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ORIGINAL ARTICLE

Feasibility of Substituting Ethylene with Sulfur Hexafluoride as a Tracer Gas in Hood Performance Test by ASHRAE-110-95 Method

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ABSTRACT

ANSI/ASHRAE 110-95 protocol is a widely acceptable method to assess the performance of laboratory hoods. In this test, sulfur hexafluoride (SF6) is applied as a tracer gas to quantitatively evaluate the performance of laboratory hoods. The environmentally hostile characteristics of SF6 as well as its cost are the major concerns. In the present study, the substitution of ethylene with SF6 in the ASHRAE 110-95 test method was investigated. Both SF6 and ethylene were applied to a laboratory hood at different face velocities and injection flow rates according to the ASHRAE 110-95 method. Meanwhile, the exposure of a mannequin stationed at the front of hood was measured. The concentration of tracer gases was measured using direct reading instruments. Linear regression of the results was used to consider the substitution of ethylene with SF6.The occupational exposure of the proposed hood operator to SF6 and ethylene were 4.2-7.3 ppm and 0.1 to 0.57 ppm respectively. SF6 exposure was increased significantly (p<0.001) by increasing the injected level while ethylene exposure was decreased significantly (p<0.001). The linear correlation between the leakage levels of two tracer gases at the injected flow rate of 4 lit/min did not fit well with experimental data. Ethylene is not recommended as a substitution for SF6 in ASHRAE 110-95 hood performance test.

Keywords: *Laboratory hood, Tracer gas, Ethylene, SF6*

INTRODUCTION

The application of laboratory hoods to reduce the chemical and biological exposure of operators has been accelerated recently [1, 2]. In hood designing, the major criterion is to limit the exposure levels of the operator to hazardous materials as much as possible [3, 4]. The laboratory operators experience occupational exposure with chemical substances mainly due to insufficient performance of laboratory hoods [5]. The United States occupational safety and health administration (U.S.OSHA) reported that laboratory operators live ten years less than normal people where chemical exposure in laboratories creates safety and health problems for them [6]. Safety and health regulations enforce the

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Fig 1. Hood area division

Fig 2. The position of mannequin

laboratory authorities to assess the performance of their hoods periodically.

To address this goal, several protocols have been proposed by governmental agencies regarding the safety of laboratory hoods [7-9]. U.S. ANSI/ASHRAE 110-1995 hood performance test is a widely believed test modified over the years by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE). In this protocol sulfur hexafluoride is recommended as a tracer gas to be applied for quantitative performance test of hoods [10, 11]. It is a suitable choice for this protocol because of its non-toxic, non-flammable properties as well as its likely of being detected at ppb levels using infrared absorption. Meanwhile, SF6 is a strong greenhouse gas while 23900 times more harmful than carbon dioxide. Typically 2 pounds of SF6 is applied in each test which is finally released to the atmosphere. The annual evaluation of all hoods may lead to a large scale releasing of SF6 to the environment [12]. High price of SF6 and its detector is another issue to be concerned. In the recent years the use of N_2O as a substitute for SF6 based on ANSI/ASHRAE 110 protocol was reported by different authors including Guffey. Guffey did not found a linear relationship between SF6 and N_2O as tracer gases [12].

Ethylene is a cheap gas with the same weight as air. Although ethylene has a global warming potential (e.g. 6.8 times more than CO_2) but it is much less harmful than Sulfur hexafluoride [13-14]. The possibility of substituting ethylene with SF6 in ASHRAE 110-95 method of hood performance test was investigated in present study.

MATERIALS AND METHODS

Application of ANSI/ASHRAE 110 method

All three types of tests described in ASHRAE-110-95 method including face velocity test, flow visualization and tracer gas leakage test were applied to a hood [15] at three different face velocities and three injected flow rates of each tracer gas. According to this standard a mannequin with 170 cm height was placed with its breathing zone 75mm far from plane of the hood sash [16]. The occupational exposure of the mannequin (as a proposed hood operator) was measured at three injected flow rates of 2, 3, and 4 l/min [17].

