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Evaluation of Laboratory Fume Hood in a Volume Generating Process

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Abstract

The purpose of this study is to quantitatively evaluate hood leakage by measuring face velocity and to introduce screening tools with smoke tubes and smoke matches for hood leakage during a volume generating process that simulates a hot process, defined here as any operation producing high temperature gases. A literature search reveals that during the last couple of decades only Johnson et al. reported a quantitative linear relationship between thermal loading and breathing zone trace gas concentrations using ASHRAE 110-1995 method. Hot processes may well be the most common and least recognized of the operational factors able to cause fume hoods to leak. Smoke tests and face velocity tests were conducted for hood performance testing. Smoke tests were executed by means of smoke tubes and smoke matches as screening tools for hood leakage. Face velocity tests were conducted at 16 points arranged to represent equal areas of the hood face when the sash was fully opened. Through smoke tests and a volume generating process, unexpected leakage above the fume hood was found through smoke testing and at the face of fume hood. These results suggest that when a hood is operated with any operation producing high temperature gases, leakage can be caused. This study shows that if there is any fume hood experiment with high temperature or able to cause fume hood to leak, the fume hood must be controlled with stable face velocity using a damper to protect workers and engineers from hazardous gases released within it.

Introduction

The goal of fume hood testing is to determine how well the hood protects the laboratory worker from the hazardous substances released within it. A hot process, defined here any operation producing high temperature gas, has been recognized as a causal factor in the leakage of contaminants from laboratory fume hoods since 1950. A volume generating process is a simulation for a hot process. Schulte et al. found appreciable smoke leakage driven by a hot process in a fume hood. Several articles relied on smoke tests to qualitatively relate thermal loading to leakage. F.H. Fuller reported heat-induced leakage through cracks, seams, and openings in the hood structure. With ASHRAE 110-1995 tracer gas testing, Johnson et al. found quantitative correlation between heat output and emissions. Maupins et al. found the tracer gas test of fume hood leakage to be representative of relative employee exposure in a survey of 46 chemical fume hoods. A literature search reveals that during the last couple of decades only Johnson et al. reported a quantitative linear relationship between thermal power of a hot process and trace gas concentrations of breathing zone. Hot processes may well be the most common and least recognized of the operational factors able to cause fume hoods to leak.

In many modern devices, we have experienced dramatic improvement in performance once real-time measurement and control were introduced. Common examples include autopilots for airliners and cruise ships, cruise control for automobile speed control, and automatic doors for hotel lobbies. The automation has started for laboratory hoods. Phoenix Controls now offers dynamic fume hood containment test video and low airflow control solution video. AccuAire has introduced the design and control concern for the entire laboratory air flow control system which includes the fume hood and air flow pattern in the fume hood through their website. It is time to take the process one step further to move from constant face velocity toward variable face velocity for real-time dynamic measurement of contaminant leakage under different working condition.

There are many factors and operations capable of causing leakage from a hood that passes the ASHRAE 110 test: a poor room ventilation design, poor worker practices, a high chemical generation rate within the hood, dynamic processes such as pouring, gas or vapor release with high momentum, and a very high heat generation rate within the hood. One limitation of the ASHRAE test is that the ASHRAE 110 mannequin for a tracer gas test does not move like a human operator. In other words, the stationary mannequins do not generate turbulence produced by human motion. In that sense, the ASHRAE tracer gas test is very similar to the face velocity test. They both test the hood under static conditions that may not represent operational reality. Additionally, the ASHRAE test measures leakage only at the breathing zone of a mannequin in a fixed location. This provides an ability to compare one hood to another quantitatively, but it fails to give complete information about the dynamics of hood leakage in an operational setting.

This research is intended to accomplish these goals:

1. Introduce visual air flow patterns during a volume generating process, used to simulate a hot process in this study, through smoke tests.
2. Define conditions associated with leakage from hoods so that engineers and industrial hygienists at all workplaces can apply this volume generating process concept to their laboratory facilities and hood designs.

