

Field Evaluation of a Passive Sampler for Assessing 2-Ethoxyethyl Acetate Exposures

Tung-Sheng SHIH¹, Ho-Yuan CHANG², Hung-Hsin LIU³, Yi-Shiao HUNG⁴ and Saou-Hsing LIOU^{5,6}

¹Institute of Occupational Safety and Health, Council of Labor Affairs, ²Department of Environmental and Occupational Health, National Cheng-Kung University Medical College, ³Department of Industrial Safety and Hygiene, Chung Hwa College of Medical Technology, ⁴Center for Environmental, Safety and Health Technology, Industrial Technology Research Institute, ⁵Department of Public Health, National Defense Medical Center and ⁶Division of Environmental Health and Occupational Medicine, NHRI, Taiwan Republic of China

Abstract: Field Evaluation of a Passive Sampler for Assessing 2-Ethoxyethyl Acetate Exposures: Tung-Sheng Shih, *et al.* Institute of Occupational Safety and Health, Council of Labor Affairs, Taiwan—This paper presents a field evaluation of a passive badge for measuring 2-ethoxyethyl acetate (2-EEAc) in a humid working environment. Forty-eight pairs of side-by-side active/passive 8-h full-shift personal samples were collected to evaluate the performance of a passive badge for monitoring 2-EEAc with the co-exposure of toluene and methyl iso-butyl ketone (MIBK) in a warm and humid workplace. Sixteen pairs of side-by-side passive badges, active charcoal tubes, and active charcoal tube with drying tube samples were also compared to evaluate the humidity effect in sampling. No statistical difference was found between the passive and active samples in assessing 2-EEAc. Linear regression showed the correlation to be high ($r=0.987$, slope=1.018, $n=48$) over the range 0.42–41.5 ppm. The mean concentration difference was 0.53 ppm and the mean relative error was 5.39%. Close correlation was also found between passive and active samples for assessing both toluene ($r=0.949$, slope=0.918, $n=16$), and MIBK ($r=0.943$, slope=1.098, $n=16$). Similar high correlation ($r>0.962$, $n=16$) was found among passive badges, active charcoal tubes, and active charcoal tube with drying tube samples. The humidity effect and the interference of co-exposure of polar and non-polar solvents were insignificant at a low sampling rate (26.6 ml/min) in assessing 2-EEAc exposures. The use of the passive samplers produces comparable findings to that of active sampling. (*J Occup Health 2004; 46: 479–485*)

Key words: 2-Ethoxy ethyl acetate, Exposure assessment, Permissible exposure limits

2-Ethoxyethyl acetate (2-EEAc) is a highly polar solvent with a high water/air partition coefficient (Johanson *et al.* 1988). 2-EEAc is a colorless, flammable liquid with a mild odor. It is widely distributed in industry and is used as blush retardant in lacquers, as solvent for nitrocellulose, oils and resins, in wood stains and vanish removers, and in products for the treatment of textiles and leathers. 2-EEAc is also used as a solvent in silk-screening operations and as a diluent in epoxy resins used for photoresistant coating of glass used for the manufacture of liquid crystal displays. 2-EEAc is known to produce spermatotoxic, fetotoxic, teratogenic, hematological and immunological effects in rats and is suspected of producing hematological effects in humans (NIOSH 1991). 2-EEAc is rapidly deacetylated, producing 2-ethoxy ethanol (2-EE), then is metabolized to 2-ethoxy acetic acid (EAA) which is excreted in the urine. Thus, the metabolism of EEAc can be considered as producing the same metabolites as 2-EE (NIOSH 1991, Johanson *et al.* 1988). Human data on occupational exposures to 2-EE or 2-EEAc were very limited and the qualitative confirmation of 2-EE or 2-EEAc in complicated mixed raw materials was poorly examined for the studies reported in the literature. The annual production of 2-EEAc was about 450 tons in the U.S., and the estimated number of exposed workers was 9,892 in the U.S.A (NIOSH, 1991). In Taiwan, the annual consumption of 2-EEAc is about 5,000–8,000 tons (IOSH, 2001).