Velocity test

Three different face velocities of 0.4, 0.6, and 0.7 m/s corresponding to the standard face velocity of different types of hoods were applied to a laboratory hood through a variable air volume fan designed for this purpose. Velocity was measured with a calibrated thermal anemometer (TA-2 model manufactured by Air Flow Co of UK). The measuring pattern of the anemometer ranged from 0 to 2 m/s with ±30% accuracy [18] which well agreed with ASHRAE 110-95 recommendations [15]. The hood opening was divided into 60 equal grids with a dimension of 15 cm (Fig 1).

Table 1. The proposed and measured air velocities in m/sec at hood opening

Proposed Velocity	Measured	
	Mean± Sd	**Range**
0.4	0.42±0.04	0.36 - 0.55
0.6	0.6±0.07	0.5 - 0.85
0.7	0.7±0.11	0.6 - 1.1

Face velocity was measured in the center point of grids through three repeats.

Smoke test

As recommended in ASHRAE 110-95 method, smoke visualization is required to test the performance of each hood. A smoke source with low and high volume of smoke was applied to observe the flow patterns on a pass-fail basis [19- 20].

Tracer gas test

The mannequin was positioned at the left, center and right side of the sash plane. According to the ASHRAE 110-95 standard, its breathing zone was 75 mm far from the plane of the sash (Fig 2).

SF6 and ethylene were injected through a gas diffuser to the hood at 2, 3 and 4 l/min, each for five minutes. Gas diffuser was located inside the hood 15 cm behind the sash. Ethylene concentration in breathing zone of the mannequin was determined by a Pho-check tiger (Ion-science Co, UK). In this apparatus, ethylene is detected through photo ionization technique using UV radiation. Its measuring pattern ranged from 1ppb to 20000 ppm with±5% accuracy. The default voltage for UV radiation was applied to optimize the measurement.

A SF6 leakage detector (manufactured by HV Hipot Electric Co, China) was used to measure SF6 concentration. In this instrument, the variation of an infrared light passing through a gas chamber is detected to quantify the concentration of the gas. The default wavelength of infrared light was used to eliminate any interference. Detection pattern of the instrument ranged from 0ppb to 500 ppm with ±10% accuracy.

Statistical analysis

Statistical analysis was applied using the SPSS-19 software. The results are expressed as means±standard deviation. The difference between ethylene and SF6 leakage test was achieved through independent *t*-test. A 3-way ANOVA was applied to analyze the influences of different face velocities and volumetric flow rates on racer gas leakage. Linear regression was used to assess the feasibility of substituting ethylene with Sulfur hexafluoride. *P*-Values<0.05 were considered significant.

RESULTS

Volumetric flow rate measurements

Face velocity was measured at 60 points for each applied velocity. The mean, minimum and maximum values are shown in Table 1. The mean measured values well agree with proposed face velocities.

Smoke tests

Smoke test was repeated 18 times and the results were reported on pass-fail basis. The tested hood was passed from smoke test (Fig 3).

Tracer gas test

The SF6 and ethylene leakage from the hood ranged 4.2-7.3 ppm and 0.1-0.57 ppm respectively. The results of tracer gas tests for both gases at three different velocities are illustrated in Table 2.

The maximum level of both tracer gas leakages was experienced at face velocity of 0.4 m/s.

Table 3 contains exposure to both tracer gases in three position of mannequin. The results show that,

Fig 3. Smoke test

Table 2. The leakage levels of tracer gases at different face velocities

Face velocity, m/s	SF6, ppm	Ethylene, ppm
0.4	5.51±0.98	0.27±0.17
0.6	4.36±0.31	0.36±0.12
0.7	4.69±0.37	0.11±0.07

Table 3. The proposed operator's exposure to the tracer gases at different mannequin position with air velocity of 0.4 m/s at the hood opening

Mannequin position	SF6, ppm	Ethylene, ppm
Right	4.63±0.4	0.26±0.17
Center	4.79±0.75	0.24±0.16
Left	5.14±1.02	0.25±0.16

operator exposure to SF6 has been changed significantly (p<0.001) at different mannequin positions.

Both tracer gases were injected to the hood at three different flow rates. The results showed that the leakage level of SF6 was increased significantly (p<0.001) as the injection rate increased (Fig 4). On the other hand, the leakage level of ethylene decreased significantly (p<0.001) as the injection rate increased (Fig 5).

