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A study on the contaminant dispersion from isolation ward under abnormal operation of facilities

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Abstract

Due to the recent outbreaks of infectious diseases, such as severe acute respiratory syndrome (SARS), Influenza and Ebola, isolation facilities have played an important role to prevent infectious diseases from spreading at initial stage. An isolation ward is a facility to isolate patients physically and to care them safely. One way to isolate a patient physically is to build a negative pressure isolation facility. However, unexpected failure or misuse of such facility makes it difficult to maintain negative pressure and eventually causes secondary infection, leaking the infectious pathogen to outside of the isolation ward. This study identifies the amount and velocity of leakage air from a patient ward by tracer gas experiment under abnormal operations of an isolation facility. In addition, computational fluid dynamics (CFD) allowed us to observe the outflow mechanism of pollutant. The results show that abnormal operations of a facility spreads pathogens to neighboring areas immediately and timely actions should be prepared against them.

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Keywords: isolation ward; infectious diseases; tracer gas experiment; CFD

1. Introduction

The more airborne diseases, such as severe acute respiratory syndrome (SARS) and Influenza A, has broken out, the more important role negative pressure isolation wards have played to prevent airborne diseases from spreading. U.S. Centers for Diseases Control and Prevention (CDC) recommends the air change rate of a negative pressure isolation ward to be over 6 air change per hour (ACH) and the pressure difference to be over 2.5 Pa. However, pathogens could spread out to other areas under the abnormal conditions such as malfunctions of facilities or door

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opening unexpectedly. When the pressure difference of an isolation ward is unstable under abnormal conditions, it is necessary that the amount of polluted air leakage from the isolation ward is measured and the countermeasures are prepared. In this study, the tracer gas experiments were performed to measure the air leakage under abnormal conditions. In addition, this study also conducted computational fluid dynamics (CFD) simulations to measure the air leakage under the same conditions and to compare the results with those from tracer gas experiments.

2. Research method

2.1. Tracer gas experiments

The tracer gas experiments was conducted to measure the air leakage from the ward under abnormal conditions that the air supply and exhaust facilities were not operational or doors between the ward and anteroom of negative pressure isolation ward opened unexpectedly. SF6 gas is used as tracer gas in the experiment. In this study, the tracer gas experiments were conducted in a negative pressure isolation facility in Korea, as shown in Fig. 1.

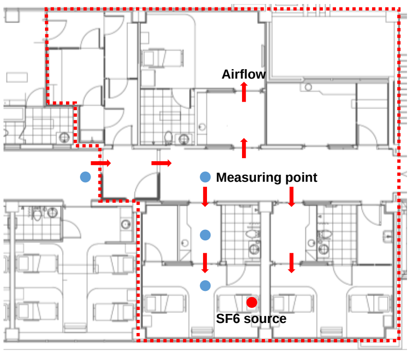

Fig. 1. Negative pressure isolation ward.

The source of SF6 was located at 0.3m above around the patient’s mouth and nose. Emission rate of SF6 was constant. This study used the multi-gas monitor (INNOVA 1412) with the SF6 gas detection limit over 0.01ppm. The pressure difference between rooms was measured by digital nanometer (DG-700) in the experiment.

Conditions of each case of tracer gas experiment are shown in Table 1. Case 1 assumes that the doors between the ward and anteroom, and those between anteroom and hall are all opened with fully functional air supply and exhaust facilities. Case 2 assumes that the exhaust facilities stop with doors closed. Case 3 is under the assumption that air supply and exhaust facilities are stopped because of an emergency (e.g. fire) with doors closed. All experiments lasted over one hour.

Table 1. Experiment conditions.

Case	Supply	Exhaust	Door
1	Run	Run	Open
2	Run	Stop	Close
3	Stop	Stop	Close

2.2. CFD simulation

The CFD simulation was conducted for the same cases of tracer gas experiments. Furthermore, the same negative pressure isolation ward was used (Fig. 2.).

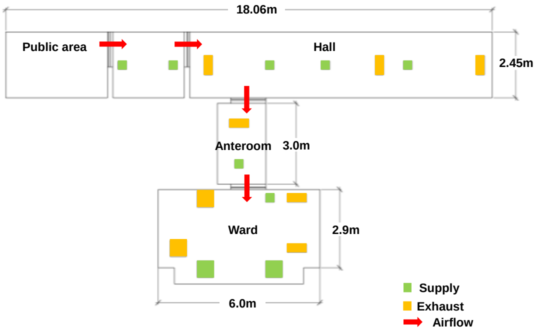

Fig. 2. Model of isolation ward in CFD simulation.