Passive sampling has become a very popular tool of exposure assessment in workplaces because of its

Received Jan 30, 2004; Accepted Sep 27, 2004

Correspondence to: S.-H. Liou, School of Public Health, National Defense Medical Center, P.O. Box 90048-509, Neihu, Taipei, Taiwan 114, R.O.C. (e-mail: shliou@ndmctsgh.edu.tw)

lightweight, small volume, low initial cost, ease of operation, and low demand for maintenance and calibration. Several validation protocols have been proposed by the U.S. National Institute for Occupational Safety and Health (NIOSH) (Cassinelli *et al.* 1987), the British Health and Safety Executive (HSE, 1983), and the European Committee for Standardization (EC, 1995) to evaluate the performance of passive samplers. These validation protocols not only require more complicated laboratory tests such as evaluation of reverse diffusion, shelf life, face velocity, and monitor orientation than are needed for traditional active samplers, but also include field validation.

Several studies have demonstrated that passive samplers can perform as well as active samplers for non-polar compounds such as toluene, benzene and styrene in the field (Hagberg *et al.* 1987; Bartolucci *et al.* 1987; Stricoff *et al.* 1981). Nevertheless, the field evaluation of passive samplers for highly polar compounds such as 2-EAAc with the co-exposure of other polar and non-polar chemicals in humid workplaces has rarely been reported in the published literature.

The U.S. NIOSH and Occupational Safety and Health Administration (OSHA) in their recommended sampling and analytical methods showed that high humidity might greatly reduced sampler capacity and breakthrough volume of activated charcoal tubes for monitoring 2-EE or 2-EEAc. Lower sampling flow rates or the addition of a drying agent (anhydrous sodium sulfate) therefore should be used in high relative humidity workplaces (OSHA, 1990; NIOSH, 1994). Since 2-EEAc is widely used in industries in many hot and humid Asian countries, the humidity effect in sampling needed to be examined.

The main purposes of this study aim to examine the field performance of a passive sampler by determining the agreement of passive badges with active samplers, and to examine the influence of environmental factors such as temperature and high humidity on passive and active samplers in assessing 2-EEAc exposures.

Materials and Methods

Manufacturing process

Fifteen printing machines were installed in separate rooms of a silk-screening plant. The inks used in the process are dissolved in technical grade 2-EEAc, toluene and methyl iso-butyl ketone (MIBK). The major processes include ink-mixing, indicia, printing, screen-cleaning, and oven heating operations.

Chemicals used in the manufacturing process

The main raw materials used in this plant include inks, 2-EEAc, toluene and MIBK. The amount of 2-EEAc used in this factory was about 1,000 kilograms per month. In addition to 2-EEAc, workers were also exposed to smaller amounts of MIBK and toluene. The qualitative

confirmation of 2-EEAc, toluene and MIBK in raw materials was reconfirmed by gas chromatography/mass spectrometry (GC/MS G 1, 800A, GCD, Hewlett Packard, CA, USA).

Sampling strategy

Forty-eight side-by-side 8-h full-shift personal breathing zone active and passive samples from exposed workers were collected to evaluate the agreement between the passive and active samples. Sixteen pairs of side-by-side 8-h personal samples of passive badges, active charcoal tubes, and active charcoal tubes with drying tubes were collected to examine the humidity effect among the three sampling methods. The results were also used to examine the agreement between the passive and active samples in assessing toluene and MIBK exposures. The relative humidity in all areas of the plant was within the range of 80–85%. The temperatures in the control room, printing room and oven heating area were 25–27°C, 25–27°C and 30–33°C, respectively.