Methods

The laboratory safety fume hood experiment was conducted at 21ºC, 1atm (Standard temperature and pressure, STP) in a general room. This room has 8.5m by 4.5m with room height 3m. The vertical rising sash type constant air volume fume hood, Kem metal by Kewaunee Scientific Corporation (710mm by 900mm with depth 730mm), was connected by welded stainless steel ducts.

Volume Generating Process

The most important factors in this study are leakage and temperature. A hot process was simulated as a volume generating process because the budget for this study was too small to support fire suppression devices required by campus safety. This volume generating process produces conditions analogous to a hot process: higher volume flow in the exhaust duct than through the hood face. Buoyancy of a hot plume was not simulated. A General Electric fan and 4-inch duct were installed so that fume hood can cause to leak at the face of fume hood as shown in Figure 1. For consistency during a volume generating experiment, the duct that generates the extra volume is located at the same position through all experiments.

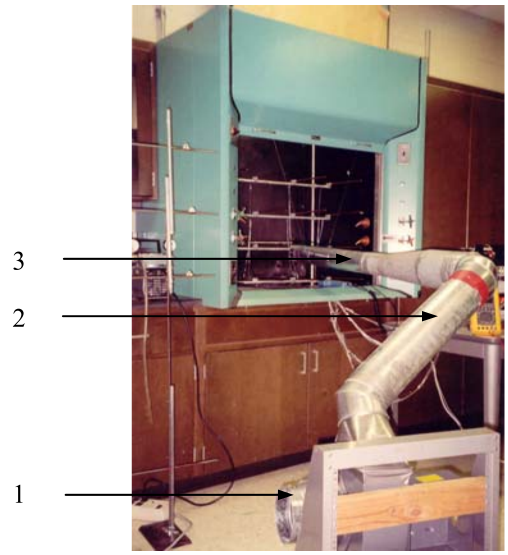

FIGURE 1. A Volume Generating Process

A hot process is able to cause the fume hood to leak because the volume in the hood changes as the temperature increases according the Ideal Gas law. The basic formulas below lead to an algorithm for this volume generating process. Heat is the energy between two conditions as a consequence of a temperature difference between them.

On the basis of the first law of thermodynamics, the energy cannot be created or destroyed. The needed temperature and energy were calculated for a thermal process equivalent to the volume flows of the experimental volume simulation process.

Given V_1 = Volume flow through hood face and V_2 = Volume flow in exhaust duct.
$V_1 = 0.37\ m^3/s$, $V_2 = 0.49\ m^3/s$
According to Boyle's law, $\frac{P\cdot V_1}{T_1} = \frac{P\cdot V_2}{T_2}$, ($T_2 = T_1 + \Delta T$, $V_2 = V_1 + \Delta V$) at constant pressure. T_1 and V_1 are temperature and volume in a fume hood during a general process at ambient conditions. T_2 and V_2 are temperature and volume in the fume hood exhaust duct during a hot process, whose change in volume flow rate matches the volume generating process. $T_2 = V_2/V_1 \times T_1$ at STP (T_1 = 294.15 K, P = 1atm). Thus, T_2 = 116.4 ºC (389.55 K); ΔT = 95.4 K.

And then, $\Delta Q = m\cdot c_p\cdot \Delta T$

where, ΔQ = The quantity of heat [J],
$m = n \cdot M$ [g], n = the number of moles, M = the molecular mass,
c_p = The specific heat of the material at constant pressure [J/(g·K)],
ΔT = The change in temperature [K]

$$n = \frac{PV_1}{RT_1} = \frac{101325[\text{Pa}] \cdot 0.37[\text{m}^3/\text{s}]}{8.314[\text{Pa} \cdot \text{m}^3/\text{mol}] \cdot 294.15\text{K}} \quad \text{or, } n = \frac{PV_2}{RT_2} = \frac{101325[\text{Pa}] \cdot 0.49[\text{m}^3/\text{s}]}{8.314[\text{Pa} \cdot \text{m}^3/\text{mol}] \cdot 389.55\text{K}}$$

where, 1atm = 101325 [Pa], R = 8.314 Pa·m^3/(mol·K)

