Developing Anti-draft BSC by Using Air-curtain Technique

以氣簾技術發展抗干擾氣流之生物安全櫃

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Abstract

Aims: To develop a biological safety cabinet with large anti-draft capability thru aerodynamic adjustment.

Method: The air curtain is set up across the cabinet aperture plane by providing a planar jet and a suction flow thru the sash nozzle and the suction slot installed at the work surface, respectively. The aerodynamic characteristics and containment performance of an air-curtain biological safety cabinet under static and dynamic situations are experimentally detected. The dynamic examination includes the walk-by, and sash movement. The aerodynamic characteristics are diagnosed by using the laser Doppler velocimeter. The containment performance is measured by using the tracer-gas leakage concentration method.

Results: The flow field can present characteristics of smoothness, two dimensionality, low turbulence intensity. When the cabinet is operated under the influences of dynamic situations, which are mostly encountered in practical use of BSC, the leakage levels of the cabinet without air curtain are significantly raised. For instance, the leakage concentration of walk-by test of the *no air-curtain* case can be higher than 150 ppb. While that of the air curtain BSC still remains almost no leakage.

Key Words: Biological safety cabinet, Air-curtain cabinet, Aerodynamic characteristics, Performance evaluation

Introduction

Biological safety cabinet (BSC) is designed to contain aerosols generated during work with pathological material. It has been a standard piece of equipment in many laboratories because of the expanding field of biological research with its simultaneous expanding hazards. The studies on the dynamic effects induced by such as the crossdraft, people walk-by, sash movement, and operator hands movement were relatively rare. Rake (1978) investigated the influence of the crossdrafts on the containment efficiency of the biological safety cabinet. He found that the BSC is very sensitive to the crossdrafts. In order to improve operator protection performance of the BSC under influence of dynamic motions, this study applied an "air curtain" technique by setting up a push jet and a suction flow across the front aperture of the BSC.

The air-curtain technique has been successfully applied to design the ventilation system for removal of contaminant vapors, fumes, or aerosols from tanks with large open surface (Huang *et al.*, 2005) and also to develop the chemical fume hood (Huang *et al.*, 2007). Applying this technique to the BSC requires somewhat complicated considerations. The configuration of the air-curtain BSC proposed in this study consists of three parts - a sash (with a channel for the supply of push jet at blow velocity V_b), a suction slot (behind the doorsill for the exhaust of contaminants at suction velocity V_s), and a cabinet (with a HEPA filter installed atop so that the sterile air goes downwards at velocity V_c).

Materials and Methods

The flow characteristics were studied by the laser-light-sheet assisted flow visualization method. The sulfur hexafluoride tracer-gas concentration detection method was employed to evaluate performance of the biological safety cabinet. Ten percent sulfur hexafluoride (SF_6) in N_2 was used as the tracer gas. Static test, walk-by test, and sash movement test were conducted. A Miran SapphIRe^{TM} Infrared Analyzer was used to measure the concentration of the sulfur hexafluoride gas.

For static test, the measurements were conducted in a way similar to the inner plane measurement method of the EN 14175-3:2003 protocol for the chemical fume hood (European Committee for Standardization, 2003). The sketches for the experimental set up can be found in Huang *et al*. (2007).

For walk-by test, a flat rectangular plate of 190 cm high, 40 cm wide and 2 cm thick, was mounted on an electric motor-controlled traversing mechanism. The plate was installed upright and perpendicular to the aperture plane, 20 cm above the floor and 40 cm from the aperture plane. When conducting experiments, the plate was driven forwards at a constant speed between 0.5 m/s and 1.5 m/s until the plate was 60 cm to the right of the cabinet face and was then immediately driven backwards across the face of the cabinet 60 cm to the left of the cabinet. A total of six traverses of the plate were done. The separation time between two subsequent back-and-forth traverses was 30 s. The gas ejector was a hollow cylinder with a diffusion plate made of sintered metal installed at the bottom.

For sash movement test, the deployment of tracer gas ejectors and sampling probes were completely the same as those used for the walk-by test. The sash was initially closed at its lowest height. The tracer gas was released into the cabinet and the SF_6 detector started to take data simultaneously (this instant is taken as the initial time). After 600 s, the sash was quickly opened to 25 cm or 50 cm within 1 s. The tracer gas concentration was continuously recorded until 780 s. The average concentration was calculated over the period of 600th s to 780th s.

