The study on influencing factors of airflow in laboratory fume hood

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Abstract. This study investigates the influence of the side wind flowing directly from different indoor environments on the airflow of the laboratory fume hood (LFH). When an LFH is used to discharge the harmful from the laboratory, the side wind can affect the airflow of the LFH, which is likely to cause the leakage of harmful fumes. In this study, incense was used to simulate harmful fumes, sampling and analysis of the total suspended particulate concentrations were performed in an LFH under different side wind conditions with or without air conditioning, operator, laboratory door open, and electric fan when the fume hood sash (FHS) is at the top, middle, and bottom positions, respectively. A laser pen and hot-wire anemometer are employed to demonstrate the airflow of the smoke and wind speed in different indoor environmental conditions. The experimental results reveal that the airflow field and distribution of harmful fumes in the LFH can be changed according to the different heights of the FHS and changes in the external airflow. Therefore, when using the LFH, the influence of the external airflow should be reduced, and the LFH should be operated for a few minutes before switching it off.

1 Introduction

Laboratory fume hoods (LFHs) are used to discharge harmful fumes from the laboratory environment, to safeguard the operators from chemicals causing health hazard in the laboratory. However, the smell of harmful fumes may still persist elsewhere in the laboratory, indicating that harmful fumes can leak from the LFH cabinet into the laboratory and may affect the health of laboratory workers. To address this issue, this study investigated the influence of the external environment on the airflow in an LFH through an incensing experiment to simulate the airflow of harmful fumes. The detection and analysis of the total suspended particulate (TSP) concentrations were conducted to determine the airflow change in the LFH cabinet under different external environmental factors.

2 Materials and methods

LFHs can be classified into four categories according to the basic structure: conventional hood, bypass hood, auxiliary air hood, and variable air volume hood [1]. The suction flow rate of the traditional type is fixed, and its suction speed is dependent on the face opening of the fume hood sash (FHS). When the height of the FHS is reduced, the face velocity of the LFH cabinet increases [2]. A traditional-type LFH hood (Chuanfu FEK-150, Taiwan) was used in the experiment conducted in this study.

The factors affecting the performance of the LFH can be divided into four states: airflow state (airflow interference from the outside environment, LFH air supply and return air conditions, wind speed, airflow mixing, phenomena of boundary layer separation, and eddy currents), pollutant state (chemical properties and release rate, temperature, and concentration distribution), operator status (action of the operator pulling the FHS, movement of people around, operator shaking in the LFH, and use of electric fans), the state of the LFH (geometry of the LFH size, height of the FHS face opening of the LFH cabinet, poor design and installation, and lack of maintenance) [3–5]. The experiment was designed to investigate the interference of the airflow in the LFH cabinet from the outside environment under different face opening heights of the FHS.

The incense smoke in the center of the LFH cabinet was used to simulate the emission of the harmful fumes in the actual operation experiment, and TSP concentrations were measured using an aerosol monitor (Met One Instruments AEROCET 531, USA). The face opening width of the LFH was 146 cm, and the height of FHS was 60 cm when fully opened to the top. The TSP concentrations were measured in a control group and seven experimental groups. The experimental conditions of the control group are designed such that the FHS is at different heights when air conditioning (AC) is switched on without the operator (OP), laboratory door open (DO), and electric fan (EF). We used 19 TSP measuring points inside the LFH and 1 OP measuring points outside the LFH cabinet for five

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different heights (plane 1 to plane 5) (Figure 1), with the FHS at the bottom (10 cm), middle (35 cm), and top (60 cm) positions.

