EXPOSURE TO ETHYLENE GLYCOL MONOBUTYL ETHER AND RELATED WORKERS HABITS IN AN INK FACTORY

[1]W. C. Lin, [2]H. Y. Chang, [*3]F. H. Chang

[1]Department of Cosmetic Science, Chia Nan University of Pharmacy and Science, Tainan 717, Taiwan (R.O.C.)

[2]Department of Environmental and Occupational Health Medical College, National Cheng Kung University, Tainan 701, Taiwan (R.O.C.)

[3]Department of Leisure, Recreation and Tourism Management, Tzu Hui Institute of Technology, Pingtung 926, Taiwan (R.O.C.)

Received 10 October 2007; revised 25 November 2007; accepted 28 December 2007

ABSTRACT

Forty six workers from an ink factory were included in this study, in which, passive badge sampler and questionnaire interview were used to assess the concentrations of airborne exposure to ethylene glycol monobutyl ether during work shifts and to understand the subjects' working habits. The geometric mean value (95% confidence interval) of the airborne ethylene glycol monobutyl ether concentrations was 0.12(0.08–0.19)ppm, with a range of <0.02–1.82ppm. The exposure group was exposed to statistically significantly higher ethylene glycol monobutyl ether concentrations than the control group (geometric mean value: 0.14*vs*. 0.03ppm; P=0.017). Some chromatograms showed that subjects were co-exposed to m-xylene, ethylene glycol monomethyl ether, and ethylene glycol monoethyl ether acetate. According to the completed questionnaires, subjects might also be exposed to 1,2,4,5-tetramethylbenzene, propylene glycol ethers, ethanol, 1,2,4-trimethylbenzene, methanol and diisononyl phthalate. This study also suggests that, the Taiwan occupational time-weighted average level of ethylene glycol monobutyl ether be reconsidered with a view to being lowered.

Key words: Occupational exposure, ethylene glycol monobutyl ether, passive badge, time-weighted average

INTRODUCTION

Ethylene glycol monobutyl ether (EGBE), one of the ethylene glycol ethers (EGEs), is often used as a solvent in surface coatings such as spray lacquers, quick-dry lacquers, enamels, varnishes, varnish removers, latex paint and printing inks; is also used as a cleaning fluid owing to its miscibility with both water and a large number of organic solvents (NIOSH, 1990). Unlike ethylene glycol monomethyl ether (EGME) and ethylene glycol monoethyl ether (EGEE), another two of the EGEs, EGBE has not been shown to be reprotoxic; rather, its main toxicological effect is hemolytic anemia (Lanigan, 1999; NTP, 1989). This lower toxicity has resulted in EGBE being the most widely used of all EGEs worldwide. However, in addition to the well-known development of hemolytic anemia resulting from EGBE exposure (both animal experiments and human studies), further harmful effects have been assessed and reported in recent years (Hughes, *et al.*, 2001). The studies mentioned above are mainly based on animal experiments and the ingestion/inhalation of high doses of EGBE. Few occupational studies have discussed the exposure scenarios and relevant health effects upon workers chronically exposed to low levels of EGBE. Long-term exposure studies of rats and mice have reported both hemolytic and carcinogenic effects, raising concern that EGBE might be a human carcinogen (Gift, 2005); unfortunately, the effects of long-term occupational exposure to EGBE in humans have not been well-studied.

The Occupational Safety and Health Administration (OSHA), American Conference of

*Corresponding author: *fhchang@ms18.hinet.net*
Tel: +886 8864 7367 ext. 158, Fax: +886 8864 7123

Governmental Industrial Hygienists (ACGIH), and the National Institute of Occupational Safety and Health (NIOSH) have set their respective airborne EGBE time weight averages (TWA) at 50, 20 and 5 ppm, respectively (OSHA, 2007), while in Taiwan, the Council of Labor Affairs (CLA) has a set TWA of 25ppm (CLA, 2003). The automation of manufacturing processes and improvements in the protective equipment being used have lowered the extent of exposure to workers. However, inhalation is not the only exposure route of EGBE for workers, and possible effects when workers are chronically exposed to low levels of EGBE need to be clarified. This paper assesses the EGBE exposure of workers in an ink factory by personal passive air sampling, evaluates subjects' working habits, and discusses the necessity of lowering the TWA value for EGBE.