Sampling and analysis of airborne 2-EEAc

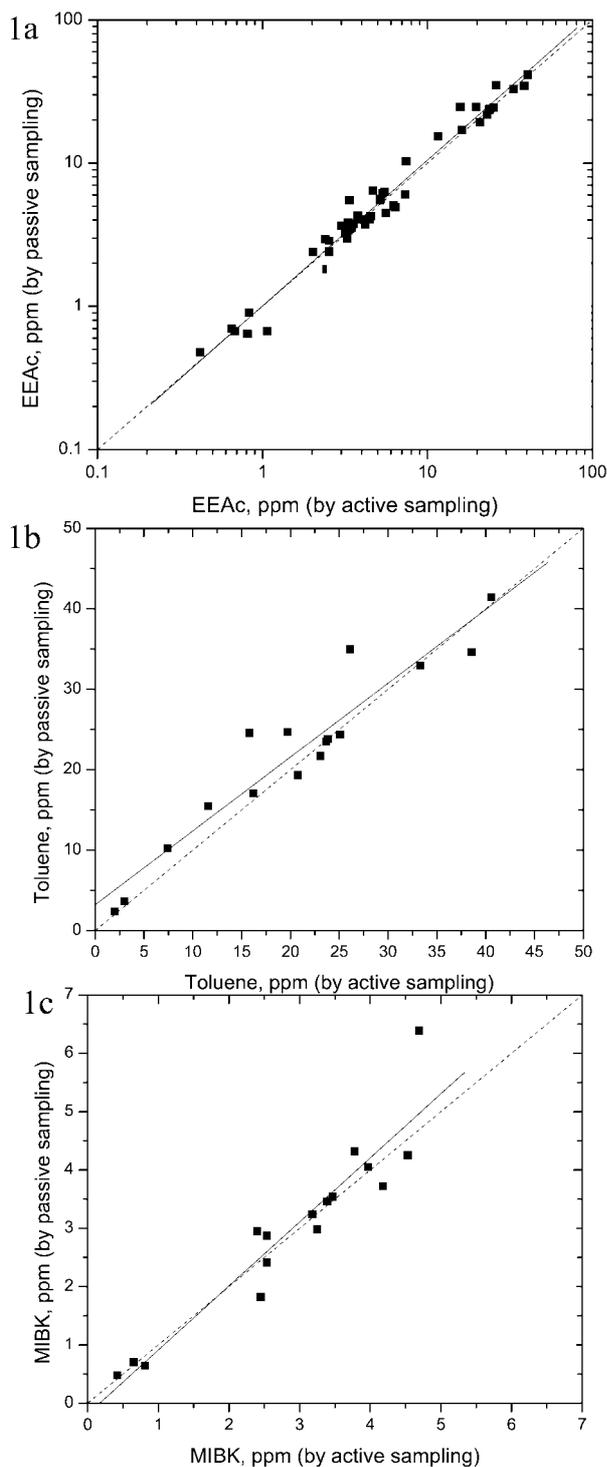
The Institute of Occupational Safety and Health (IOSH) 1215 recommended the sampling and analytical method (IOSH, 1994), originating in the U.S. The NIOSH 1403 (NIOSH, 1994), and the OSHA 79 methods (OSHA, 1990), were adopted in this study as the reference methods to validate the passive samplers. These methods have been fully validated by a dynamic standard gas generation system and also by three accredited industrial hygiene laboratories in Taiwan (IOSH, 1994):

