RESEARCH ARTICLE

A comparison study between passive and active workplace personal air monitoring techniques for airborne isopropyl alcohol concentrations

This research project involved a comparison between the performance of active and passive sampling methods used to collect isopropyl alcohol vapor in an industrial setting. This field experiment was conducted in a real-world industry setting with workers exposed to isopropyl alcohol. In order to create sample sets, passive diffusive samplers (3M 3520 Organic Vapor Monitor) were paired, side-by-side, with active samplers (charcoal solid sorbent tubes). A total of 17 paired sample sets were collected, which yielded data with a non-parametric distribution. Post hoc analysis showed that 4 of the 17 paired sample sets were potential outliers. A Wilcoxon signed-rank test showed that the passive samplers were significantly different from the active air samples (alpha = 0.05), regardless whether or not the potential outliers were included or excluded from the data. A linear regression analysis found a linear relationship between active and passive sampling results. An R^2 value of 0.97 (when including potential outliers) and 0.79 (when excluding potential outliers) suggests that the model fits well with the data. Satisfactory correlation between the samplers was found when including potential outliers (r = 0.9859) and excluding potential outliers (r = 0.8863). The passive samplers reported higher concentrations than the active samplers in 15 of the 17 sample sets. On average, the passive samplers reported 25% higher results when including potential outliers and 16% higher results when excluding potential outliers when compared to the paired active sampling results. Based on the strong correlation values and the trend of passive samplers reporting higher results than the active samplers, occupational health specialists could reliably use the passive samplers in this study to demonstrate compliance to isopropyl alcohol exposure limits.

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INTRODUCTION

Isopropyl alcohol (IPA) is a colorless flammable compound that can cause a variety of health effects. Symptoms of high personal exposure include drowsiness, dizziness, headache, dry or cracking skin, and irritation of the eyes, nose, and throat.[1] A repetition of high exposure levels can induce confusion, loss of coordination or consciousness, may affect the liver and kidneys and may even cause death.[2] IPA is used in a variety of consumer and industrial products including: cosmetics, skin and hair products, perfumes, de-icers, paints, resins, pharmaceuticals, inks, adhesives, lacquers, dyes, and cleaners.[2,3] IPA is also used as an intermediary chemical in processes that produce actone, methyl isobutyl ketone, isopropylamines, and isopropyl esters.[3] IPA is easily absorbed through mucous membranes and exposure routes include inhalation, ingestion, and to a lesser degree, skin/eye contact.[4] Workers exposed through more than one route can quickly become over exposed.[2]

Passive diffusion badges and adsorbent tubes connected to active air pumps (Figure 1) are two methods commonly employed by industrial hygienists for quantifying chemical

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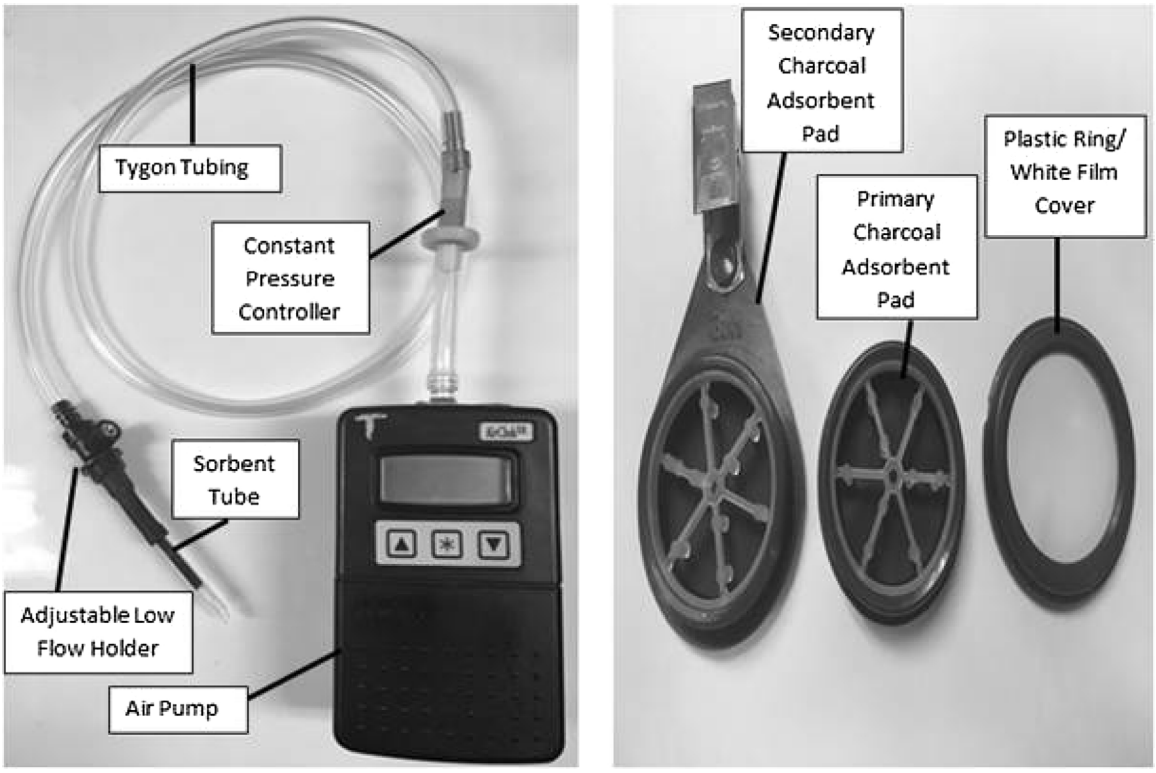