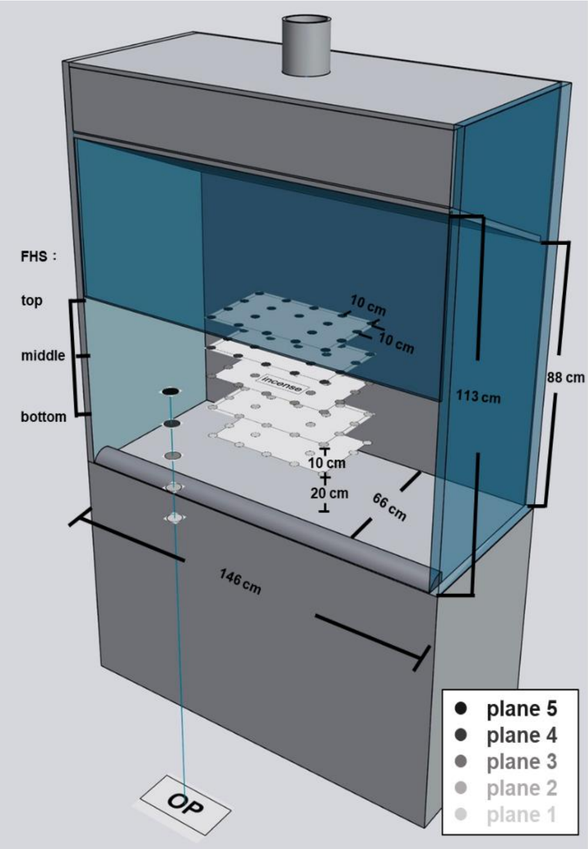

Fig. 1. The TSP measuring points in five different height measurement plane.

The incensing position is at the center of points 3, 7, 8, 12 in plane 3. The number of measurement points in each plane is illustrated in Figure 2. A pretest was conducted to measure the TSP concentration in the LFH cabinet in order to determine the optimal measurement point prior to the experiment in this study. The results of the pretest reveal that the TSP can only be detected in the near locations around the incense, as shown in the points in Figure 1, with undetected and extremely low concentrations in the other locations not marked in Figure 1. Therefore, the TSP concentration is only measured at these points, as depicted in Figure 1, in this experiment of this study. A green laser plane was created by a laser pointer (Lutron electronic YK-2005AH, America) to illuminate the smoke produced by the incense and observe the flow pattern and direction of smoke under different conditions. A hot-wire anemometer was used to measure the change in the wind speed across the face opening ofthe LFH.

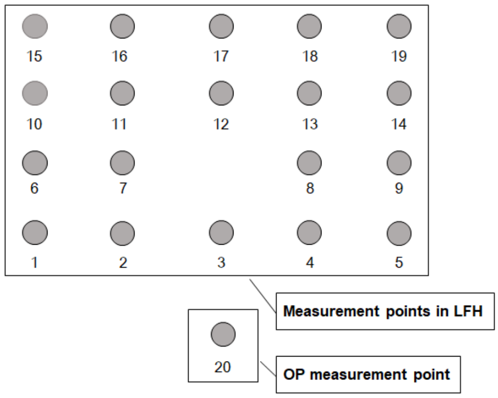

Fig. 2. The number of each TSP measurement points in each measurement plane.

3 Results

When the LHF is in operation, the airflow of the LFH cabinet is mainly from the exterior to the interior and from the front to the rear section of the LHF, most of the airflow is sucked into the exhaust pipe and discharged. However, part of the airflow is guided by a guide baffle located above the LFH, creating a circulating airflow from the rear to the top of the front section, yielding a suspended vortex at the upper corner, and another stream of airflow moves downwards and merges with the airflow from the exterior [4]. When fumes are present in the circulating airflow, the fumes accumulate in the vortex such that the fume concentration continues to increase, and most of fumes flow downward and mix with the airflow from the outside of the LFH.

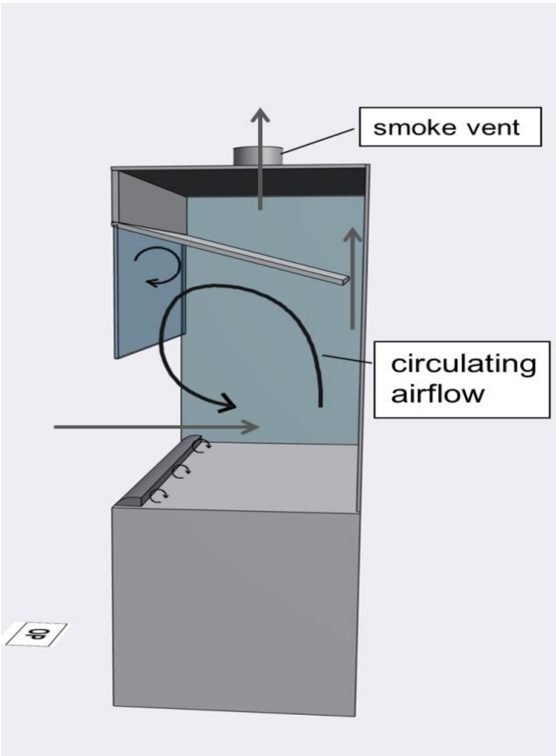

Fig. 3. The circulating airflow is formed above the LFH space under LHF operation.

3.1 TSP of the control group

3.1.1 TSP of the operator position

Table 1 lists the TSP concentration of the operator position in the control group. The TSP observed at OP of point 20 (0.001~0.004 mg/m³) is less than that at other locations; however, this value still exceeds the background value of 0.001 mg/m³.