Active samples are collected by drawing air through standard size (100 mg/50 mg) coconut shell charcoal tubes (SKC Inc., Cat. NO: 226-01, batch No. 120, Eight Four, PA, USA), with constant low flow personal pumps (Gilian Instrument Corp., Model LFS-114, West Caldwell, NJ, USA). Pre-drying tubes (SKC Inc., Cat. NO: 226-44, Eight Four, PA, USA) were connected to some of the charcoal tubes in grouped samples to remove water vapor and control the humidity effect. The sampling flow rates for active samplers were set at 26.6 ml/min \pm 5% equivalent to the sampling rate of the 3M passive badge for 2-EEAc. Passive samples were collected by 3M 3500 passive badges (3M Co., Model 3500, St. Paul, USA). In the laboratory, the materials collected by active samplers and passive samplers were desorbed in 1 ml and 1.5 ml of a mixed solvent of 95:5 (v/v) dichloromethane (99.7%, Merck, Darmstadt, Germany) and methanol (99.7%, Merck), respectively. After shaking for 40 min, the desorbed 2-EEAc was analyzed by a gas chromatograph (GC) (Hewlett-Packard 5890 Series II, Palo Alto, CA, USA) equipped with an HP 7673A auto-sampler and a flame ionization detector (FID). A magabore column (J&W DB-WAX, 30 m* 0.53 mm, 1.0 μ m film thickness) was used. The overall accuracy (bias

Table 1. Linear regression of paired passive and active samples

	n	r	$\beta_0 \pm s$ (intercept)	$\beta_1 \pm s$ (slope)	Concentration range (ppm)
2-EEAc	48	0.987	0.003 ± 0.211	1.018 ± 0.024	0.42–41.5
Toluene	16	0.949	3.213 ± 1.896	0.918 ± 0.081	2.50–45.0
MIBK	16	0.943	-0.186 ± 0.329	1.098 ± 0.104	0.42–6.39

n: numbers of paired passive and active samples; r: correlation coefficient of the linear regression model of passive versus active plot; β_0 : intercept; β_1 =slope; s: standard deviation



plus 2 times precision) for the sampling and analysis method was $\pm 7.5\%$, the concentration range of the standard curves was 6.56 to 105 ng/ml, the reliable quantification limit was 5.65 ng. The sampling flow rates of active samplers were calibrated before and after each sampling. Triplicate analyses were conducted for every 5–10 air samples. Air samples were stable for at least one month at room temperature and in a refrigerator (4°C). Air samples were taken by certified industrial hygienists and were analyzed by an accredited industrial hygiene laboratory in Taiwan.

Data analysis

Paired sample t-tests, linear regression, concentration difference (passive-active) versus mean of passive and active concentration plot (Bland, 1986), and relative error (difference/active *100%) versus mean of passive and active concentration plot were used to assess the agreement between passive and active sampling methods. Linear regression was also used to assess the agreement among passive badges, active charcoal tubes, and active charcoal tubes with drying tubes for humidity effects. Since replicate analyses performed on an industrial hygiene sample are usually normally distributed, one-way analysis of variance (ANOVA) was also used to compare the differences among passive badges, active charcoal tubes, and active charcoal tubes with drying tubes.

Results

Quality control (QC) samples

Solvent blanks, medium blanks, and field blanks showed no sample contamination during sample shipping and storage processes. The retention time of gas chromatograms and the spectra of mass spectrometry of both bulk samples and randomly selected air samples indicated no interfering chemicals existed in the workplaces. The mean recovery of 20 sets of blind QC samples was 99.68%. The mean recovery of proficiency

Fig. 1. Scatter plots of the following measurements obtained from passive and active samplers: 1a) EEAc; 1b) toluene; 1c) MIBK.

Table 2. Agreement of paired passive and active samples

	n	\bar{d} ppm	LOA ppm	95% CI of bias	95% CI of lower LOA	95% CI of upper LOA	Relative error (%)
2-EEAc	48	0.53	-3.90, 4.95	-0.21, 1.17	-5.01, -2.78	3.84, 6.06	5.39
Toluene	16	1.51	-5.58, 8.61	-0.38, 3.40	-8.86, -2.31	5.33, 11.88	12.89
MIBK	16	0.10	-0.97, 1.17	-0.19, 0.38	-1.46, -0.48	0.67, 1.66	2.44