The linear relation between the leakage levels of SF6 and ethylene were found to be a suitable measure to see if ethylene can be substitute with SF6. For this purpose, the linear trend of SF6 leakage levels versus ethylene for different injected flow rates were determined (Fig 6).

The linear trend of SF6 leakage levels versus ethylene did not fit well with experimental data (R^2=0.0063). Thus, other trends were tried to find out the best fitting trend. For this purpose, the best trend for SF6 leakage levels versus ethylene was found to be polynomial (Fig 7) having the regression value of R^2=0.213 which is still a poor fitting level.

In 3rd attempt the polynomial trend of log–log values of SF6 leakage levels versus ethylene (Fig 8) was found to have the highest regression value of R^2=0.8293 which is an acceptable trend.

Discussion

ANSI/ASHARE 110 method recommended SF6 to test the effectiveness of laboratory hoods. The application of SF6 (as a harmful gas for the environment) in this test which is finally released to the environment is a hurdle of this protocol [21, 22]. This study was carried out to investigate the likely hood of substituting a less harmful gas (e.g. Ethylene) with SF6 as a tracer gas in ANSI/ASHRAE 110 method.

A very good correlation between measured and proposed face velocities which was obtained in present study (Table 1) showed that the ventilation rates of tested hood were adjusted according to the proposed volumes. The results revealed that the tested hood was satisfactorily passed the face velocity and smoke tests.

According to ASHRAE 110 test method, the level of SF6 leakage should not exceed 0.1 ppm for five minutes of gas injection. The concentration of SF6 in breathing zone of the mannequin was higher than this recommended level. This discrepancy with ASHRAE 110 standard was reported in some studies [1,12,17]. Only 4.5% of the hoods which were tested according to ASHRAE 110 test method had an acceptable level of tracer gas leakage [1] which does not contravene the

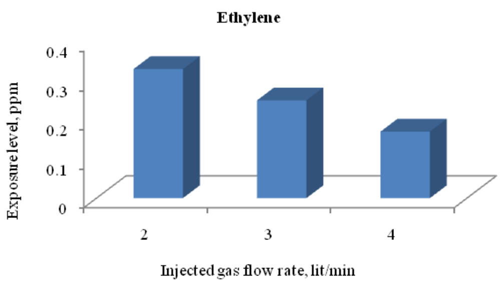

Fig 4. Leakage levels of ethylene at different injection flow rates and face velocity of 0.4 m/s

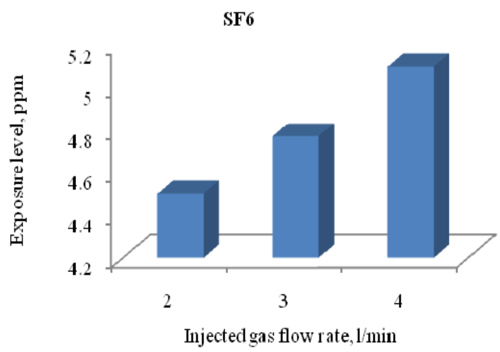

Fig 5. Leakage levels of SF6 at different injection flow rates and face velocity of 0.4 m

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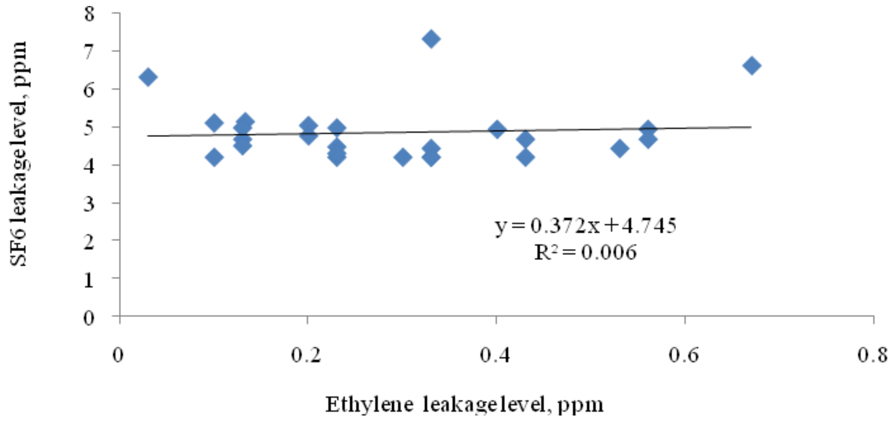