Results and Discussion

Flow field characteristics

By seeding the smoke particles into the jet flow as the light scattering media and applying the laser-light sheet across the vertical cross section of the air curtain in the symmetry plane, the flow patterns (oblique view) as shown in Fig. 1 are observed. Three fundamental flow patterns are identified at different combinations of jet velocity V_b, suction flow velocity V_s, and descending flow velocity V_c. Figures 1(a), 1(b), and 1(c) present the *straight curtain*, *slightly concave curtain*, and *severely concave curtain* characteristic flow modes, respectively. They appear at different set values of V_c, V_s, and V_b. Operating the cabinet in the regime of *slightly concave curtain* may be a better strategy for the personnel, product, and cross-contamination protections. However, it requires further tracer-gas evaluation which will be presented in the following sections.

Static leakage

Tables 1 and 2 show the leakage levels detected under the static test condition at the sash height H = 50 cm and 25 cm, respectively. The leakage levels of the *straight curtain* are the highest among the tested situations. The leakage levels of *severely concave curtain* are lower than those of the *straight curtain*, but are higher than the *slightly concave curtain* and the *no air curtain* condition. At H = 25 cm, the leakages of the *no air curtain* condition and the *severely concave curtain* have relatively low values. Because the biological safety cabinets are mostly operated at low sash opening, therefore the existing widely used cabinets operated without air curtain configuration rarely display severe hazards under the static test conditions. However, the leakage levels of the *slightly concave curtain* present the lowest values among all characteristic modes at both high and low sash heights. At H = 25 cm, the leakages are barely detected. Comparing the leakage levels of the *no air curtain* condition ((V_b, V_s, V_c) = (0, 8, 0.25) m/s) with the *slightly concave curtain* mode ((V_b, V_s, V_c) = (0.5, 8, 0.25) m/s) listed in Table 2, it is apparent that providing a small jet velocity at the front aperture to set up the air curtain of *slightly concave curtain* mode can improve the personnel protection performance of the cabinet.

Dynamic leakage

Tables 3 and 4 show the leakage levels detected under the walk-by test condition at H = 50 cm and 25 cm, respectively. The sweep velocity of plate is V_p = 1.0 m/s. At the *no air curtain* condition (V_b = 0), the leakages at V_s = 8 m/s and 10 m/s are all unexpectedly large, no matter the sash height is 50 cm or 25 cm. Apparently the personnel protection would be drastically deteriorated as the walk-bys are applied in front of the aperture at *no air curtain* condition. Operating the cabinet at *straight curtain* mode will induce the largest leakage, no matter the sash height is 50 cm of 25 cm. The reason for this is that the in-cabinet pressure is close to the environmental pressure which makes the jet straight and thus impinge on the doorsill as shown in Fig. 3. Sweeping the plate across the front aperture would induce low pressure in the wake region. The pressure difference between the wake and the cabinet becomes negative so that the leakage level becomes high. At high sash H = 50 cm (Table 3), the leakage can be decreased to a negligibly low level at suction velocity V_s = 10 m/s. At low sash height H = 25 cm (Table 4), which is about the aperture height recommended for use of most biological safety cabinets, the leakage levels are almost negligible when the cabinet is operated either at *severely concave curtain* mode or *slightly concave curtain* mode. Since the *severely concave curtain* mode may induce deteriorations of the product protection and cross-contamination protection, operating the cabinet at low suction velocity of the *slightly concave curtain* mode will therefore be reasonable for optimizing the leakage and energy consumption considerations. In this case, operation condition (V_b, V_s, V_c) = (0.5, 8, 0.25) m/s for low sash H = 25 cm and (V_b, V_s, V_c) = (1, 10, 0.32) m/s for high sash H = 50 cm are recommended. The plate velocity V_p varying from 0.5 m/s to 1.5 m/s is tested in the study. It is found that the above recommended operation conditions can still perform well. However, the leakage concentration of SF_6 at *no air curtain* condition increases significantly with the increase of the sweep velocity of plate. For instance, at V_p = 1.5 m/s, C_{ave} attains 0.548 ppm and 0.381 ppm at (V_b, V_s, V_c) = (0, 8, 0.25) m/s for H = 50 cm and 25 cm, respectively. This result corresponds to the observation of Rake (1978) for the influence of crossdrafts on the leakage level of the conventional biological safety cabinet that the leakage of containment increases drastically with the increase of draft velocity as the draft velocity is greater than about 0.4 m/s.