n: numbers of paired passive and active samples; \bar{d} : mean concentration difference; LOA: limits of agreement ($\bar{d} \pm 2s$); 95% CI of bias: ($\bar{d} - t_{0.95(2), n-1} * (s_2/n)^{1/2}$, $\bar{d} + t_{0.95(2), n-1} * (s_2/n)^{1/2}$); 95% CI of lower LOA: (lower LOA - $t_{0.95(2), n-1} * (s^2/n)^{1/2}$, lower LOA + $t_{0.95(2), n-1} * (s^2/n)^{1/2}$); 95% CI of upper LOA: (upper LOA - $t_{0.95(2), n-1} * (s^2/n)^{1/2}$, upper LOA + $t_{0.95(2), n-1} * (s^2/n)^{1/2}$); CI: confidence interval; relative error (%)=(passive - active)/active * 100%; s: standard deviation

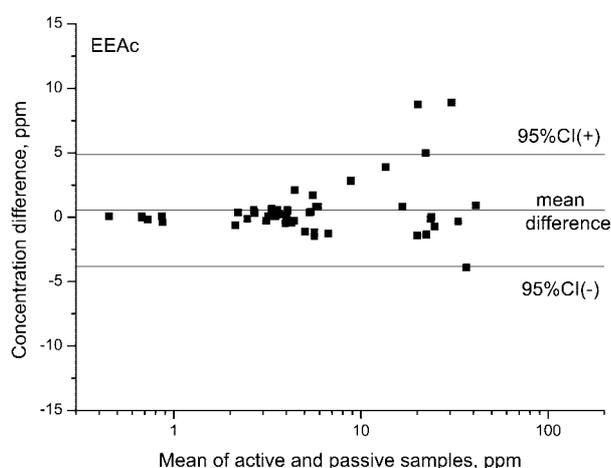


Fig. 2. Plot of concentration differences versus mean concentrations of paired active and passive samples (n=48) for 2-EEAc. Solid lines indicate the mean concentration difference and its 95% confident intervals (limits of agreements).

analytical testing (PAT) samples from three accredited industrial hygiene laboratories was 98.5%. These results validate the reliability of the exposure monitoring data.

Agreement between passive and active samples

Paired sample *t*-tests showed no significant difference ($p=0.1054$) between 48 pairs of active and passive samples in assessing 2-EEAc over the concentration range of 0.42 to 41.5 ppm. Linear regression also showed a strong correlation ($r=0.987$, slope = 1.018, $n=48$) between passive and active samples, as shown in Table 1 and Fig. 1. The mean concentration difference (\bar{d}), limits of agreement (LOA), 95% confidence interval (CI) of bias, 95% CI of lower LOA, 95% CI of upper LOA, and the mean relative error for 2-EEAc are shown in Table 2, Figs. 2 and 3. Satisfactory correlation coefficients (r ranged from 0.935 to 0.978, $p<0.001$) were also observed between each pair-wise comparison of passive and active

samples for 2-EEAc, toluene and MEK in the control room, the printing area and oven heating area.

Paired sample *t*-tests showed no significant difference between 16 pairs of active and passive samples in assessing both toluene ($p=0.1089$) and MIBK ($p=0.4733$). A close correlation between active and passive samples was also found for both toluene and MIBK ($n=16$) over the concentration ranges of 2.50–42 ppm and 0.42–6.39 ppm, respectively. The correlation (r , slope) between passive and active samplers for toluene and MIBK was 0.949 (0.918) and 0.943 (1.098), respectively, as shown in Table 1. The \bar{d} , LOA, 95% CI of bias, 95% CI of lower LOA, 95% CI of upper LOA, and the mean relative error for toluene and MIBK are shown in Table 2.

