Improvement of Indoor Air Environment in a Large Welding Factory by Displacement Ventilation

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ABSTRACT

The design of ventilation equipment is important because it affects the ventilation performance directly. To improve the ventilation efficiency of the displacement ventilation, a new ventilation system was proposed in this study. The experiment was performed to measure the fume concentration and the visibility at four points under working conditions. In experimental results, the concentration of dust with a new ventilation system was decreased by about 42-60% compared to that of the existing system. The visibility was increased by about 11-18%. Numerical analysis was conducted to solve the existing and new ventilation system performances for various wind velocities and the wind directions. In numerical results, it was found that the fumes concentration of a new system was kept much lower than that of an existing system in all cases.

KEYWORDS

Indoor Air Environment, Welding fumes, Ventilation system, CFD

INTRODUCTION

The workers in a large room such as a shipyard could be easily exposed to welding fumes, dust, and toxic gases generated from welding processes. These contaminants may cause serious problems to workers if they are exposed for a long time. The displacement ventilation is a very useful way to remove the contaminants in an industrial field as well as an office. However, it is not easy to design the ventilation system in a large room because of the huge size, the control of contaminants, and the fan performance etc. In Korea, the Ministry of Labor (1997) regulated the limit of fumes concentration to 5 mg/m^3 in the factory. Kwag (1997) and Byeon (1995) examined that the exposure to welding fumes and other toxic gases is a considerable problem in the industrial environment. Raimo et al. (2001) have investigated the stratification of welding fumes and grinding particles in a large factory hall equipped with the displacement ventilation. Philip et al. (2002) studied an experimental method for contaminant dispersal characterization in large industrial buildings for indoor air quality (IAQ) applications. Watson et al. (2001) developed a push-pull ventilation system to control solder fume. He proposed this ventilation system to electronics factories. Robert (1991) investigated a local ventilator or fan as a mechanical ventilation equipment to make up for natural ventilation. Recently, the jet fans as a mechanical ventilator are frequently used in industrial places like tunnel, garage, etc. Due to the characteristics on high static pressure and high flow rate, the application of jet fans increases gradually. In this study, the jet fans of mechanical ventilation equipments were chosen to dilute the welding fumes effectively. The aim of this study is to investigate the performance of a new ventilation system in a large welding factory by the displacement ventilatioin. Numerical analsysis was conducted to predict the air flow and the fumes concentration for the wind directions through the computational fluid dynamics (CFD). Also, the dust concentration of a new ventilation system was compared with that of an existing ventilation system through the experiment.

RESEARCH MODEL

The schematic of a large welding factory in this study is shown in Figure 1. The welding factory has the three sections, which are connected one another. First section (6 BAY) of 45×150×33 m has two openings in the northern and southern sides. Second and third sections (7, 8 BAY) of 100×64×26 m have one opening in the western side respectively. In the welding factory, there are fourteen welding blocks and fifty-five welding machines. Fourteen automatic welding machines and forty-one manual welding machines are operated in the second and third section, respectively.