Figure 1. Active and passive sampling trains.

content in the air, and IPA is no exception. For many years, active air pump sampling was the recognized standard for determining air borne chemical exposure levels. Active air pump samplers function by drawing known volumes of air through a detector or collection device by means of pumping or forced air convection.[5] In the case of IPA sampling, the collector is two charcoal tubes.[4] However, the tubes need to be separated and capped immediately after sampling in order to prevent analyte loss, which potentially skews the sampling results.[4] When passive diffusion samplers were introduced as an alternate method for collecting chemical air samples, they soon became recognized as a valuable and efficient method for chemical exposure sampling. Passive samplers collect analytes from the surrounding air by means of permeation or natural diffusion, collecting the analyte onto a collector within the sampler.[5] Passive samplers, with their low weight, the fact they do not require calibration, and less cumbersome design make these the preferred sampler over active air pump samplers.

The National Institute for Occupational Safety and Health (NIOSH) has established guidelines for acceptable chemical monitoring methods, including passive samplers.[6,7] The guidelines state that an acceptable criteria for accuracy is ±25% of the true concentration at the 95% confidence interval.[6,7] Other factors that could potentially affect sampling outcomes are also considered, including but not limited to: temperature effects, shelf life, storage stability, and sampling capacity. One such factor is studying the samplers "behavior in the field" or "field evaluation" of the sampler.[6,7] Field evaluations of sampling methods require that the proposed method under study be paired with a validated independent sampling method as sampling pairs in the field.[6,7] Statistical tests should be used to compare the method under study to the validated independent sampling method.

Many side-by-side studies comparing active air pump samplers side-by-side with passive diffusion samplers have been performed. A popular method for conducting this type of study is to pick a well-known highly toxic chemical and monitor it in a controlled laboratory or out in the field where the chemical is used in the workplace. Some studies have found that passive diffusion sampling can be more precise than active air pump sampling. For example, the use of passive diffusion samplers was found to meet NIOSH accuracy requirements when sampling for ethylene oxide and was also found to be more precise than active air pump charcoal field test sampling.[8] Another study found that when sampling for benzene, passive monitors provided acceptable results within the criteria set by NIOSH and were generally more precise than active sampling with a charcoal tube for 8-h sampling.[9]

Even long-term environmental sampling has found that passive badge sampling and active air pump sampling can yield similar results. A long-term pesticide environmental study showed

that agreement in the average concentrations improved with increasing length of sampling time between active and passive samplers.[10] A comparison study monitoring nitrogen dioxide in urban air showed that the results obtained with the passive sampler were comparable to the results from the active sampling method (within 10–20% of each other).[11]

However, it should not be assumed that comparison trends will be the same for all chemicals when comparing two different sampling methods. For example, a comparison study by Delcourt and Sandino found good agreement between the studied passive monitor and active sampling method when monitoring for 9 different chemicals simultaneously.[12] However, the mean trends were not the same for each individual chemical. The mean trends differed in that the passive monitors reported a higher overall mean for 2 of the chemicals, a lower overall mean for 5 of the chemicals, and similar means for 2 of the chemicals when compared to the studied active air pump sampling method.[12] Another comparison study by Hickey and Bishop showed either strong correlation or no consistent significant differences between paired sampler results when monitoring for 22 different organic chemicals, with the exception of methylcyclohexane and *n*-octane.[13] This again shows that sampling trends between two different methods can be different for each individual chemical.