Humidity effects for active samples

ANOVA showed no significant differences ($p=0.3158$) among 16 pairs of passive badges, active charcoal tubes, and active charcoal tubes with drying tubes in assessing 2-EEAc over concentration ranges of 0.42 to 41.5 ppm. High correlation was found for 2-EEAc among passive badges, active charcoal tubes, and active charcoal tubes with drying tubes ($r > 0.962$, slope=1.044, $n=16$). The same analytical procedure in determination of the 2-EEAc concentration was performed for all drying tubes containing anhydrous sodium sulfate and no detectable 2-EEAc was found.

Discussion

The true value of the exposure level in the field is never known, but the accuracy of the active sampling method was fully validated in well-controlled experimental conditions in our previous laboratory chamber study, and by blind quality control samples and inter-laboratory proficiency analytical test (PAT) samples (IOSH, 1994). Therefore, the good agreement between the passive badges and the traditional active samplers in paired samples over a wide range of exposure indicates that the accuracy of the passive badges in assessing 2-EEAc exposures is acceptable.

Another more qualitative approach in comparing the

Table 3. Comparison of results obtained from paired passive and active samples

	n	AM (ppm)	SD (ppm)	GM (ppm)	GSD	Range (ppm)
2-EEAc	48	9.26 (A)	10.5 (A)	5.15 (A)	3.10 (A)	0.42–41.5
		9.78 (P)	10.9 (P)	5.34 (P)	3.21 (P)	
Toluene	16	20.7 (A)	11.3 (A)	16.2 (A)	2.35 (A)	2.50–45.0
		22.2 (P)	10.9 (P)	18.2 (P)	2.20 (P)	
MIBK	16	2.89 (A)	1.33 (A)	2.40 (A)	2.07 (A)	0.42–6.39
		2.99 (P)	1.55 (P)	2.45 (P)	2.12 (P)	

n: numbers of paired passive and active samples; AM: arithmetic mean; SD: standard deviation; GM: geometric mean; GSD: geometric standard deviation;

Table 4. Humidity effects of 2-EEAc for different paired sampling methods

	n	AM (ppm)	SD (ppm)	GM (ppm)	GSD	Range ^a (ppm)
Passive badges	16	11.2	11.1	6.34	3.28	0.26–41.5
Active charcoal tubes	16	10.7	10.8	6.17	3.15	
Active charcoal tubes with drying tubes	16	11.5	11.3	6.61	3.34	

n: numbers of paired passive and active samples; AM: arithmetic mean; SD: standard deviation; GM: geometric mean; GSD: geometric standard deviation; ^aRange: results obtained from active charcoal tubes

two sampling methods is to consider whether the same occupational hygiene decisions would arise from the data obtained from either of the two techniques. The results for both active and passive samples in this study, shown in Table 3, are in good agreement and the interpretations of the data from a health protection viewpoint are identical.

A minimum face velocity on the surface of a passive sampler is critical in getting a constant and reliable sampling rate. High wind velocity accelerates the diffusion over the bound layer of solid absorbent. Since all the data we collected were obtained from personal samples, and general ventilation was provided to the entire coating department, the required minimum wind velocity (usually 0.2–0.4 m/s) can be easily reached by workers' movement or wind velocity in the workplace in this study. This provided good conditions for passive badges to get results comparable to those from active samples. For fixed-point sampling in calm air, lower measuring results might be obtained for passive samplers due to the low wind velocity.

No 2-EEAc was found in the drying tubes after sampling, and the influence of relative humidity was small in this field study. Although the relative humidity was high, the actual amount of water collected in the drying tubes was small with the low sampling flow rate (26.6 ml/min) used in this field study. This was consistent with the suggestion of NIOSH (NIOSH, 1994) to use much lower sampling flow rates of 20 to 50 ml/min to minimize

the influence of humidity.