Table 2 shows the conditions of the CFD simulation. The pollutant in this simulations was passive scalar. Molecular diffusivity of the passive scalar was set at 7.3E-6 m^2/s, same as that of SF6 gas in air. Emission rate of SF6 was constant. In addition, the air flow rate measured in tracer gas experiments was used as boundary conditions of CFD simulations. Indoor air temperature of isolation ward was set at 23˚C. CFD simulation first calculated the result under a steady state to stabilize the concentration of the passive scalar and to set the base case, then changed the conditions by each case and conducted the unsteady calculation for 1,800 s condition.

Table 2. Conditions of the CFD simulation.

CFD code	Star-CCM+ v.9
Analysis method	Mesh: 700,000
	Turbulence model: Standard k-ε model
Boundary conditions	**Supply** (temperature: 22.4 ˚C)
	: Isolation ward – 1,600 CMH / Anteroom – 320 CMH
	: Hall – 960 CMH / Anteroom of Hall – 800 CMH
	Exhaust
	: Isolation ward – 1,760CMH / Anteroom – 320 CMH / Hall – 320 CMH
	: Undercut(toilet) – 240 CMH / Other ward undercut – 400 CMH
	Heat Flux – human face (62.8 W/m^2)
	Passive scalar – molecular diffusivity(7.3E-06 m^2/s)
	Unsteady calculation – 1,800 s

3. Results

3.1. Tracer gas experiments

The results are shown in Table 3 with the average SF6 concentration of each case. Base concentration in Table 3 indicates average concentration under stabilized conditions. In Case 1 that doors were opened with fully functional the air supply and exhaust facilities, average concentration of the ward decreased by 40% in comparison to base concentration. After 10 minutes when doors opened with fully functional air supply and exhaust facilities, average concentration of the anteroom increased to that of the ward since pressure difference between the ward and anteroom was 0 Pa in Case 1. Average concentration of the hall increased by almost 25 times compared to the base concentration. Average concentration in the public area was lower than the detection limit. When the doors were closed under the abnormal condition in Case 1, it took about half an hour for SF6 concentration to be stabilized.

According to the result, if doors are opened with facilities fully operational, it is possible to reduce air leakage and stabilize it very quickly.

In Case 2 that the exhaust facilities were not operational with doors were closed, average concentration of the ward increased by 2 times compared to the base concentration. Since the pressure difference changed the positive, average concentration of the anteroom, hall and public area increased due to the diffusion of SF6. It took about 20 minutes for average concentration of the anteroom and hall to increase. It took about more than 20 minutes to increase average concentration of the public area. When the exhaust facilities were operational under the abnormal condition in Case 2, it took more than one hour for stabilized SF6 concentration to decrease. Therefore, if the exhaust facilities are not operational with doors closed, it is possible to reduce and stabilize the air leakage for a long time.

In Case 3 that the air supply and exhaust facilities stopped and doors closed, average concentration of the ward was higher than the other two cases. In addition, even though the doors were closed, average concentration in the anteroom and hall increased. It took more than 20 minutes for average concentration of the anteroom and hall to increase. Average concentration of the public area was similar to the base concentration. When the air supply and exhaust facilities were operational under the abnormal condition in Case 3, it took about half an hour to reduce the SF6 concentration that was stabilized. In this result, if the air supply and exhaust facilities stopped with doors closed, it is possible to reduce the air leakage and stabilize it very quickly.

Table 3. Average SF6 concentration (ppm) of tracer gas experiments.