There are also situations where passive badge monitors have failed to meet NIOSH criteria in comparison studies. For example, one study sampled for benzene in an atmosphere with a complex mixture of competing organic vapors using an active air sampling method and 3 different brands of passive diffusion badge monitors.[14] Of the 3 different brands of passive diffusion badge monitors, only 2 were found to report acceptable results within the NIOSH criteria.[14]

Some studies have found a wider range of results for passive sampling when compared to active air pump sampling. For example, a study on formaldehyde in pathology and histology laboratories compared active sampling to passive diffusion sampling.[15] The results in that study showed that passive diffusion monitors generally reported higher formaldehyde concentration levels than active samplers.[15] However, the authors of that particular effort did note that individual passive samples can show lower results than a paired active sampler, thus single results should be treated with caution.[15]

The purpose of the current study is to further examine the similarities and differences between active air pump sampling and passive diffusion sampling. A large portion of the current comparison studies were performed in laboratory settings using chemicals that are very toxic or are of a high public concern (i.e., benzene, pesticides, etc.). This study focused on a low-toxicity chemical that does not receive a lot of interest, IPA, in a real-world occupational setting. Although IPA has a lower toxicity than other chemicals, it is still regulated by the Occupational Safety and Health Administration and high exposure levels may negatively impact worker health. Further, IPA's current ubiquity in personal and industrial products necessitate an evaluation of the best method for sampling worker exposure.

METHODS

A SKC XR5000® active air pump (SKC Inc., Eighty Four, PA) with an attached solid sorbent tube (coconut shell charcoal, 100 mg/50 mg) and a 3M 3520 Organic Vapor Monitor® passive badge monitor (3M, St. Paul, MN) were used to monitor for IPA as a sampling set. Seventeen (17) personal sampling sets were collected by placing the samplers side-by-side on workers. Each sampling set was numbered 1–17. Proper IRB approval was granted by the University of Utah, with the sole inclusion criteria being that workers be engaged in IPA related processes. Workers selected for this study handled drums full of IPA and bags of an essential chemical powder. The bags of chemical powder were soaked and transported in IPA for safer over-the-road transportation. Workers had to dump excess IPA into a waste container and then remove the IPA soaked bags for drying.

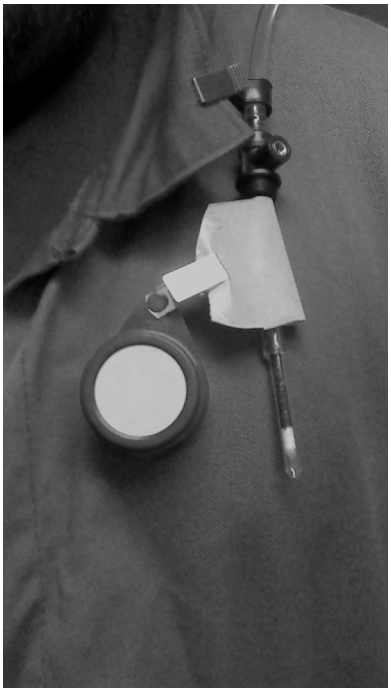

Figure 2. Both samplers attached to a worker.

Workers were fitted with a belt that held the active air pump in place, with low-flow fixture tubing running up and over the right or left shoulder (see Figure 2). The low-flow fixture tubing was connected to a solid sorbent tube that was placed in the breathing zone of the worker. The passive badge monitor was affixed near the solid sorbent tube on the same shoulder, in such a way as to not impede and/or restrict air flow into the tube. Chemical monitoring for this study occurred over the course of multiple days inside the process facility. Temperatures ranged from 21 °C to 27 °C.