Additionally, the TSP concentrations at the detection heights of planes 1 and 2 increased significantly compared to all 5 detection heights at point 20 regardless of the FHS height slippage. The increase in TSP concentration is particularly significant in the bottom, allocating between three different FHS heights. This finding is similar to that of the study by Pietrowicz et al. that the vortex can be noticed in the space under the FHS door when the LFH cabinet is operating. In this area there may also be an adverse effect of the outflow of air from the LFH cabinet to outside, which is unacceptable from the safety point of view [7-8].

Table 1. TSP concentration at the operators' position in the control group.

	The FHS at bottom (mg/m³)	The FHS at middle (mg/m³)	The FHS at top (mg/m³)
Background	0.001	0.001	0.001
Plane 5	0.003	0.002	0.001
Plane 4	0.002	0.002	0.001
Plane 3	0.001	0.002	0.001
Plane 2	0.004	0.003	0.004
Plane 1	0.004	0.003	0.003

3.1.2 TSP of the FHS at the bottom position

Figure 4 plots the measured TSP concentration when FHS is pulled to the bottom position. The TSP concentration observed at OP of point 20 of 0.001~0.004 mg/m³ is less than other locations, but still exceeds the background value 0.001 mg/m³. The results demonstrate that the TSP can be measured at most of the measurement points, even at the lower higher in plane 1 and plane 2, but it almost always exists below the average value of 0.013 mg/m³. When the measured height is relatively higher in plane 3, plane 4, or plane 5, the TSP concentration will be more than the average value and will clearly occur at positions 2, 3, 4, 7, 9 and 12.

In particular, smoke from the combustion of substances flows upwards with the heat convection generated through combustion releasing heat energy [6]. The above reason may be attributed to the higher-than-average TSP concentration near the incineration point at height above the plane 3 (the same height as the incense burning position) and measurement points 2, 3, 4, 7, 12. In addition, the circulating air formed in the space above the LFH will cause an air stream with partially unexhausted fumes to be carried near the FHS and cause a concentration increase in the anterior points 2, 3, and 4 close to the FHS.

Although the height of the measured point 8 is identical to that of plane 3 and close to the incineration point, the TSP concentration is not as more as at point 9. This may be attributed to the nonuniform airflow in the LFH cabinet, by thermal convection from incineration, turbulence of the measuring instrument or interference from the LFH external environment.

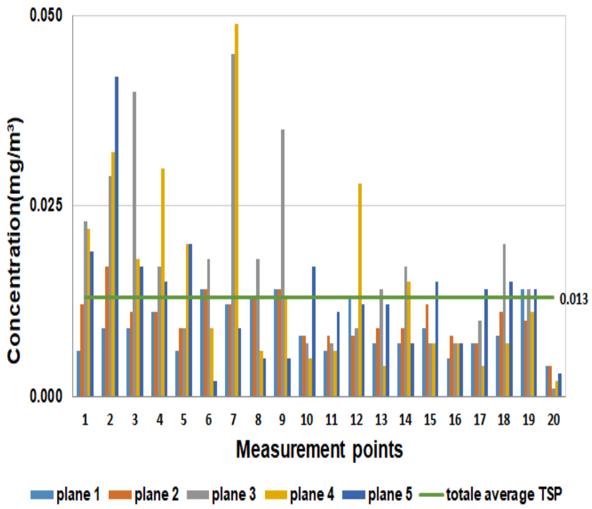

Fig. 4. TSP concentration inside the LFH when the FHS is at the bottom position.

3.1.3 TSP of the FHS at middle and top positions

The result of the measured TSP concentration when FHS is pulled to the middle and top position are depicted in Figures 5 and 6. The TSP concentration observed at OP of point 20 is 0.002~0.003 mg/m³ and 0.001~0.004 mg/m³ when FHS is middle and top positions, respectively. This value is less than other locations; however, it still exceeds the background value 0.001 mg/m³. Most TSP concentrations of the measurement points are less than the average value, whereas the concentrations at only point 12 and 17 are extremely more, and the concentration at point 16 also increases. The point 12 and 17 are located directly behind the incineration point and point 16 or 18 are beside to point 17.

When the sliding door of FHS is lifted up, the face opening area of the FHS increase. A horizontal air flow forms under the LFH cabinet bottom from the front to the rear section, and the circulating airflow above the hood carries the residual smoke along with the rear section together [7]. Therefore, the TSP concentrations at points 12 and 17 increases and even points 16 or 18 are also affected, resulting in slight increase in the TSP concentration. These result clearly demonstrate that the influence of the height of the sliding door on the direction of airflow.