Tables 5 and 6 show the leakage levels detected under the sash-movement test condition at H = 50 cm and 25 cm, respectively. The *straight curtain* mode presents the largest leakage concentration among all cases and the *slightly concave curtain* mode has almost negligible leakage concentration. Open the sash of cabinet when operating at the *no air curtain* condition would experience risk of containment leakage much higher than that at the *slightly concave curtain*.

Conclusions

The aerodynamic flow properties and operator protection performance of the biological safety cabinet are improved by setting up an air curtain across the aperture of the cabinet. Three typical characteristic flow modes, *straight curtain*, *slightly concave curtain*, and *severely concave curtain*, are identified at different combinations of the jet, suction flow, and descending flow velocities. When operated at the *slightly concave curtain* mode, the in-cabinet flow presents characteristics of smoothness, two dimensionality, and no vortex structure. Using the tracer-gas concentration method to examine the leakage levels for both the static and dynamic tests (including the walk-bys and sash movement tests), the results indicate that the cabinet without installing the air curtain presents low leakage level under the static test situation, while the dynamic test results show significant deterioration in personnel protection.

References

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Table 1 Results of tracer gas concentration measurements of static tests. H = 50 cm.

Grid Position	No air curtain (V_b, V_s, V_c) = (0, 8, 0.25) (m/s)		Straight curtain (V_b, V_s, V_c) = (1, 6, 0.32) (m/s)		Severely concave curtain (V_b, V_s, V_c) = (1, 6, 0.09) (m/s)		Slightly concave curtain (V_b, V_s, V_c) = (1, 8, 0.25) (m/s)		Slightly concave curtain (V_b, V_s, V_c) = (1, 10, 0.32) (m/s)	
	C_{ave} (ppm)	C_{max} (ppm)	C_{ave} (ppm)	C_{max} (ppm)	C_{ave} (ppm)	C_{max} (ppm)	C_{ave} (ppm)	C_{max} (ppm)	C_{ave} (ppm)	C_{max} (ppm)
P1 upper left	0.002	0.004	0.003	0.014	0.010	0.035	<0.001	0.002	0.001	0.002
P2 upper middle	0.001	0.003	0.002	0.005	0.001	0.003	<0.001	0.003	<0.001	0.002
P3 upper right	0.002	0.005	0.007	0.050	0.002	0.005	0.001	0.005	<0.001	0.001
P4 lower left	0.001	0.003	0.006	0.010	0.003	0.019	0.002	0.004	0.001	0.002
P5 lower middle	0.003	0.005	0.011	0.017	0.010	0.028	0.002	0.004	<0.001	0.002
P6 lower right	0.003	0.004	0.009	0.017	0.003	0.012	0.002	0.005	0.001	0.003

Table 2 Results of tracer gas concentration measurements of static tests. H = 25 cm.

Grid Position	No air curtain (V_b, V_s, V_c) = (0, 8, 0.25) (m/s)		Straight curtain (V_b, V_s, V_c) = (0.5, 3, 0.25) (m/s)		Severely concave curtain (V_b, V_s, V_c) = (0.5, 8, 0.12) (m/s)		Slightly concave curtain (V_b, V_s, V_c) = (0.5, 8, 0.25) (m/s)		Slightly concave curtain (V_b, V_s, V_c) = (0.5, 10, 0.32) (m/s)	
	C_{ave} (ppm)	C_{max} (ppm)	C_{ave} (ppm)	C_{max} (ppm)	C_{ave} (ppm)	C_{max} (ppm)	C_{ave} (ppm)	C_{max} (ppm)	C_{ave} (ppm)	C_{max} (ppm)
P1 left	0.001	0.003	0.003	0.007	0.001	0.002	<0.001	0.002	<0.001	0.001
P2 middle	0.001	0.002	0.003	0.006	0.001	0.003	<0.001	0.001	<0.001	0.002
P3 right	0.002	0.004	0.004	0.007	0.001	0.004	<0.001	0.001	<0.001	0.001

Table 3 Results of tracer gas concentration measurements of walk-by tests. H = 50 cm, V_p = 1 m/s.

