Velocity ( Case 3 )

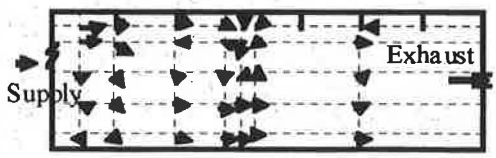


Fig. 12 Calculated Velocity ( Case 3 )

Airborne particle concentration[6]

Figure 13 shows the airborne particle concentration at point B for cases 2(prototype ) and 4 (alternative ). For case 2, the concentration at point B increased as the time progressed but for case 4 there was little change in concentration. This indicates that for the latter the reverse contaminated flow did not occur, but for the former it did. Figure 14 shows the average concentration of the airborne particles in the working area and Figure 15 shows that of the stock yard. The calculated results of the airborne particle concentration $C_t$ are also shown in these figures. The equation used to calculate the concentrations is as follows:

$$C_t = \left[\int_0^t \left(nC_0 + \frac{M}{V}\right)e^{nt}dt + C_i\right]e^{-nt} \tag{5-1}$$

Where the terms and variables are defined as follows:

$C_0$: concentration of the supply air
$C_i$: concentration of the initial state
$M$: emission rate
$n$: air change rate
$V$: volume of the space

The initial values for the concentration and the emission rate of the airborne particles were obtained by the measurement. The emission of particles was stopped after a short while ( $t=t_r$ ) during measurement, and the calculated concentration is as follow:

For $0 \le t \le t_r$ $\quad M = M_c$,

$$C_t = \left(C_0 + \frac{M_c}{Q}\right)(1 - e^{-nt}) + C_i e^{-nt} \tag{5-2}$$

$t \ge t_r$ $\quad M = 0$

$$C_t = C_0 + (C_{tr} - C_0)e^{-nt} \tag{5-3}$$

where $C_{tr}$ is the concentration at time $t_r$.. As shown in figure 14, the concentration of case 4 does not change and the particles emitted are believed to not reach the working area. For case 4, the calculation was applied to the stock yard only i.e. the volume V was that of the stock yard. Therefore there is no graph representing the calculation results from case 4 in figure 14. As shown in figure 15, the good agreement between the calculations and the measurements for case 4 indicates that the air curtain can divide the space into two parts i.e. the working area and

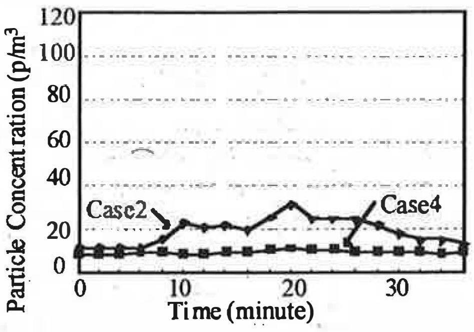


Figure 13 Particle Concentration at point B (Measured)

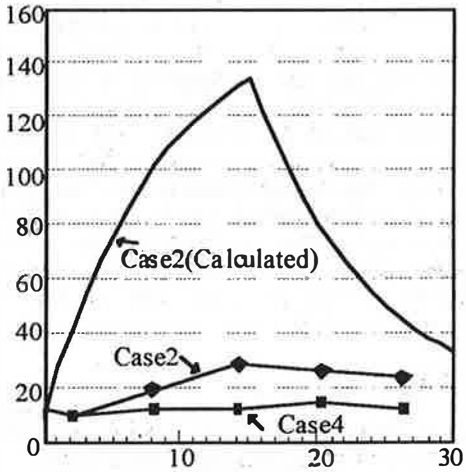


Figure 14 Particle Concentration in the Working Area

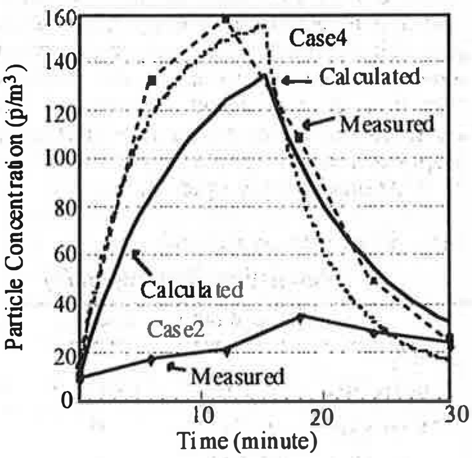


Figure 15 Particle Concentration in the Stock Yard

the stock yard, and that in the stock yard we can assume that there is perfect diffusion. On the other hand, for case 2 the calculation does not agree with the measurement. The reason for this discrepancy is that a uniform diffusion does not occur, and the particles emitted are exhausted out before being completely captured by the measuring instrument. The measured concentration is lower than that of the calculation for case 2, but in the working area the measured concentration of case 2 is higher than that of case 4. As far as the estimation of ventilation performance, it can be concluded that case 4 is better than case 2.

## CONCLUSION

An effective ventilation system which prevents pollutants from entering the working area was investigated by numerical simulation and a mock-up experiment. The system with an air curtain and a wind shield screen is proved to be the most effective choice. The measurements carried out in the actual building, which was equipped with the developed system, confirms that this system can increase the efficiency of removing the pollutant with an only 3% increase in ventilation.

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