Active pump sampling was conducted in accordance with the NIOSH method 1400 Issue 2[16] and passive badge sampling was conducted in accordance with the manufacturer's instructions.[17] Active pumps were calibrated pre- and post-sampling using a Bios DryCal Defender Series® Pump Calibrator (Mesa Labs, Butler, NJ). The flow rates were set at approximately 0.09 L/min, which is within the flow rates of NIOSH method 1400 Issue 2 (0.01 L/min minimum, 0.2 L/min maximum).[16] Only pumps

that had a <5% difference between the pre- and post-calibration flow-rates were deemed valid for use in the study, in accordance to good sampling practices. The sampling time ranged from 20 min to 29 min in order to meet the minimum volume requirements of NIOSH method 1400 Issue 2.[16] Blanks of solid sorbent tubes and passive badges were submitted to the lab as a quality control for each sampling event and were found to be lower than the limit of detection.

Sampling media was analyzed by a laboratory certified through the American Industrial Hygiene Association's Laboratory Accreditation Program (AIHA-LAP). Sampling media was delivered to the laboratory the same day the sampling took place, following an acceptable chain-of-custody protocol. Charcoal tubes used in the sampling were chilled in a cooler for transportation to the lab per NIOSH method 1400 Issue 2.[16] The laboratory calculated passive diffusion badge sample results by using the equation found in the 3M Technical Data Bulletin for Organic Vapor Monitors.[17]

After completing an initial portion of the sampling, power calculations were completed and it was determined a sample size of 13 would be needed to achieve a power of 0.8. Power calculations and subsequent statistical analysis were performed using the SAS® software version 9.4 (SAS, Cary, NC, USA). Statistical tests include testing for normality, Tost test for equality, Wilcoxon signed-rank test (the non-parametric equivalent to a paired t-test), Pearson Correlation test, and linear regression. Prior to conducting sampling for this study, it was decided that approximately ±10% of the active sample data mean would be used as the upper and lower range in determining equality for the Tost test at the alpha = 0.05 level. Once sampling was completed and upon receipt of laboratory results, it was found that the active sample data mean was 99 ppm when excluding potential outliers. Based on that mean, it was decided that an upper and lower range of ±10 ppm would be used to determine if the active and passive samplers were statistically equivalent.

Potential outliers in the data were determined based on unusual site sampling conditions and by looking for abnormalities in the sampling data. Potential outliers were identified post hoc of sampling. It was determined that the statistical results would be presented for all the data and for the data when excluding potential outliers.

RESULTS

A total of 17 personal sample sets were collected. The paired sampling set data is shown in Table 1. Post hoc analysis showed that there were potential outliers in the paired datasets. The sampling site conditions were different when monitoring for sample sets 1–3. The hosting company had fewer workers on shift to process the barrels of chemical powder and IPA. Subsequently, the workers had to compensate for less personnel and each had to handle more barrels than normal. This resulted in the employee IPA exposure being 3–5 times higher for sample sets 1–3 than the rest of the collected

Table 1. Sample results for paired active pump samples and passive badge samples.

	Active pump samples	Passive badge samples	Approximate difference in passive sample results from active sample results
1[a]	528 ppm	680 ppm	+29%
2[a]	523 ppm	550 ppm	+5%
3[a]	355 pm	460 ppm	+30%
4	81 ppm	99 ppm	+22%
5	87 ppm	110 ppm	+26%
6	76 ppm	110 ppm	+45%
7	75 ppm	100 ppm	+33%
8	130 ppm	130 ppm	+0%
9	104 ppm	120 ppm	+15%
10	140 ppm	150 ppm	+7%
11	124 ppm	130 ppm	+5%
12	93 ppm	98 ppm	+5%
13	80 ppm	100 ppm	+25%
14	95 ppm	110 ppm	+16%
15	85 ppm	98 ppm	+15%
16	115 ppm	110 ppm	−4%
17[a]	38 ppm	100 ppm	+163%
Average Difference between all datasets (N = 17)			+25%
Average Difference between datasets excluding potential outliers (N = 13)			+16%

[a] Identified as a potential outlier.

Table 2. Univariate statistical output for N = 17.

Univariate analysis: active samples		Univariate analyisis: passive samples	
Mean	161	Mean	191
Median	95	Median	110
Std deviation	153	Std deviation	182
Variance	23,403	Variance	33,211
Skewness	1.95	Skewness	2.04
Kurtosis	2.57	Kurtosis	2.89
Range	490	Range	582
Interquartile range	49	Interquartile range	30

Table 3. Summary of Tost Test, Wilcoxon two sample test, Pearson Correlation Coefficient, and linear regression analysis for N = 17.