Modes	V_b, V_s, V_c (m/s)	C_{ave} (ppm)	C_{max} (ppm)
No air curtain	0, 80, 0.25	0.236	0.313
	0, 10, 0.32	0.157	0.284
Straight curtain	1, 3, 0.25	2.076	3.111
Severely concave curtain	1, 8, 0.12	0.028	0.088
Slightly concave curtain	1, 8, 0.25	0.029	0.093
	1, 10, 0.32	0.003	0.019

Table 4 Results of tracer gas concentration measurements of walk-by tests. $H = 25$ cm, $V_p = 1$ m/s.

Modes	V_b, V_s, V_c (m/s)	C_{ave} (ppm)	C_{max} (ppm)
No air curtain	0, 80, 0.25	0.204	0.283
	0, 10, 0.32	0.112	0.172
Straight curtain	0.5, 3, 0.25	2.312	4.199
Severely concave curtain	0.5, 8, 0.12	< 0.001	0.003
Slightly concave curtain	0.5, 8, 0.25	< 0.001	0.001
	0.5, 10, 0.32	< 0.001	0.002

Table 5 Results of tracer gas concentration measurements of sash-movement tests. $H = 50$ cm.

Modes	V_b, V_s, V_c (m/s)	C_{ave} (ppm)	C_{max} (ppm)
No air curtain	0, 80, 0.25	0.032	0.081
	0, 10, 0.32	0.027	0.067
Straight curtain	1, 3, 0.25	1.606	2.228
Severely concave curtain	1, 8, 0.12	0.021	0.164
Slightly concave curtain	1, 8, 0.25	0.002	0.004
	1, 10, 0.32	0.002	0.003

Table 6 Results of tracer gas concentration measurements of sash-movement tests. $H = 25$ cm.

Modes	V_b, V_s, V_c (m/s)	C_{ave} (ppm)	C_{max} (ppm)
No air curtain	0, 8, 0.25	0.028	0.088
	0, 10, 0.32	0.022	0.056
Straight curtain	0.5, 3, 0.25	0.224	0.293
Severely concave curtain	0.5, 8, 0.12	< 0.001	0.001
Slightly concave curtain	0.5, 8, 0.25	0.003	0.005
	0.5, 10, 0.32	0.001	0.003

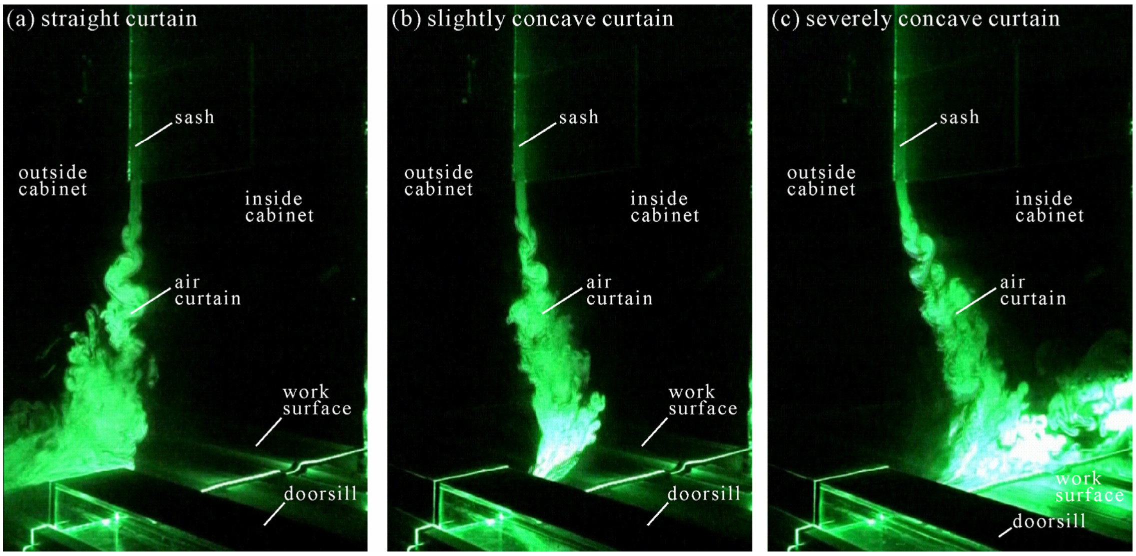

Fig. 1 Typical smoke flow patterns of air curtain. (a) *straight curtain*, (b) *slightly concave curtain*, (c) *severely concave curtain*.