Current NIOSH, HSE and CEN validation protocols (Cassinelli *et al.* 1987; HSE, 1983; EC, 1995) used *t*-tests, paired sample *t*-tests, and linear regression as the statistic methods to evaluate the performance of passive samplers. Basically, *t* tests or paired-sample *t* tests can only investigate whether in general the mean concentrations of active and passive samples are statistically different from each other, but not identify the sources of the differences. NIOSH in their "Protocol for the evaluation of passive monitors" (Cassinelli *et al.* 1987), used a criterion of 15% difference at the 95% confidence level between passive and independent sampling methods. With the large sample size (n=48) and small standard deviations of both active and passive methods, the power of the paired-sample *t*-test in this study was greater than 90%. There is adequate evidence in this study to declare that there is no significant difference between the passive and active samples in assessing exposure to 2-EEAc in this study.

Linear regression is another frequently used statistical method for passive sampler evaluation. In this study, the correlation coefficients were very high, the 95% confidence interval (CI) of slopes covered 1, and the 95% CI of intercepts covered 0, which again indicated a very good agreement between active and passive samples.

In addition to the abovementioned statistic methods, this paper also presents the concentration difference versus mean concentration plot, the mean relative error,

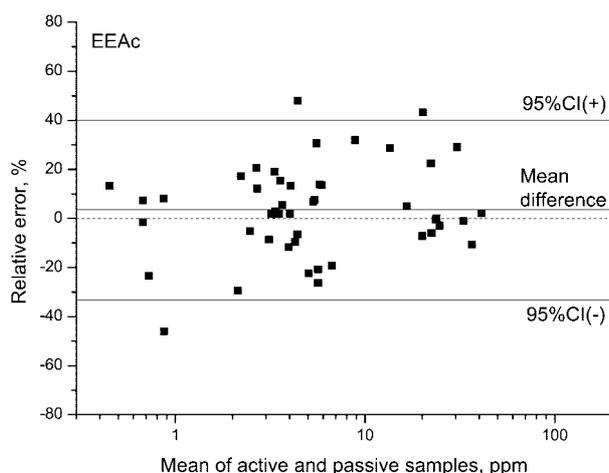


Fig. 3. Plot of relative errors versus mean concentrations of paired active and passive samples ($n=48$) for 2-EEAc. Solid lines indicate the mean relative error and its 95% confident intervals.

the 95% CI of bias, and the 95% CI of upper and lower limits (Bland *et al.* 1986), which are more informative approaches to examine the agreement of passive samplers with traditional active samplers. These plots provide examination of the relationship between the measurement error and the “true” value at different concentrations. The true value of exposure in the field is never known, and the mean of the two measurements is the best estimate we can have.

Currently, the NIOSH, OSHA, HSE and other related organizations have recommended a $\pm 25\%$ overall accuracy (bias $\pm 2 \times$ precision) at the PEL requirement for recommended sampling and analytical methods (OSHA, 1990; OSHA, 1994; HSE, 1986). NIOSH 1403 method (NIOSH, 1994), OSHA 79 method (OSHA, 1990), and IOSH 1215 method (IOSH, 1994) all demonstrated that this requirement seemed reasonable for the validation of single pure compound 2-EEAc in a well-controlled laboratory. In the field studies, however, a lot of environmental factors and other unknown parameters can make this requirement too stringent to be feasible. Fig. 3 shows that this requirement might be difficult to meet in a low concentration range. This could be due to the smaller amount of material collected on the samplers resulting in an increased analytical error. Recently, the PEL of many hazardous chemicals has become reduced dramatically, and this kind of problem will become a more important issue in the method validation. It is suggested that more laboratory and field data are needed to re-examine the current method validation protocol and the field validation requirement.

This is one of the very few field validation reports focusing on the performance of passive samplers for a

highly polar compound in a high humidity workplace. As passive samplers become more popular for use in work environmental monitoring in Asian countries, this kind of information will become increasingly important.

The performance of both active and passive samplers found in this study was consistent with that obtained in other laboratory validation studies (OSHA, 1990; NIOSH, 1994; IOSH, 1994). The observed overall environmental effects such as temperature, relative humidity, wind speed, personal activities and concentration fluctuation, seemed to be small for both active and passive sampling in the environment (25–33°C and 80–85%) observed in this field study.