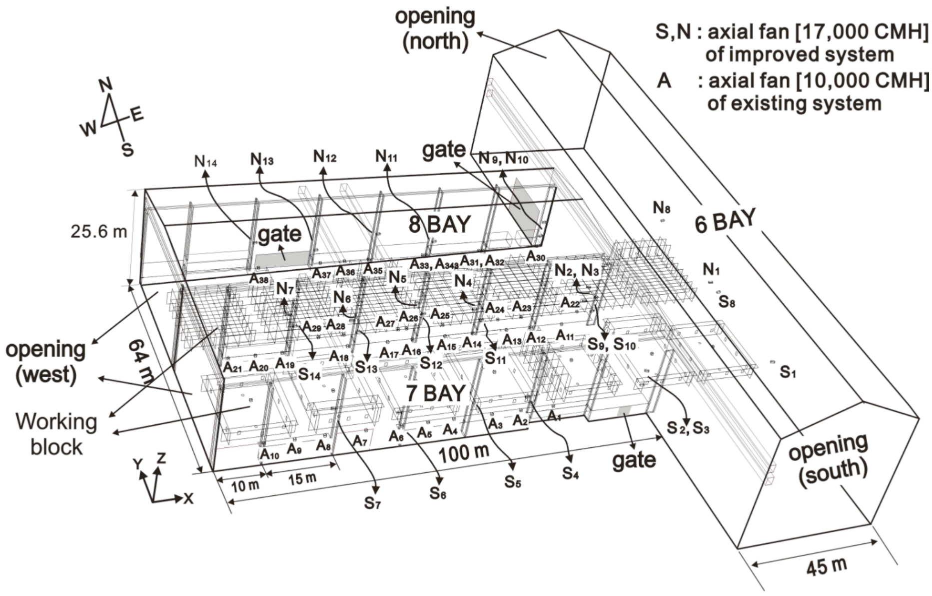

Figure 1: Schematic of a large welding factory

Governing Equations and Boundary Conditions

The flow under consideration is 3-dimensional, steady, and turbulent. The governing equations conserve mass, momentum, the turbulent kinetic energy, the dissipation rate of turbulent kinetic energy, the energy, and the concentration. All properties are assumed to be constant and the adopted turbulent model is the standard k-ε. The Schmidt number of turbulent (Sc_t) and the diffusion number of welding fumes (D) to solve the concentration equation of welding fumes are assumed to be 0.7 and 1.9×10^{-5} m^2/s, respectively. Boundary conditions in this study are shown in Table 1.

TABLE 1
Boundary conditions

Locations	Conditions		
	ESE	WSW	N
A_1-A_{38}	v_n=10 m/s		
N_1-N_{14}	v_n=35 m/s		
S_1-S_{14}	v_n=35 m/s		
Wall	u=v=w=0		
Gate	outflow		
Opening (west)	Outflow	v_0=1.5 m/s	Outflow
Opening (north)	Outflow	Outflow	v_0=-1.5 m/s
Opening (south)	v_0=-1.5 m/s	v_0=1.5 m/s	Outflow
Welding machine	S=6.6×10^{-6} kg/(m^3·s)		

Modeling of Welding Fumes

In the present study, the assumptions to model the welding fumes are as follows:
- The property of welding fumes is constant.
- The flow behavior of welding fumes is similar to that of the air.

EXPERIMENT SETUP

The purpose of the experimental analysis is to validate the numerical model and evaluate the quantitative air environment for the existing and new ventilation systems. Experimental apparatus is composed of the dust measurement device (TSI, Dust TRAK), the visibility device (SICK, VISIC 610), and a PC as shown in Figure 2. Dust measurements were carried out at twenty-four points (P_1-P_{24}) in height of 1.5 m. Also, visibility measurements were done four points (M_1-M_4) in height of 5 m and we measured the dust concentration at the same points simultaneously. The dust and visibility measurements were performed in each ventilation system for two hours.

RESULTS AND DISCUSSION

Results of the dust concentrations measured in a welding factory with the existing and new ventilation systems are shown in table 2. In the existing ventilation system, the Dust concentrations at z=1.5 m are about 0.36~1.2 mg/m^3 in the second section and 0.38~1.14 mg/m^3 in the third section. The averaged dust concentration is 0.65 mg/m^3 in the second section and 0.94 mg/m^3 in the third section. In the new ventilation system, the dust concentrations are about 0.24~0.55 mg/m^3 in the second section and 0.28~0.62 mg/m^3 in the third section. The dust concentration with the new ventilation system decreased by 42% for the second section and by 60% for the third section compared to these of the existing ventilation system.

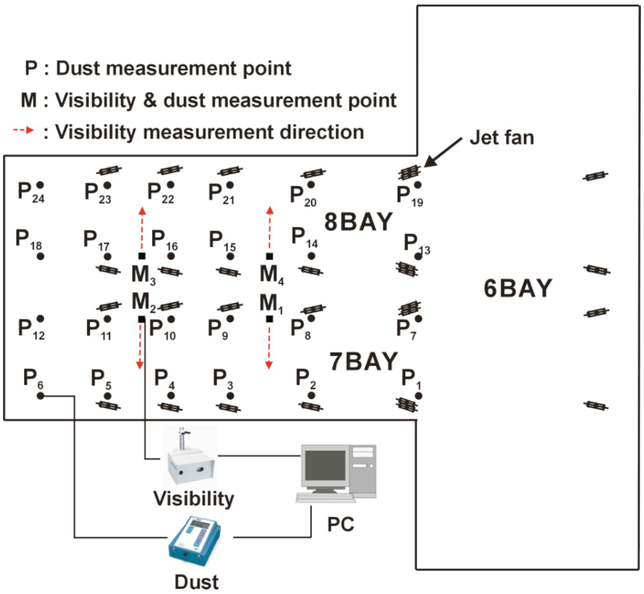

Figure 2: Experimental apparatus and measurement points:

Table 2: Results of dust measurement for the existing and new ventilation systems

unit : mg/m^3

Points (7 BAY)	Existing system	New system	Points (8 BAY)	Existing system	New system
P_1	0.57	0.32	P_{13}	0.62	0.51
P_2	0.91	0.44	P_{14}	0.89	0.43
P_3	0.61	0.37	P_{15}	0.79	0.30
P_4	0.85	0.46	P_{16}	0.46	0.35
P_5	0.53	0.34	P_{17}	0.48	0.28
P_6	0.37	0.31	P_{18}	0.38	0.27
P_7	0.48	0.52	P_{19}	0.77	0.48
P_8	0.77	0.55	P_{20}	3.30	0.62
P_9	1.20	0.39	P_{21}	1.14	0.46
P_{10}	0.48	0.33	P_{22}	0.72	0.31
P_{11}	0.37	0.28	P_{23}	0.74	0.28
P_{12}	0.36	0.24	P_{24}	0.76	0.30
Avg.	0.65	0.39	Avg.	0.94	0.39

Results of the visibility and dust measurement in the existing and new ventilation systems are shown in Table 3. The visibility of the existing and new ventilation systems in the second section is lower than that of the third section where more amount of welding works are done. In the new ventilation system, the visibility increased by about 11-18% compared to that of the existing ventilation system. And the dust concentrations at the same points decreased by about 33-67%.

Table 3: Results of the visibility and dust measurements for the existing and new ventilation systems

Points		Existing system		New system	
		Visibility [m]	Dust [mg/m^3]	Visibility [m]	Dust [mg/m^3]
Second section	M_1	1,621	0.269	1,799	0.109
	M_2	1,427	0.457	1,629	0.258
Third section	M_3	1,476	0.236	1,721	0.097
	M_4	1,265	0.518	1,489	0.355

To compare the ventilation performance between the existing ventilation system and the new ventilation system for the east-southeastern wind, steady-state fume concentration is shown in Figure 3.

Figure 3 shows the steady-state fume concentration with the existing ventilation system and new ventilation system. The distributions of fume concentration in the existing ventilation system at z=5.0 m are shown in Figure 3(a), 3(c), 3(e), repectively. The average fume concentrations are 2.66 mg/m^3 for ESE wind, 2.12 mg/m^3 for WSW wind, 2.5 mg/m^3 for N wind because the welding fumes are raised by buoyancy force and mixed with supplied air. But the fumes near the blocks are hardly exhausted due to the stagnant air. In this reason, there is high fumes concentration in occupied zones. Therefore it is necessary to exhaust fumes to outdoor.

The distributions of fume concentration for the new ventilation system at z=5.0 m is shown in Figure 3(b), 3(d), 3(f), respectively. The fume concentration is below 2.0 mg/m^3 except the some part of the third section. The average fume concentrations are found to be 0.49 mg/m^3 for N wind and 0.49 mg/m^3 for ESE and WSW winds in the new ventilation system.

CONCLUSIONS

Experimental and numerical analyses of an existing ventilation system and a new ventilation system in a large welding factory were concluded as follows:
1) In experimental results, the concentration of dust with a new ventilation system decreased by about 42-60% compared to that of the existing system. The visibility increased by about 11-18%.
2) In the new ventilation system, the dilution effect and the ventilation performance with the west-southwestern wind which is the opposite direction of the axial jet fans are worse.
3) The dilution effect and the ventilation performance are maximized with the northern wind. And the fume concentration decreased by about 77% compared to that of the existing ventilation system.