MATERIALS AND METHODS

Study factory and subjects

The ink factory investigated in this study specializes in the manufacture and sale of photoimageable solder and etching resist inks used in the production of rigid printed circuit boards. The raw materials used in the manufacture of the inks include pigments, solvents, resins (or binders) and other additives. The fluid component of the ink, made of binders (oils and resins) and solvents, called the vehicle, is the major source of volatile organic compound emissions. Batch process production of ink involves four major steps: preassembly and premix, pigment grinding/milling, product finishing/blending, and product filling/packaging. The workers in charge of the preassembly and premix processes (Group A) and those in charge of the pigment grinding/ milling processes (Group B), both groups in the Department of Production, are considered as being exposed to EGBE more seriously than do those in charge of product finishing/blending and filling/ packaging (Group C) in the Department of Production and the management staff (Group D). Group C has a lower exposure to EGBE because these employees work in a clean room with excellent ventilation control and process automation. Forty-one workers from Groups A and B formed the exposure group, while five workers from Groups C and D were the control group. All subjects were recruited voluntarily and when the sampling day proved convenient for them.

Sampling and analysis of airborne EGBE

Personal monitoring was performed using passive badges during February 2005 (phase I) and July 2006 (phase II). Measurements were performed on twenty-two and twenty-four voluntary workers in the first and second phases, respectively.

The concentration of EGBE vapor in the breathing zone of individual workers (Groups A–D) was measured by a diffusible sampling method, using a 3M personal passive badge (3M Co., Model 3500, St. Paul, USA). This study referred to the laboratory method (MDHS 88) of the Health and Safety Executive (HSE, 1997) and to a previous study (Sakai, *et al*., 1993) that have used passive badges to collect samples for the determination of levels of glycol ethers. In brief, the passive badge was attached to the worker's collar during the work shift. The diffusive uptake rate for the 3M 3500 sampler is 28.2mL/min (HSE, 1997). When the sampling was completed, the badge was sealed tightly with a plastic cap, temporarily stored in an ice-can, and then delivered back to the laboratory and kept at 4°C in a refrigerator until analysis. The materials collected by the passive samplers were desorbed in 1.5mL carbon disulfide (99.7%, Merck, Darmstadt, Germany). After shaking vigorously by hand and standing for 2 hours, the desorbed EGBE was analyzed by injecting the extract into a Varian 3800 gas chromatographer equipped with a flame ionization detector (GC-FID) and a Varian CP-8400 autosampler (Walnut Creek, CA, USA). A HP-5 capillary column (30m×0.32mm, 0.5μm film in thickness, Agilent Technologies, USA) was used for the separation of each relevant compound. Injector and detector temperatures were set at 220°C; the column temperature was programmed to be 40°C for the initial 2 minutes, then increased from 40°C to 120°C at 10°C/min, and finally increased to 220°C at 15°C/min. The standard solutions of EGME, EGBE, ethylene glycol monoethyl ether acetate (EGEEA) and xylenes used were reagent grade, and were obtained from Merck Co. (Merck, Darmstadt, Germany).

Quality control

A quality assurance protocol for the sampling and analysis of airborne EGBE was implemented prior to the field study. The correlation coefficients (*r*) of the five-point calibration curves for EGBE were above 0.995. The desorption efficiency (DE) of EGBE was determined by spiking 90-µg liquid EGBE into the unused blank 3M 3500 samplers, sealing and leaving for at least 16 hours, then finally calculating the weight recovered divided by the weight applied; the DE in this study was found to be 132±3.8% (mean ± standard deviation). All the EGBE concentrations in the field studies were adjusted for their corresponding recoveries. The detection limit of EGBE was 0.02 ppm. During the period of real sample analysis, calibration checks and blank sample analysis were performed to ensure the analytical quality.