Thus, n = 15.33 mol, $m = n \cdot M$ =15.33 mol × 28.96 g/mol = 443.96 g, $\Delta Q = m \cdot c_p \cdot \Delta T$ = 443.96 g × 1.01 J/(g·K) × 95.4 K = 42777 J, or Watt·s

As a result, for air, $\Delta T \fallingdotseq$ 95 K when the heating rate is 43 kW. Then, the experimental volume generating process produces the same ΔV as the hot process.

Smoke Test

Flow visualization experiments were done with smoke tubes and smoke matches. The smoke test was executed by means of a smoke generator, which was set up at the face of the laboratory fume hood. The smoke test was done to test the hood's performance qualitatively as well as to find leakage in a volume generating process. This generator consists of SKC Air current test smoke tubes (Model # 800-25301) that were connected with 9 T-type connectors. These smoke tubes were installed using a steel frame at the face of fume hood. A General Electric fan, Model # DOA-104-AA, was used to generate smoke for about 5 minutes. Smoke test was also conducted with smoke matches that could generate smoke for 20 seconds.

Results

Volume Flow Rate in a Volume Generating Process

One of the most important assumptions of industrial ventilation is derived from the fact that matter cannot be created or destroyed. Table I, II, III, and IV indicate the volume flow rate in the volume generating fan, in the fume hood at each condition, and in the 9-inch exhaust duct. This simple experiment is to check if there is any unexpected factor in the fume hood flow patterns as well as to find the needed volume for a hot process. In Table I, velocity pressures were measured using a Pitot tube, which was connected with MKS Baratron transducer at three different points of a volume-generating duct. Velocity pressures were also measured using a TSI VelociCALC Velometer and a Dwyer manometer at the same points for a volume flow rate. In Table II, average face velocities were obtained at the 100% open hood using a TSI VelociCALC Velometer. In Table III, average velocities were also obtained in the 9-inch exhaust duct for comparing the volume flow rate at different conditions.

TABLE I. Volume Flow Rate in the Volume Generating Fan ($Q_{simulation}$)

$Q_{simulation}$ Unit: [m^3/s]	Inlet	Outlet	
	Position #1[A] Mean ± SD	Position #2 Mean ± SD	Position #3 Mean ± SD
Experiment #1	0.117	0.097	0.105
Experiment #2	0.137	0.100	0.106
Experiment #3	0.159 ± 0.013	0.115 ± 0.020	0.118 ± 0.003

$Q_{simulation}$ Unit: [ft^3/min]	Inlet	Outlet	
	Position #1 Mean ± SD	Position #2 Mean ± SD	Position #3 Mean ± SD
Experiment #1	248	205	223
Experiment #2	291	212	226
Experiment #3	338 ± 28	243 ± 42	250 ± 6

Notes:
Experiment #1 was conducted using a TSI velometer and a Pitot tube.
Experiment #2 was conducted using a Dwyer manometer and a Pitot tube.
Experiment #3 was conducted using only a TSI VelociCALC.
[A]Position # = Measurement points are indicated in Figure 1.

TABLE II. Volume Flow Rate in the Open Hood with TSI (Q_{open})

Face Velocity Mean ± SD Unit: [m/s]	Area of the open hood Unit: [m^2]	Q_{open} Mean ± SD Unit: [m^3/s]	Q_{open} Mean ± SD Unit: [ft^3/min]
0.580 ± 0.081	0.639	0.371 ± 0.075	786 ± 160

Note: Face velocity was measured and recorded using a TSI VelociCALC.