Fig 6. The linear trend of SF6 leakage levels versus ethylene at4 lit/min injected flow rate

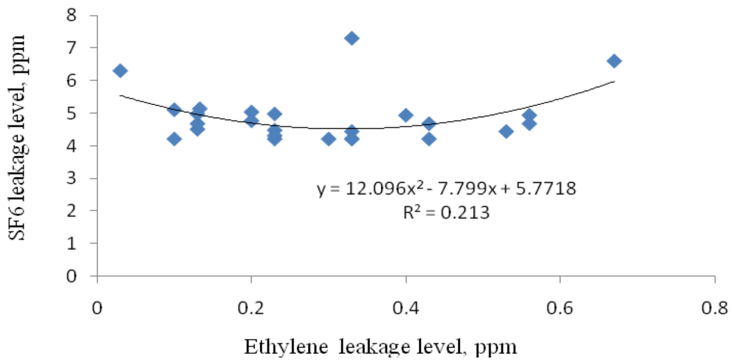

Fig 7. The polynomial trend of SF6 versus ethylene leakage levels at 4 lit/min injected flow rate

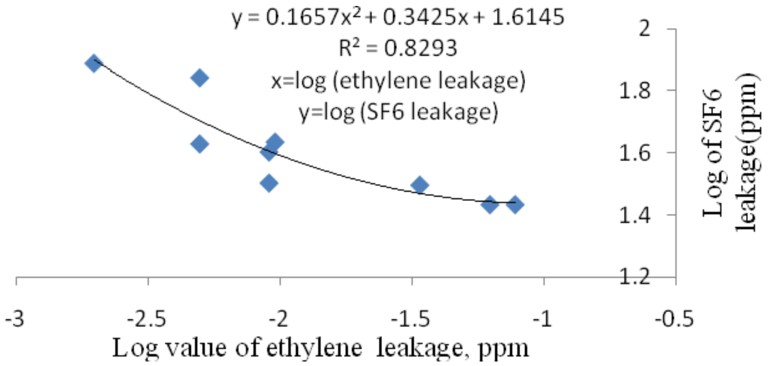

Fig 8. The polynomial trend for log-log values of SF6-ethylene leakage levels at 4 lit/min injected flow rate

present study.

The main concern for ethylene as a substitute for SF6 is its flammability. The results showed that while the LEL (lower explosive limit) of ethylene is 2.7%, its applied concentration in this study did not exceed 0.022% which is far less than its LEL. The application of ethylene for this purpose is safe [7].

While, the face velocity is a main factor in hood performance test [1,23], the hood performance could not be evaluated only with this parameter.

According to Fig 4, the detected leakage level of ethylene does seem to be rational. The detected leakage level is expected to increase by increasing the injected volume of tracer gas, but it does not act this way. Fig 5 shows that the detected level of SF6 leakage level performs rationally since it increases as the injected flow rate is increased from 2 to 4 l/min. This controversy could be from the low detecting instrument. It seems that the phochek used to measure ethylene does not detect the low levels of ethylene accurately.

ASHRAE 110 method recommended the input flow rate of tracer gas to be 4 l/min. The leakage levels of both studied gases at this input flow rate are expected to have a linear relation. The results revealed that they do not have a linear relation. According to Fig 8, the best fitted trend between the leakage levels of both studied gases at 4 lit/min injected flow rate is the polynomial trend of log-log values with R^2=0.8293. However this result is much better than similar studies.

Nitrous oxide substitution was substituted with sulfur hexafluoride as a tracer gas in ASHRAE 110 protocol. It achieved a linear regression of 0.36 when they fitted the logs of the leakage levels of tracer gases [12].

The controversies between two studied tracer gases show that ethylene is not a proper substitute for SF6. The lack of a high accurate detecting instrumentation for ethylene seems to be the major limitation of the present study. Therefore, further studies using more accurate detecting instrumentation for ethylene is highly recommended.

Conclusion

Ethylene is not recommended as a substitution for SF6 in ASHRAE 110-95 hood performance test.

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