Questionnaire interview

Forty-six questionnaires in total were completed voluntarily by the workers in order to collect information on demographics, personal and working habits (smoking, alcohol drinking, personal protection equipment usage, etc.), and occupational history (department worked in, length of service, types of solvents used, etc.).

Data treatment and analysis

Data were calculated and analyzed, using EXCEL (Microsoft EXCEL 2003, Redmond, WA, USA) and SPSS software (Version 10.0; SPSS, Chicago, IL, USA). Concentrations below the detection limit (DL) were set to DL/2 for further data treatment. Student's *t*-test and one-way analysis of variance (ANOVA) were used to test the hypotheses that there were no differences in age, length of service or respiratory EGBE levels between or among the study groups, followed by Scheffe (equal variance) or Dunnett's T3 (unequal variance) *Post Hoc* tests if necessary.

The normality of the data was evaluated using the Shapiro-Wilk test, due to the sample size being less than 50. Raw data not fitting the normal distribution were transformed to log base 10 values before ANOVA. The chi-square test was used to compare the working habits among the study groups. A value of $P<0.05$ (two-tailed) was considered statistically significant when testing the hypotheses. Descriptive statistics including arithmetic mean (AM), standard deviation (SD), geometric mean (GM) and its 95% confidence interval (95%CI), range and percentiles were calculated to present the airborne EGBE concentrations.

RESULTS

Analysis of basic personal information and working habits

Seventeen of the 22 voluntary workers studied in the first phase (February 2005) were also included in the total of 24 voluntary workers studied in the second phase (July 2006). Therefore, when analyzing the data from the questionnaires, information from the same phase (i.e., 2005 or 2006) was first collected together and compared. The results of a comparison of phase I with phase II showed that, there was no significant difference in age, length of service or working habits (use of mask, gloves and protective clothing) (P=0.479, 0.517, 0.599, 0.260 and 0.694, respectively; data not shown here).

Table 1 shows the details of the 22 voluntary workers in the first phase, divided into Group A (n=9), Group B (n=11) and Group C (n=2). All were male, and their average age was 32.8 (±5.4) years, with an average length of service of 5.8 (±1.9) years. While, there was no significant difference in age or length of service between the groups (P=0.596 and 0.720, respectively), there was a significant difference (all $P<0.05$) in the use of mask, gloves and protective clothing. Group A workers, who wore masks, gloves and protective clothing for more than 50% of their working hours, had the best protection of all the three groups. Workers in Groups B and C wore protective clothing for less than 50% of their working hours.

The results for the 24 workers in the second phase are shown in Table 2. There were 9 workers in Group A, 12 in Group B and 3 in Group D; all were male, and their average age was 33.8 (±5.8) years, with an average length of service of 6.9 (±2.3) years. There was no significant difference in age, length of service or the use of mask or gloves between the groups (P=0.880, 0.405, 0.421 and 0.259, respectively); however, there was a significant difference ($P<0.05$) in the use of protective clothing. Similar to the results of phase I, the workers in Group A used protective clothing for more than 50% of their working hours, while workers in Groups B and C used protective clothing for less than 50% of their working hours.

Respiratory EGBE exposure concentrations of workers

Fig. 1 shows the airborne EGBE concentrations of Groups A–D. Though the EGBE exposure concentrations of workers show differences between the groups, these differences were not statistically significant (P=0.090; Group A (AM; 0.38 ppm)>Group B (0.29ppm)>Group C (0.07ppm)>Group D (below DL: 0.02ppm)). When the data were further analyzed by comparing the exposure group (Groups A and B) and control group (Groups C and D), the results show that the exposure group (AM=0.33ppm) has a higher level of exposure than the control group (AM=0.03ppm), and this difference is statistically significant (P=0.017) (Fig. 2).