TABLE III. Volume Flow Rate in the 9-inch Exhaust Duct with TSI ($Q_{exhaust}$)

$Q_{exhaust}$	Face Velocity Mean ± SD Unit: [m/s]	D_{area} Unit: [m^2]	$Q_{exhaust}$ Mean ± SD Unit: [m^3/s]	$Q_{exhaust}$ Mean ± SD Unit: [ft^3/min]
100% Open Hood	11.34 ± 0.72	0.041	0.466 ± 0.030	987 ± 63
100% Open Hood in the VGP[A]	11.28 ± 0.83	0.041	0.463 ± 0.034	981 ± 72
35% Open Hood	11.41 ± 0.84	0.041	0.469 ± 0.034	993 ± 73
35% Open Hood in the VGP	11.32 ± 0.63	0.041	0.465 ± 0.026	985 ± 55

Notes: [A]VGP = Volume Generating Process
Face velocity was measured and recorded using a TSI VelociCALC.

TABLE IV. Volume Flow Rate Comparison in the Fume Hood

Condition	Q Unit: [m^3/s]	Q Unit: [ft^3/min]
$Q_{open} + Q_{simulation}$	0.489 ± 0.042	1036 ± 89
$Q_{exhaust}$ at the 100% Open Hood	0.466 ± 0.030	987 ± 63
$Q_{exhaust}$ at the 100% Open Hood in the VGP	0.463 ± 0.034	981 ± 72

Note: Volume flow rates were calculated using a TSI VelociCALC.

The volume flow rate in the exhaust duct must be the same as the sum of the volume flow rate in the open hood and in the volume generation duct according to the conservation of mass, momentum and the first law of thermodynamics.

$Q_{open}+Q_{simulation}=Q_{exhaust}$

In Table IV, $Q_{open}+Q_{simulation}=0.489$ m^3/s, where $Q_{open}=0.371$ m^3/s (See Table II), $Q_{simulation}=0.118$ m^3/s (See position #3 in Table I). The volume flow rate in the exhaust, $Q_{exhaust}$, is 0.466 m^3/s at the 100% open hood with TSI VelociCALC. This means there is an unexpected leakage in the fume hood because the volume flow rate, 0.489 m^3/s was expected as $Q_{exhaust}$ not 0.466 m^3/s.

Smoke Test

Figures 2 and 3 illustrate the smoke test using smoke tubes and smoke matches. Two figures show how the airflow pattern is changed during a volume generating process. There is strong air turbulence that can cause the disorder of smoke flow at the face of fume hood. The calculating methods for turbulence parameters were introduced in time and space in the thesis of author.

FIGURE 2. Smoke Test Using SKC Smoke Tubes

FIGURE 3. Smoke Test Using Smoke Matches

Discussion

The volume flow tests were conducted; the same volume flow rate was not found at the face of the open hood and in its exhaust duct (See Table V). This suggested unexpected leakage and losses during the volume generating process. Thus, a smoke test was conducted again to find the reason of volume flow rate difference. At that time, leakage above the fume hood was found between the sash and the frame during the volume generating process but not during the general work condition.

Through an additional smoke test, the volume generating process caused unexpected leakage above the fume hood as well as at the face of fume hood when the hood passes a face velocity test. It can circulate in the laboratory to a worker's breathing zone. This unsafe work condition could exist if hazardous gases and carcinogens were used during a hot process.

Conclusions

The purpose of this study is to introduce screening tools with smoke tubes and smoke matches for hood leakage during a volume generating process that simulates a hot process. Through smoke tests and a volume generating process, unexpected leakage above the fume hood was found through smoke testing and at the face of fume hood. These results suggest that when a hood is operated with any operation producing high temperature gases, leakage can be caused.

This study shows that if there is any fume hood experiment with high temperature or able to cause fume hood to leak, the fume hood must be controlled with stable face velocity using a damper to protect workers and engineers from hazardous gases released within it.

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