Tost test	$p = 0.98$
Wilcoxon signed-rank test	$p < 0.0001$
Pearson Correlation test	$r = 0.9859$
Linear regression analysis	
- Dependent variable	Active Pump Sample
- Intercept	2.07
- Slope	0.83
- Equation (where X equals the passive sample data)	$Y = 0.83\ (X) + 2.07$
- r^2	0.97

sampling data. Thus, sample sets 1–3 are potential outliers due to the sampling site work conditions being different than the rest of the sampling events, and due to the effect that a few extreme values can have on the overall mean of sampling data.

Additionally, the post hoc analysis showed that active sample 17 was extremely lower than the rest of the active sampling data and the paired passive sample 17. A low result value such as this would suggest an operator error in the manner in which the sample was taken. However, there were no noted operator errors during the time of sampling. The cause of this value abnormality is unknown. Due to the uncertainties surrounding this sample and the effects that a single extreme low value can have on the overall mean of the data, sample set 17 was labeled as a potential outlier.

Statistical analyses were performed on the entire set of samples (N = 17). Univariate analysis showed that the data points most closely resemble a non-parametric distribution, as seen in Table 2. The univariate datasets for both the active and passive sample sets having a skewness of 1.969 and 2.039, respectively, demonstrate the data's non-parametric distribution. In addition, the kurtosis of the active and passive datasets were 2.57 and 2.89, which also demonstrate that the data are non-parametric. The mean and median were found to be higher for the passive sampling data (191 and 110 respectively) than the active sampling data (161 and 95 respectively).

The Tost test for equivalence found that the sampling methods were not statistically equivalent ($p = 0.98$) at the ±10 ppm range (Table 3). Because of the non-parametric trends in the data and the use of paired datasets, a Wilcoxon signed-rank test was determined appropriate for data analysis. Table 3 shows the results of this analysis, which indicate a statistically significant difference between the active air pump samples and the passive diffusion samples ($p < 0.0001$). A linear regression analysis and the Pearson Correlation Coefficient were calculated for the entire set of samples (N = 17) to further understand the relationship between the paired data. An r value of 0.9859 was found (Table 3) indicating strong correlation. Linear regression analysis (Figure 3 and Table 3) predicted a linear model that fits well with the data ($R^2 = 0.97$).

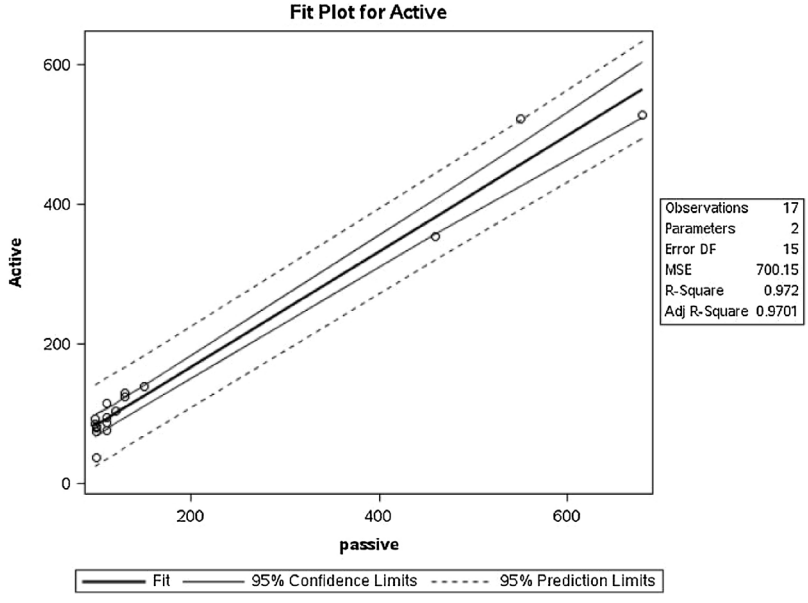

Figure 3. Fit plot for active pump-passive badge sampling (N = 17).

Table 4. Univariate statistical output for N = 13.