Table 1: Characteristics of the study subjects included in the first phase

Parameters		Group A (*n* = 9)	Group B (*n* = 11)	Group C (*n* = 2)	Groups A-C (*n* = 22)	P value
Age (years)		31.6±5.7	33.9±5.7	32.1±0.3	32.8±5.4	0.596[b]
Length of service (years)		5.4±2.2	6.0±1.8	6.2±0.2	5.8±1.9	0.720[b]
Gender	male	9	11	2	22	-[c]
wearing a mask when	< 50% of working hours	0	7	0	7	<0.05[d]
working[*,a]	≥ 50% of working hours	9	4	1	14	
Wearing gloves when	< 50% of working hours	1	4	2	7	<0.05[d]
working[*]	≥ 50% of working hours	8	7	0	15	
Wearing protective clothing	< 50% of working hours	0	11	2	13	<0.05[d]
when working[*]	≥ 50% of working hours	9	0	0	9	

[*]Significant parameters (P<0.05), [a]One missing value found, [b]Using one-way ANOVA, [c]No test conducted, [d]Using chi-square test

Table 2: Characteristics of the study subjects included in the second phase

Parameters		Group A (*n* = 9)	Group B (*n* = 12)	Group D (*n* = 3)	Groups A, B and D (*n* = 24)	P value
age (years)		33.1±5.5	34.4±6.7	33.8±2.1	33.8±5.8	0.880[a]
length of service (years)[b]		7.5±0.8	6.3±3.2	6.6±2.3	6.9±2.3	0.405[a]
gender	male	9	12	3	24	-[c]
wearing a mask when	< 50% of working hours	1	4	1	6	0.421[e]
working[d]	≥50% of working hours	8	7	2	17	
wearing gloves when	< 50% of working hours	0	3	1	4	0.259[e]
working[d]	≥50% of working hours	8	9	2	19	
wearing protective	< 50% of working hours	3	8	2	13	<0.05[e]
clothing when working[*,f]	≥50% of working hours	6	1	0	7	

[*]Significant parameters (P< 0.05), [a]Using one-way ANOVA, [b]Three missing values found, [c]No test conducted, [d]One missing value found [e]Using chi-square test, [f]Four missing values found

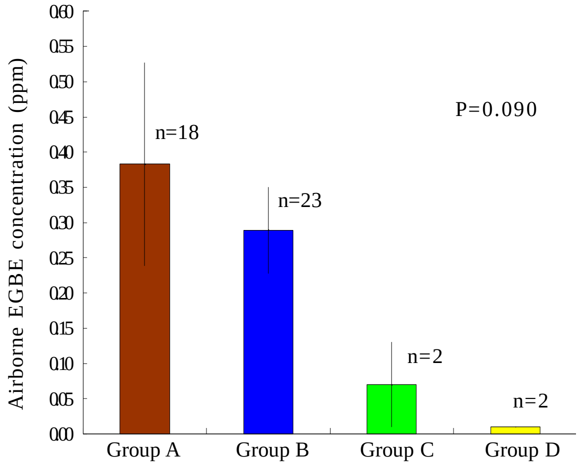

Fig. 1: Arithmetic means of airborne EGBE concentrations (ppm) according to job category. Mean values±standard error of the mean. The difference in airborne EGBE concentrations was not statistically significant (P=0.090) (one-way ANOVA after logarithmic transformation)