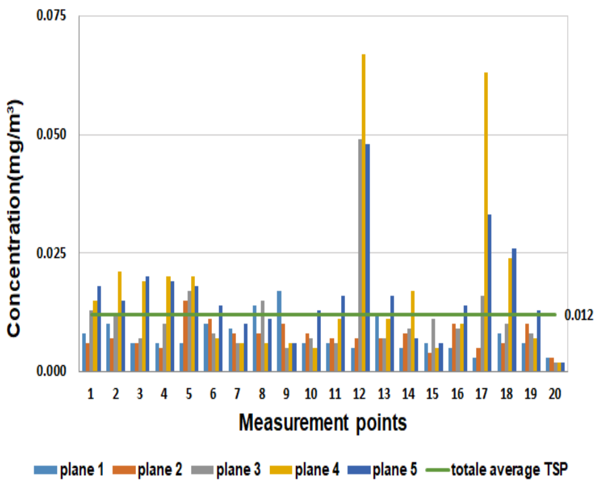

Fig. 5. TSP concentration inside the LFH when the FHS is at the middle position.

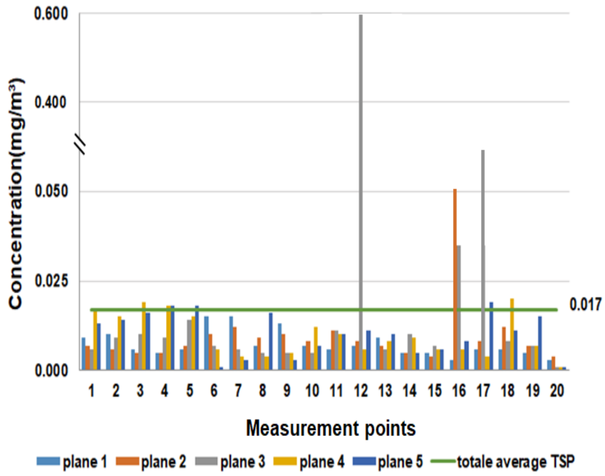

Fig. 6. TSP concentration inside the LFH when the FHS is at the top position.

3.2 TSP under different conditions of environmental factors

The experimental results of the average TSP concentrations under different conditions were plotted in Figure 7. No matter the height of the FHS, the TSP concentrations in the cabinet when the EF is switched on are less than in the control group. At top position of FHS, the TSP concentrations measured by the AC is switched on (0.019 mg/m³) is less than when the AC is switched off (0.021 mg/m³). Presumably, because the air outlet of AC is located above the front of the LFH, the LFH drawn some of the air flow of the AC from the top to bottom position into the FHS and make the TSP concentrations become less in the LFH cabinet. In particular, the TSP concentrations are more readily affected by external interference factors when the FHS at high position.

According to Dunn et al., an evaluation was conducted to assess the leakage from LFH using different methodologies, including tracer gas, tracer, nanoparticles, and nanopowder handling tests. The study found that the static tracer gas tests demonstrated good containment across most test conditions when the AC was switched off [9].

As the FHS at top position, the total average TSP concentration in the LFH cabinet is 0.014 mg/m³ which is more than the FHS at bottom (0.012 mg/m³) and middle (0.011 mg/m³) positions.

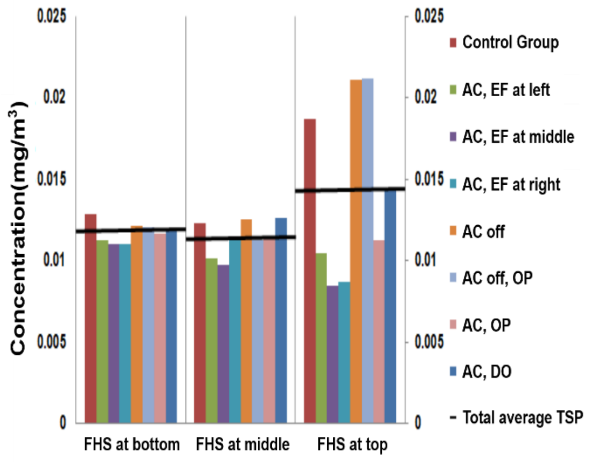

Fig. 7. The TSP concentration when pull the FHS at bottom, middle and top in different conditions.