Univariate analysis: active samples		Univariate analyisis: passive samples	
Mean	99	Mean	113
Median	93	Median	110
Std deviation	22	Std deviation	16
Variance	477	Variance	251
Skewness	0.73	Skewness	1.23
Kurtosis	−0.81	Kurtosis	1.10
Range	65	Range	52
Interquartile range	34	Interquartile range	20

Table 5. Summary of Tost Test, Wilcoxon two sample test, Pearson Correlation Coefficient, and linear regression analysis for N = 13.

Tost test	$p = 0.89$
Wilcoxon signed-rank test	$p = 0.0015$
Pearson Correlation test	$r = 0.8863$
Linear regression analysis	
- Dependent variable	Active pump sample
- Intercept	−38.84
- Slope	1.22
- Equation (where X equals the passive sample data)	$Y = 1.22\ (X) - 38.84$
- r^2	0.79

Statistical analysis was again performed on the dataset, excluding sample sets 1–3 and 17 as outliers (N = 13). Univariate analysis showed that the active sampler data points most closely resemble a normal distribution (Table 4) due to having a skewness of 0.73 and a kurtosis of −0.81. However, univariate analysis showed that the passive sampler data points most closely resemble a non-parametric distribution (Table 4) due to having a skewness of 1.23 and a kurtosis of 1.10. The mean and median were again found to be higher for the passive sampling data (113 and 110 respectively) than the active sampling data (99 and 93 respectively).

The Tost test for equivalence found that the sampling methods were not statistically equivalent ($p = 0.89$) at the ±10 ppm range (Table 5) when excluding potential outliers. Because of the non-parametric distribution in the passive sampler dataset and the use of paired datasets, a Wilcoxon signed-rank test was determined appropriate for analysis. Table 5 shows the results of this analysis, which indicate there is a significant difference in the data reported by the active air pump samples and the passive diffusion samples ($p = 0.0015$).

A linear regression analysis and the Pearson Correlation Coefficient was again calculated for the set of samples excluding potential outliers (N = 13) in order to further understand the relationship between the paired data. An r value of 0.8863 was found (Table 5) indicating strong correlation. Linear regression analysis (Figure 4 and Table 5) predicted a linear model that fits well with the data ($R^2 = 0.79$).

DISCUSSION

When including all the sample sets (N = 17), both active and passive monitors were shown to report statistically different results. Although the samplers were found to report statistically different results, a strong linear correlation between the samplers was found. This suggests that if the concentration value from one of the samplers is known, then the other value can be reasonably predicted using the linear

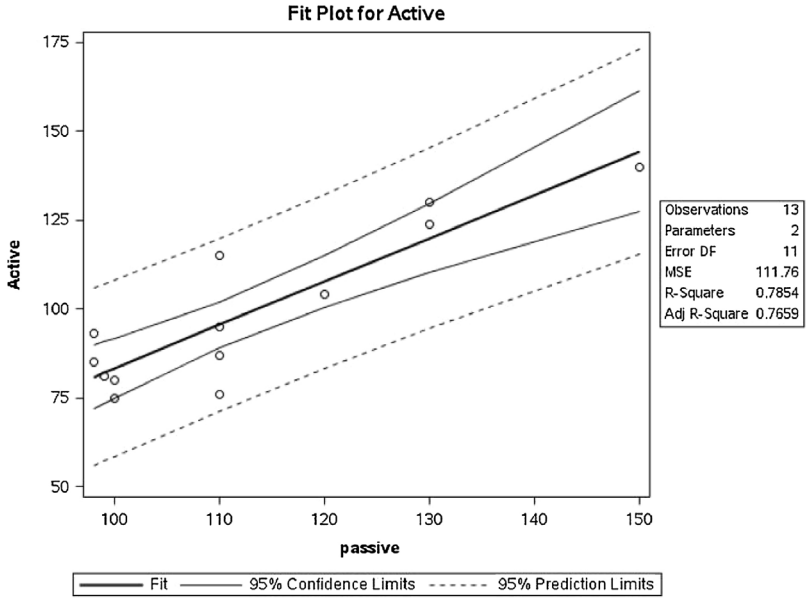

Figure 4. Fit plot for active pump-passive badge sampling (N = 13).

model developed by the regression analysis.