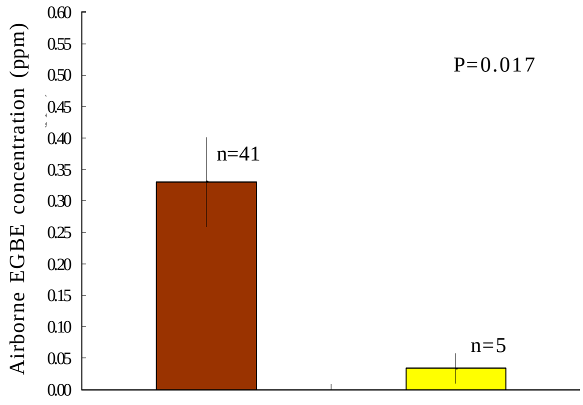

Fig. 2: Arithmetic means of airborne EGBE concentrations (ppm) according to exposure category. Mean values±standard error of the mean. The difference in airborne EGBE concentrations was statistically significant (P=0.017) (student's t-test after logarithmic transformation)

If the workers are not considered by job category, the EGBC concentrations in the air were neither normal nor log-normal distributions in phases I, II and I+II (Table 3).
In addition, the data show AM>median>GM (phase I: 0.38>0.16>0.09ppm; phase II: 0.22>0.17>0.10ppm), which indicates that the distribution of the concentration values is right-skewed. The concentrations of EGBE ([EGBE]) in the two phases were then compared: when using $\log_{10}$ (EGBE) to perform Student's *t*-test, no difference was found between the two phases (P=0.994). Therefore, the data from the two phases can be combined to calculate the EGBE concentration in the ink factory. The results showed the following: AM(SD)=0.30 (0.44)ppm> median=0.17ppm>GM(95%CI)=0.12(0.08–0.19)ppm; maximum concentration=1.82ppm.

Table 3: Results of personal exposure (ppm) to airborne EGBE in the ink factory, phases I and II

Phase	*N* (*n* < DL)	P5	P50	P95	Range	AM (SD)	GM (95%CI)	Normality[a]
I	22 (8)	ND	0.16	1.79	ND–1.82	0.38 (0.58)	0.09 (0.04–0.22)	neither normal nor log-normal
II	24 (7)	ND	0.17	0.96	ND–1.05	0.22 (0.24)	0.10 (0.05–0.19)	neither normal nor log-normal
I + II	46 (15)	ND	0.17	1.62	ND–1.82	0.30 (0.44)	0.12 (0.08–0.19)	neither normal nor log-normal

N=sample size, DL=detection limit (0.02 ppm), *n*<DL=number of values below detection limit (values below DL were set to DL/2), ND=below DL, P5, P50, P95=percentiles, AM=arithmetic mean, SD = standard deviation, GM=geometric mean, 95%CI=95% confidence interval for GM.
[a]Using Shapiro-Wilk normality test

Comparison between data from the literature relating to occupational EGBE exposure

Fig. 3 shows the reference values for airborne EGBE concentration obtained from the literature relating to occupational EGBE exposure and from this study. In a comparison with the results of other studies performed in the last decade, this study recorded lower levels (median: 0.17 ppm; GM: 0.12ppm; AM:0.30ppm) than the study by Haufroid *et al.*, of 31 workers in a beverage package production plant (AM ± SD = 0.59 ± 0.27 ppm) and than the study by Yang (2002) of 20 workers in a printing circuit board company (the exposure concentrations in the morning-shift workers in the printing and developing areas were: AM±SD=1.52±1.18 and 0.37±0.30ppm, respectively). Since 1985, airborne EGBE concentrations in occupational environments have seldom been reported to be higher than the recommended exposure limit of 5 ppm issued by NIOSH (Angerer, *et al.*, 1990; Haufroid, *et al.*, 1997; OSHA, 2007; Sakai, *et al.*, 1993; Söhnlein, *et al.*, 1993; Veulemans, *et al.*, 1987; Vincent, *et al.*, 1993; Winder and Turner, 1992; Yang, 2002), the only exceptions being in the results of four studies reported around 20 years ago (Baker, *et al.*, 1985; Denkhaus, *et al.*, 1986; Kullman, 1987; Salisburg and Bennett, 1987). It is apparent that, the levels of occupational exposure to airborne EGBE have decreased in the past 20 years.