Upon opening laboratory door, the TSP concentration decreases from 0.019 mg/m³ to 0.014 mg/m³, presumably due to the influence of outdoor wind flowrate and outdoor air quality. Upon irradiating the smoke from incense with a laser pointer, we observed that when the EF is used, the smoke would flows out of FHS from the LFH cabinet, as illustrated in Figures 8 and 9.

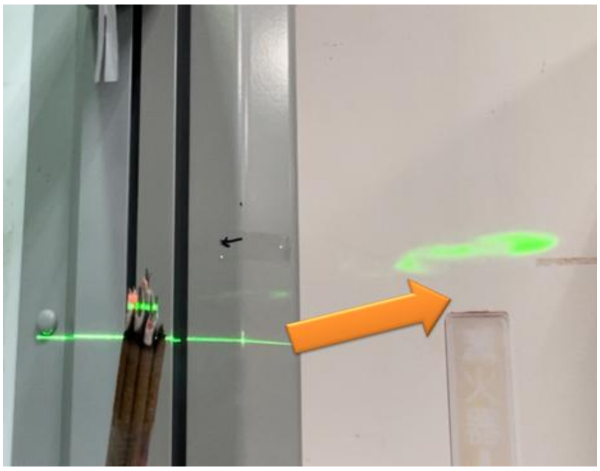

Fig. 8. The smoke flow out (arrow direction) when FHS at middle.

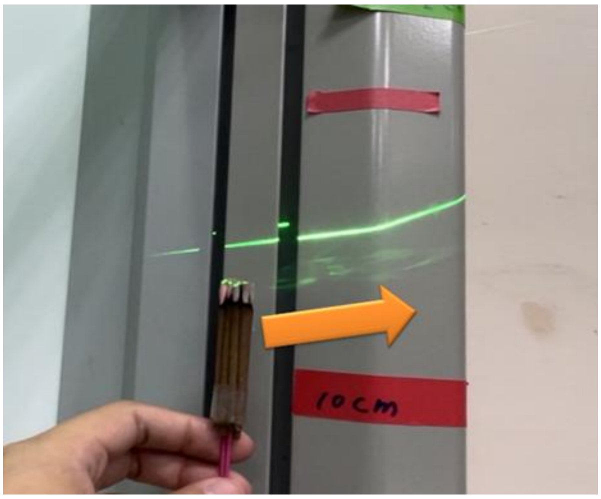

Fig. 9. The smoke flow out (arrow direction) when FHS at top.

3.3 The wind speed on the face opening of LFH

Using a hot-wire anemometer, the change in wind speed is measured at the face opening of the LFH when the AC is switched on (control group) under different FHS door height and the EF is used. The result found that the air velocity at the face opening of the LFH is affected when EF is used (Table 2). When the LFH is operating, the flow field inside the cabinet is easily influenced by the side wind from indoor environment, particularly when the FHS at high position. If the EF is used at the same time, especially at left or right side, it is more likely to result in leakage of harmful fumes.

Table 2. The wind speed on the face opening of LFH

	FHS at bottom wind speed (m/s)	**FHS at middle wind speed (m/s)**	**FHS at top wind speed (m/s)**
AC , No OP	0.68±0.00	0.39±0.00	0.11±0.01
EF at left	1.33±3.02	0.63±0.93	0.28±0.37
EF at middle	0.41±0.07	0.25±0.02	0.16±0.01
EF at right	1.00±0.84	0.48±0.68	0.29±0.28

4 Conclusion

This study clearly demonstrated the influences of laboratory environmental factors on the airflow in laboratory fume hood by correlating the results obtained from incense experiments with concentration measurements of the total suspended particulate matter. The concentration of the total suspended particulate matter was more than the background value could be measured at the operator position in almost all environmental factor conditions no matter the height of fume hood sash is at bottom, middle or top positions. The airflow field and distribution of harmful fumes in laboratory fume hood could readily are easy to be changed according to the different heights of fume hood sash couple with the influence of factors such as the design of the laboratory fume hood, changes in the external airflow, and the characteristics of harmful fumes. When the height of the fume hood sash was at top and middle positions, and use the electric fan readily contributed to the spreading of fumes and leakage, thereby raising the risk to laboratory workers' exposure.

Therefore, we recommend reducing the influence of the external airflow, avoiding the use of electric fan, and operating the laboratory fume hood should be run for a few minutes before switching off it after use. This strategy will prevent the residual harmful fumes in laboratory fume hood cabinet to leakage into the laboratory. This study only can have evaluated the impact on the airflow of the laboratory fume hood, and the impact on the performance of the laboratory fume hood should be further discussed in future studies.

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