As mentioned earlier, there is reason to believe that sample sets 1–3 and 17 are outliers; therefore, this study performed additional analysis in which these 4 sample sets were excluded (N = 13). The results showed that excluding the potential outliers reduced the difference between the mean and median in the datasets, thus reducing the effect that a few extreme outlying values had on the mean of the datasets. Before excluding the potential outliers, the passive sample data mean was 74% higher than the passive sample median and the active sample data mean was 69% higher than the active sample median. After excluding the potential outliers, the passive sample data mean was only 3% higher than the passive sample data median and the active sample data mean was only 6% higher than the active sample mean. In that way, the statistical analysis of N = 13 sample sets are probably more accurately representative than the statistical analysis of N = 17 sample sets.

The analysis of the N = 13 sample set also showed that the active and passive monitors reported statistically different results. Again, a strong linear correlation between the samplers were found and if the concentration value from one of the samplers is known, then occupational health specialists can predict the value of the other sampler using the linear model developed by the regression analysis.

Another finding of this study is that the passive sampler used here, in general, overestimated IPA air concentrations when compared to the active sampler. This is demonstrated by the higher overall mean and median for both the N = 17 and N = 13 sample set analysis. 15 of the passive samplers reported higher results than the paired active samplers for N = 17 and 12 of the passive samplers reported higher results than the paired active samplers for N = 13 (Table 1). On average, the passive samplers reported 25% higher results for N = 17 and 16% higher results for N = 13 when compared to the paired active sampling results. As found in other comparison studies,[15] passive samplers overestimating air chemical concentrations is beneficial for proving compliance with an occupational exposure limit.

Limitations

Due to funding limitations, only 17 paired sample sets were collected. Future studies should aim to increase the sample size to provide >90% power. Increasing the power will further validate the findings discussed herein.

The period of time over which sampling was conducted may also be a limitation. The industrial process monitored for this paper only lasted approximately 30 min. While short-term sampling is allowed in the active sampling method and the passive sample manufacturer instructions, resulting short-term sampling comparison trends are not necessarily applicable to longer, full-shift sampling. As has been shown in other studies,[10] longer sampling times can affect the agreement between active and passive sampling data in comparison studies. Industrial processes involving IPA at other companies might expose employees for the duration of the entire shift. Longer sampling times covering a full-shift might reveal different trends and comparison results than the short-term sampling times using in this study.

Four of the 17 sample sets were identified as potential outliers. The probable cause for these discrepancies is known for three of the four outliers, whereas active sample 17 reported a concentration much lower than expected (38 ppm) with no known explanation. Other samplers collected during that same sampling event showed employee exposure was in the range of 90–160 ppm depending on the sample set. Passive sample 17 was placed on the same shoulder as active sample 17 and showed a concentration of 100 ppm. The cause of active sample 17's low concentration results is unknown.

Strengths

One strength of this study was the method of pairing the sample sets. In other comparison studies one instrument is generally attached to the left shoulder and the other is attached to the right under the assumption that both shoulders are exposed to the same concentrations of contaminate. However, a right- or left-hand preference could potentially reduce or increase a worker's exposure depending on body position in relationship to the exposure. In this study, both instruments were placed on the same shoulder within a few inches of each other, thus further ensuring that both sampling devices received the same exposure.

Another strength of this study was conducting this monitoring in a real-world working environment as opposed to conducting the monitoring in the controlled environment of a laboratory. While monitoring in the laboratory environment provides valuable data, it cannot replicate the changing and unpredictable nature of uncontrolled real-world work settings. Actual chemical exposure compliance monitoring by occupational health specialists takes place in real-world working environments, not in the controlled environment of a lab. It is vital for occupational health specialists to know that monitoring with passive diffusion badge methods will yield similar results as active pump sampling methods in real-world situations.

IPA was the only liquid chemical used in this process. No other competing solvents or organic chemicals were present in the air during the sampling events. Sampling results were not affected by chemical interferences.

CONCLUSIONS

Data from this study show that the passive badge monitor used here reported statistically different results compared to the active air pump sampler for monitoring IPA in a workplace. A strong linear correlation relationship was found between the datasets. Using the linear models contained in this study, occupational health specialists can, with a high degree of reliability, predict the concentration value of one of the sampling methods as long as the other method's concentration value is known.