Solvents co-exposed with EGBE in the ink factory

The kinds of solvents mainly used in the ink factory were investigated by questionnaire, the results of which are shown in Table 4. From the responses of the workers to the questionnaires, 1,2,4,5-tetramethylbenzene (TeMB), EGEs, propylene glycol ethers (PGEs), ethanol (EtOH) and 1,2,4-trimethylbenzene (TMB) were found to be the top five solvents most frequently said to be used during ink processing, accounting for approximately 92% of the total number of solvents mentioned in the responses. TeMB was the most frequently-mentioned solvent, with the percentage of cases being approximately 67% (26/39), followed by EGEs, PGEs, EtOH and TMB at 62% (24/39), 62% (24/39), 26% (10/39) and 21% (8/39), respectively. These results suggest that workers are not only exposed to EGBE, but also to all of the solvents listed above. This has been proven by analysis of the samples by chromatogram (Fig. 4).

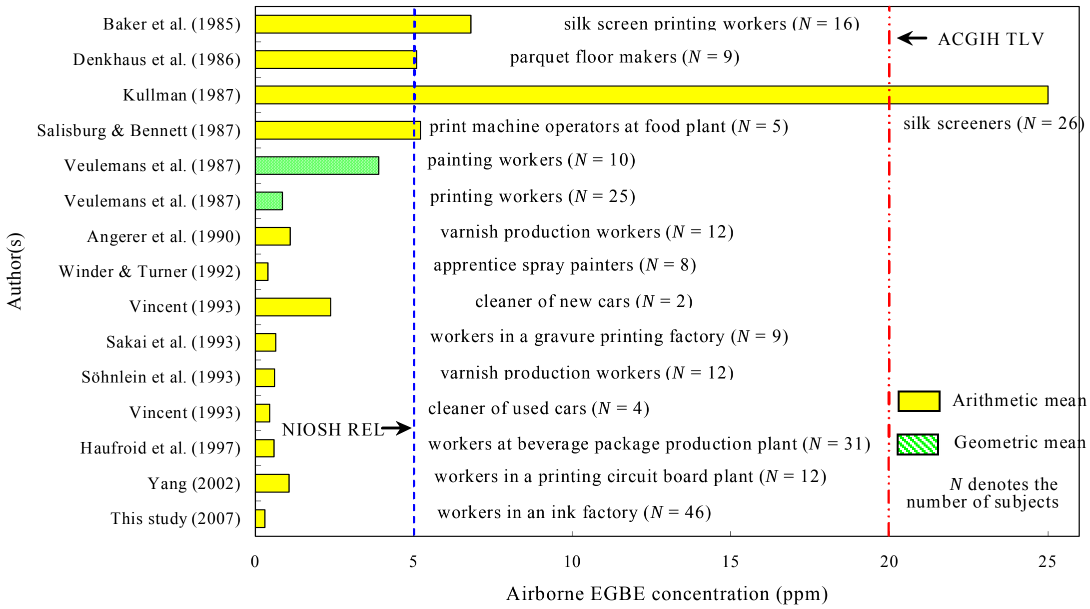

Fig. 3: Reference values for airborne EGBE concentration obtained from the literature relating to occupational EGBE exposure and from this study. NIOSH REL=recommended exposure limit issued by the National Institute for Occupational Safety and Health, ACGIH TLV=threshold limit value established by the American Conference of Governmental Industrial Hygienists

Table 4: Solvents mainly used in the ink factory, from the workers' responses to the questionnaires

Phase	Number of questionnaires	Number of solvents responded (percentage of cases)							Total number of solvents responded
		TeMB	EGEs	PGEs	EtOH	TMB	MeOH	DINP	
I	19[a]	11 (58%)	10 (53%)	8 (42%)	1 (5%)	8 (42%)	6 (32%)	0 (0%)	44
II	20[b]	15 (75%)	14 (70%)	16 (80%)	9 (45%)	0 (0%)	0 (0%)	2 (10%)	56
I + II	39	26 (67%)	24 (62%)	24 (62%)	10 (26%)	8 (21%)	6 (15%)	2 (5%)	100