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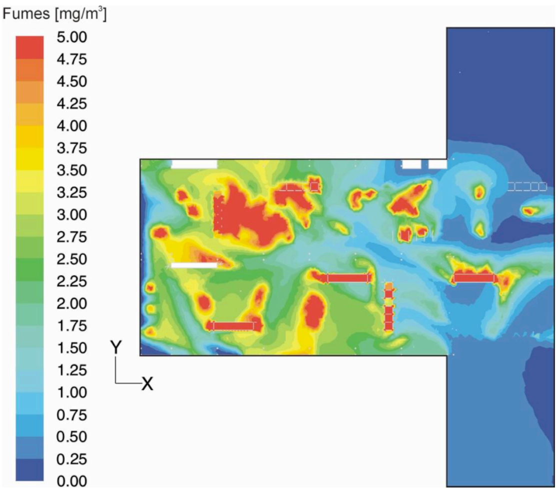
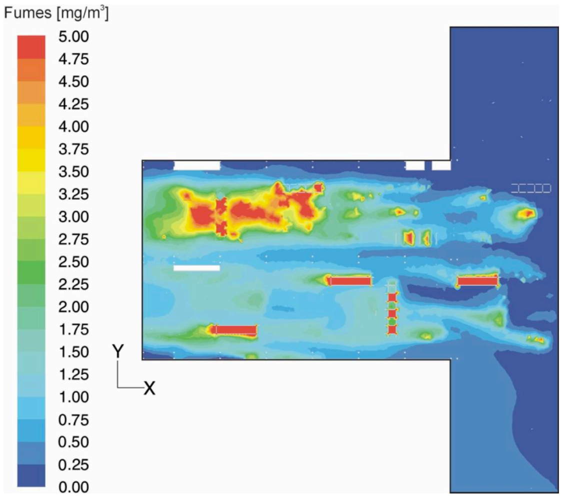
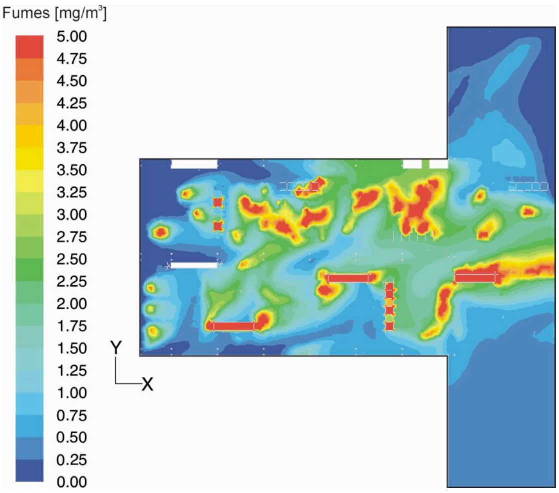


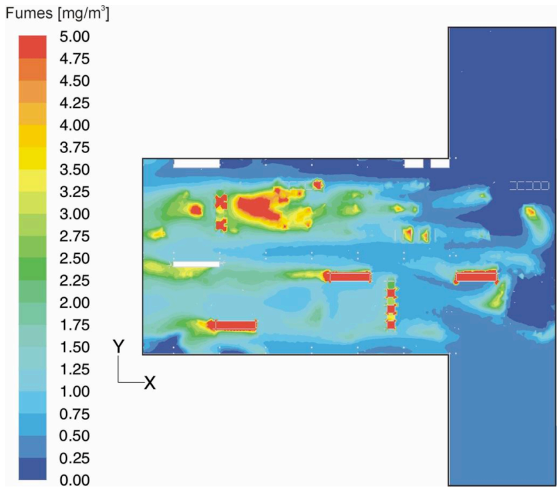
(a) existing ventilation system(ESE)



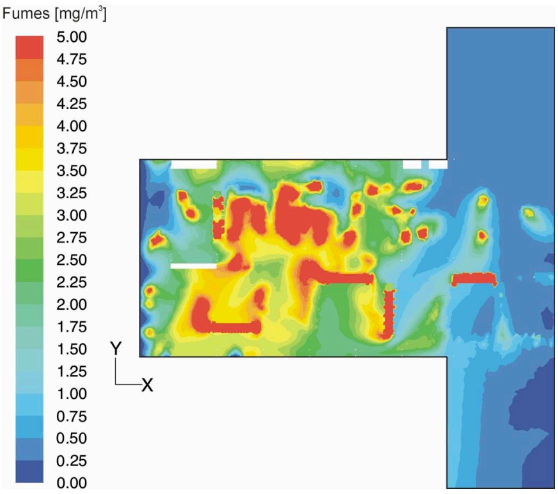
(b) new ventilation system(ESE)



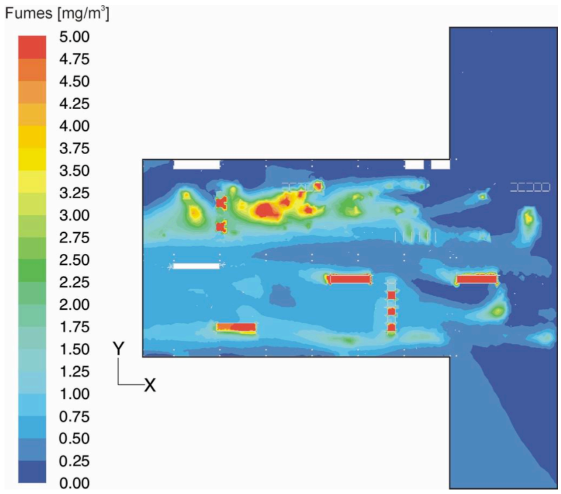
(c) existing ventilation system(WSW)



(d) new ventilation system(WSW)



(e) existing ventilation system(N)



(f) new ventilation system(N)

Figure 3: Distribution of the fumes concentration with ventilation system at z=5.0 m.