It is concluded that the humidity effects for both active and passive samples were insignificant for 2-EEAc at a low sampling rate (26.6 mL/min). The use of the passive samplers to assess 2-EEAc exposures produces comparable findings to those of active sampling.

Acknowledgments: This work was supported by the IOSH, Council of Labor Affairs, Executive Yuan, Taiwan, Republic of China (IOSH grant 90-A307).

References

- 1) Bartolucci GB, Perbellini L, Gori GP, Brugnone F, De-Rosa E. Field Comparison of Charcoal Tubes and Passive Dosimeters for the Determination of Solvents in Air. Diffusive Sampling. An Alternative Approach to Workplace Air Monitoring, Berlin A, Brown RH, and Saunders KJ, eds. London: Royal Society of Chemistry, 1987: 228–230.
- 2) JM Bland and DG Altman: Statistical Methods for Assessing Agreement Between Two Methods of Clinical Measurement. *The Lancet* 8, 307–310 (1986)
- 3) Cassinelli ME, Hull RD, Crable JV and Teass AW. Protocol for the Evaluation of Passive Monitors. Diffusive Sampling. An Alternative Approach to Workplace Air Monitoring, Berlin A, Brown RH, and Saunders KJ, ed. London: Royal Society of Chemistry, 1987: 190–192.
- 4) European Committee for Standardization. Workplace Atmospheres—Diffusive Samplers for the Determination of Gases and Vapors—Requirements and Test Methods. (EN 838) European Committee for Standardization, Brussels, Belgium, 1995.
- 5) Hagberg S, Nordlinder R, Sallsten G. Field Comparison of Charcoal Tubes and Passive Vapor Monitors for Organic Vapors. Diffusive Sampling. An Alternative Approach to Workplace Air Monitoring, Berlin A, Brown RH, and Saunders KJ, eds. London: Royal Society of Chemistry, 1987: 242–245.
- 6) Health and Safety Executive. Methods for the Determination of Hazardous Substances: Protocol for Assessing the Performance of a Diffusive Sampler, MDHS 27, London: HSE, 1983.
- 7) Institute of Occupational Safety and Health (IOSH). Recommended sampling and analytical method (No. 1215) for monitoring ethylene glycol ethers.

- Publication No. 83-A307, Taipei, Taiwan, Republic of China, 1994.
- 8) Institute of Occupational Safety and Health (IOSH). Nationwide exposure survey of ethylene glycol ethers in Taiwan. Publication No. 90-A307, Taipei, Taiwan, Republic of China, 2001.
 - 9) G Johanson and B Dynesius: Liquid/Air Partition Coefficients of Six Commonly Used Glycol Ethers. *Br J Ind Med* 45, 561–564 (1988)
 - 10) National Institute of Occupational Safety and Health. Criteria for a Recommended Standard—Occupational Exposure to Ethylene Glycol Monomethyl Ether, Ethylene Glycol Monoethyl Ether, and their Acetates. Washington, DC: NIOSH, 1991. (Publication No. 91-119)
 - 11) National Institute of Occupational Safety and Health. Method 1403 4th ed., *Manuals of Analytical Methods*. 4th Edition. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Services, Centers for Disease Control, 1994.
 - 12) Occupational Safety and Health Administration. Method 79, 2nd ed., Salt Lake City, UT: U.S. Department of Labor, Occupational Safety and Health Administration, Organic Methods Evaluation Branch, OSHA Analytical Laboratory, 1990.
 - 13) Stricoff RS, Summers C. An Evaluation of Organic Vapor Passive Dosimeters Under Field Use Conditions. *Chemical Hazards in the Workplace, Measurement and Control*. ACS Symposium Series No. 149: 209–221, 1981.