	Case 1			Case 2			Case 3		
	Base	Door Open	Restore	Base	Exhaust stop	Restore	Base	Supply/Exhaust Stop	Restore
Isolation ward	72.4	32.0	72.7	72.5	137.8	77.0	74.8	338.5	71.1
Anteroom	0.08	25.7	0.16	0.13	56.9	2.24	0.22	13.8	0.21
Hall	0.02	0.55	0.08	0.05	9.74	1.57	0.12	0.47	0.11
Public area	0.00	0.02	0.03	0.19	5.74	4.96	0.26	0.31	0.19

Results of the tracer gas experiment indicate that the infectious pathogens can spread out to infect people in other areas under the abnormal condition. In Case 1, the pressure difference between the ward and anteroom or hall was 0 Pa, and the infectious pathogens in the ward leaked to the anteroom and hall. However, average SF6 concentration of the public area showed only slight increase compared to the base concentration, because the negative pressure difference between the public area and isolation ward increased. When doors are closed under the abnormal condition of Case 1, it takes about half an hour to reduce air leakage and stabilize it. When the air exhaust facilities did not operate with the doors closed (Case 2), average SF6 concentration of other areas except the ward showed highest result compared to other two cases. Therefore, with dysfunctional air exhaust facilities and wrong pressure level in a negative pressure isolation ward, the infectious pathogens leaks to the public area more easily. When the exhaust facilities are operational under the abnormal condition in Case 2, it takes more than one hour to reduce air leakage and stabilize it. In addition, when the air supply and exhaust facilities stopped under emergency with the door closed (Case 3), average concentration of the ward is the highest among three cases. When the air supply and exhaust facilities stopped under the abnormal condition in Case 3, it also takes about half an hour to reduce air leakage and stabilize it. Under abnormal situations as described above, relevant facilities of a negative pressure isolation ward should be under a regular and close inspection in order to protect medical staffs and other people from contagion.

3.2. CFD simulations compared to tracer gas experiments

Results of CFD simulations are shown in Figure 3 with the normalized concentration of tracer gas experiments. Normalized concentration in Figure 3 indicates the concentration in comparison with concentration of the ward that was stabilized in each cases. Triangular points with dotted lines indicate the normalized concentration of CFD simulations and dots indicate the normalized concentration of tracer gas experiments.

Figure 3. (a) shows the normalized concentration of the ward in all cases, both tracer gas experiments and CFD simulations. In Case 1 that the doors were opened with fully functional air supply and exhaust facilities, the normalized concentration of the ward decreased both CFD simulation and tracer gas experiment. In Case 2 that the air exhaust facilities stopped with doors closed, the normalized concentration of the ward increased both CFD simulation and tracer gas experiment. In Case 3 that the air supply and exhaust facilities stopped with doors closed, the normalized concentration increased both CFD simulation and tracer gas experiment. In addition, in Case 3, the normalized concentration of the ward both in tracer gas experiments and CFD simulations was the highest. The normalized concentration of all cases in CFD simulations was higher than that of all cases in tracer gas experiments, because the pressure difference between rooms was different and the undercut of door which could have an effect on the air leakage in CFD simulations was not same as the real undercut which could have an effect on the air leakage in tracer gas experiments.

Figure 3. (b) shows the normalized concentration of the anteroom in all cases, both tracer gas experiments and CFD simulations. In Case 1 that the doors were opened with fully functional air supply and exhaust facilities, the normalized concentration of the anteroom increased both CFD simulation and tracer gas experiment. In Case 2 that the exhaust facilities stopped with doors closed, the normalized concentration of the anteroom increased both CFD simulation and tracer gas experiment. In Case 3 that the air supply and exhaust facilities stopped with doors closed, the normalized concentration of the anteroom increased both CFD simulation and tracer gas experiment.

Figure 3. (c) shows the normalized concentration of the hall in all cases of tracer gas experiments and CFD simulations. In Case 1 that the doors were opened with fully functional air supply and exhaust facilities, Case 2 that the exhaust facilities stopped with doors closed), and Case 3 that the air supply and exhaust facilities stopped with doors closed), the normalized concentration of the hall increased slightly both CFD simulation and tracer gas experiment. However, in Case 3, the normalized concentration of the hall in CFD simulation was lower than 1.4E – 4 which was the normalized concentration of detection limit 0.01 ppm.