Overall, one of the primary reasons chemical samples are collected is to determine compliance to occupational exposure limits in order to keep

workers safe. Due to the strong correlation values and due to the finding that the passive sampler in this study generally overestimated the IPA concentrations when compared to the active sampler, occupational health specialists could reliably demonstrate IPA occupational exposure limit compliance using the passive samplers contained in this study. Future IPA sampling comparison studies similar to this one should seek to conduct sampling for entire 8-h shifts rather than short-term samples to determine if extended sampling periods affect the relationship trends between passive and active samplers.

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REFERENCES

1. Chemical Sampling Information: Isopropyl Alcohol. Available at: *https://www.osha.gov/dts/chemicalsampling/data/CH_248400.html, accessed 01/17/2017.*
2. New Jersey Department of Health. Hazardout Substance Fact Sheet: Isopropyl Alcohol. Available at: *http://nj.gov/health/eoh/rtkweb/documents/fs/1076.pdf, accessed 02/19/2017.*
3. Andrew Guy Jr: Chemical Profile: US isopropanol. Available at: *http://www.icis.com/resources/news/2014/04/14/9771491/chemical-profile-us-isopropanol/, accessed 01/17/2017.*
4. Isopropyl Alcohol. Available at: *https://www.osha.gov/dts/sltc/methods/organic/org109/org109.html, accessed 02/19/2017.*
5. Fowler, W. K. Fundamentals of passive vapor sampling. *Am. Laborat.* **1982**, *12*, 80–87.
6. Cassinelli, M.; Hull, R.; Crable, J.; Teass, A. Protocol for the evaluation of passive monitors, In Berlin, A.; Brown, R. H.; Saunders, K. J. (Eds.), *Diffusive Sampling: An Alternative Approach to Workplace Air Monitoring*, Royal Society of Chemistry Burlington House: London, 1987, pp. 190–202.
7. Kennedy, E. R.; Fischback, T. J.; Song, R.; Eller, P. M.; Shulman, S. A. *Guidelines for air sampling and analytical method development and evaluation.* A NIOSH Technical Report. 1995. DHHS (NIOSH) Publication Number 95-117.
8. Kring, E. V.; Damrell, D. J.; Basilio, A. N.; McGibney, P. D.; Douglas, J. J.; Henry, T. J.; Ansul, G. R. Laboratory validation and field verification of a new passive air monitoring badge for sampling ethylene oxide in air. *Am. Ind. Hygiene Assoc. J.* **1984**, *45*, 697–707.
9. Pristas, R. Benzene in air – organic vapor monitors versus charcoal tubes. *Am. Hygiene Assoc. J.* **1991**, *52*, 297–304.
10. Hayward, S. J.; Gouin, T.; Wania, F. Comparison of four active and passive sampling techniques for pesticides in air. *Environ. Sci. Technol.* **2010**, *44*, 3410–3416.
11. Royset, O. Comparison of passive and active sampling methods for the determination of nitrogen dioxide in urban air. *Fresenius' J. Anal. Chem.* **1998**, *360*, 69–73.
12. Delcourt, J.; Sandino, J. P. Performance assessment of a passive sampler in industrial atmospheres. *Int. Arch. Occup. Environ. Health,* **2001**, *74*, 49–54.
13. Hickey, J. L. S.; Bishop, C. C. Field comparison of charcoal tubes and passive vapor monitors with mixed organic vapors. *Am. Ind. Hygiene Assoc. J.* **1981**, *42*, 264–267.
14. Spielman, C. R.; Blehm, K. D.; Buchan, R. M.; Hagar, R. N. An evaluation of benzene in the presence of gasoline by active and passive sampling methods. *Appl. Ind. Hygiene,* **1987**, *2*, 66–70.
15. Lee, E. G.; Magrm, R.; Kusti, M.; Kashon, M. L.; Guffey, S.; Costas, M. M.; Boykin, C. J.; Harper, M. Comparison between active (pumped) and passive (diffusive) sampling methods for formaldehyde in pathology and histology laboratories. *J. Occup. Environ. Hygiene,* **2017**, *14*, 31–39.
16. Williamson, G. *Alcohols NIOSH Method 1400 Issue 2*. NIOSH Manual of Analytical Methods (NMAM). Fourth Edition 1994. August 15.
17. 3M Occupational Health and Environmental Safety Division (OH&ESD). Organic Vapor Monitor Sampling and Analysis Guide. 3M Technical Data Bulletin 1028: Organic Vapor Monitors. St. Paul, Minnesota.