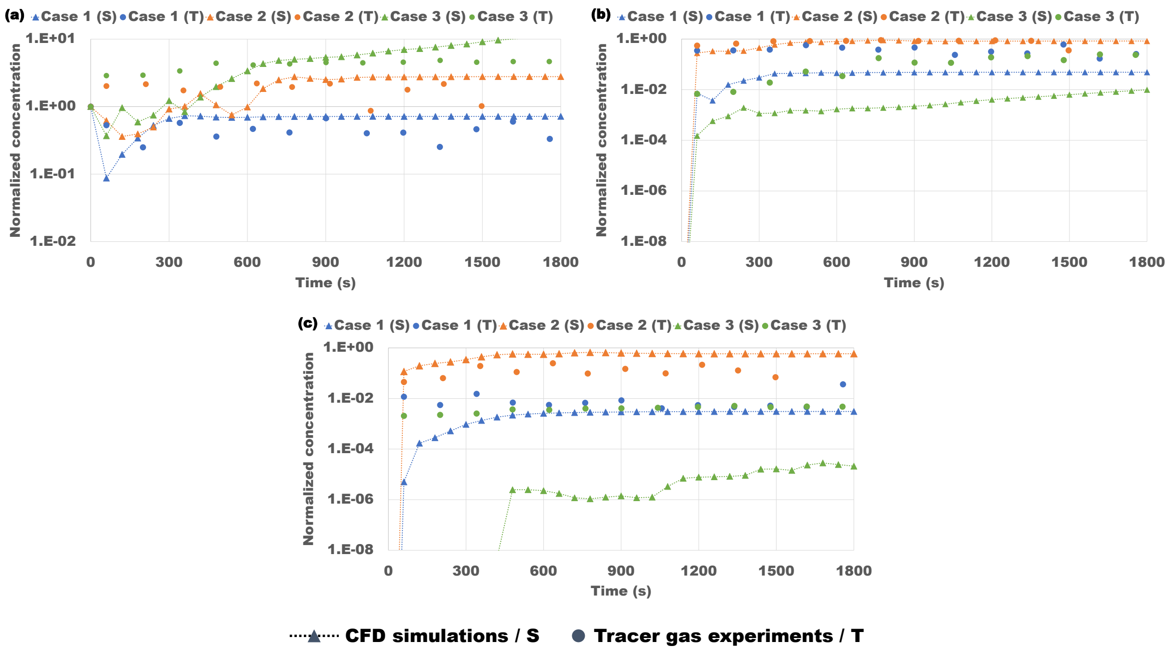

Fig. 3. Normalized concentration of CFD simulations and tracer gas experiments (a) isolation ward; (b) anteroom; (c) hall

4. Discussion and conclusions

Through tracer gas experiments and CFD simulations, this study confirms that the polluted air leaks when the pressure difference of the negative pressure isolation ward is unstable due to the malfunction of the facilities or an opened door.

Results of the tracer gas experiments and CFD simulations showed that the infectious pathogens can spread out to infect people under the abnormal conditions such as the malfunction of facilities and door opening. However, results of the normalized concentration in CFD simulations were slightly different in tracer gas experiments, since the pressure difference between rooms was different and the undercut of door which could have an effect on the air leakage in CFD simulations was not same as the real undercut which could have an effect on the air leakage in tracer gas experiments. In Case 1 that the doors opened during the air supply and exhaust facilities were operating, results indicate the air leakage is identified in anteroom and hall, because the pressure difference changes 0 Pa by doors opened. In Case 2 that the air exhaust facilities stopped with doors closed, results showed that the amount of air leakage to anteroom, hall and public area is highest in all case. It indicates if the exhaust facilities stopped, polluted air leaks more critically than when the doors are opened or all air facilities stopped, because the pressure difference changes to positive between rooms. In Case 3 that the air supply and exhaust facilities stopped with doors closed, the concentration of polluted air in the ward is highest in all cases. Also the polluted air leaks because of the diffusion, but it is not that much than Case 2. Therefore, in case of being stopped the air exhaust facilities, it is the most dangerous situation in all abnormal situations and takes long time to restore the situation like the normal situation.

Furthermore, countermeasures are necessary to reduce the damage of the air leakage under abnormal situations as assumed in the experiments. Alarm system is crucial to notify managers of a negative pressure isolation ward and help them take necessary actions in order to minimize the damage of the air leakage or to prevent the contagion. Emergency systems, such as uninterruptible power supplies (UPS), can help the restoration under abnormal situations. It can also help the restoration to activate only the exhaust system or extra exhaust system under abnormal situations. In order to keep a negative pressure isolation ward safe, the further studies for countermeasures of abnormal situations and management methods of isolation ward are necessary.

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