TeMB=1,2,4,5-tetramethylbenzene, EGEs=ethylene glycol ethers, PGEs=propylene glycol ethers, EtOH=ethanol, TMB=1,2,4-trimethylbenzene, MeOH=methanol, DINP=diisononyl phthalate. [a]Three missing data found, [b]Four missing data found

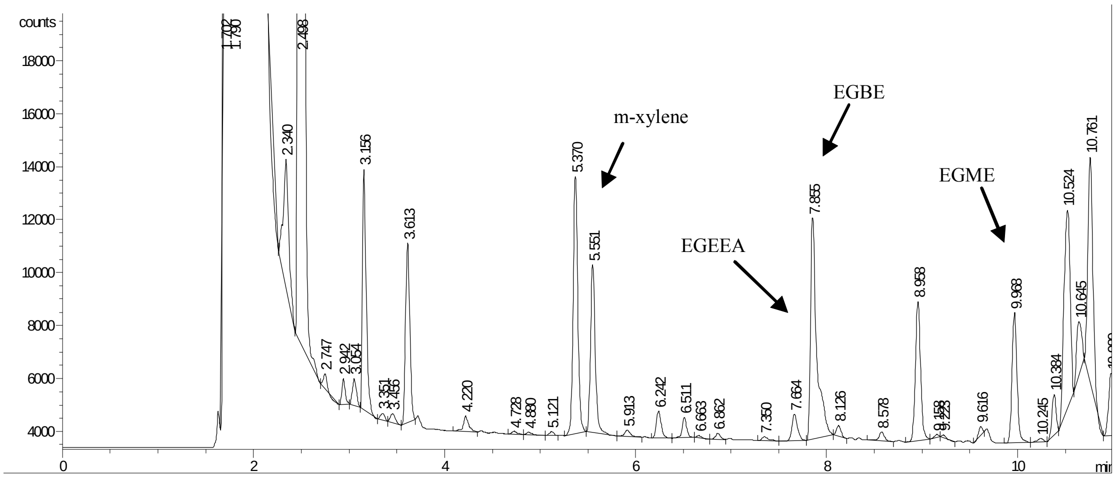

Fig. 4: Chromatogram from the analysis of a real air sample. A Varian 3800 GC-FID and a HP-5 capillary column (30 m×0.32mm, 0.5µm film in thickness) were used to carry out the determinations of the relevant compounds. Injector and detector temperatures were set at 220°C, the column temperature was programmed to be 40°C for the initial 2 minutes, then increased from 40°C to 120°C at 10°C/min, and finally increased to 220°C at 15°C/min

DISCUSSION

In this study, it was found that, the exposure of workers in this ink factory to EGBE was at a low level. A total of 32.6% of the 46 workers were exposed to levels below the detection limit (0.02ppm; Table 3). Analysis of the exposure concentrations showed that the distribution is right-skewed, which indicates that the median or GM is a better way to represent the results than the AM. In addition, to avoid overestimating the exposure concentration and including any statistical bias, values below detection limit were not processed as missing values.

The EGBE exposure measurements of all the workers in the exposure group in this study were lower than the TWA values of OSHA, ACGIH and NIOSH (OSHA, 2007), and were also much lower than the TWA value suggested by the CLA of Taiwan–25ppm (CLA, 2003). This study proposes that the TWA value for EGBE suggested by the CLA of Taiwan needs to be reduced to a lower level, according to the results of our study and the recommendation of NIOSH. In addition to accounting for human variability as recommended by NIOSH, our suggestion is based on the considerations listed below:

1. An improvement in management and workers' working habits in the factory can reduce exposure to EGBE. The study by Yang (2002) pointed out that the concentration of 2-butoxyacetic acid (metabolite of EGBE) in the urine of workers is associated with the EGBE concentration in the atmosphere (P<0.001), the length of service (P=0.007), and the habit of wearing gloves (P=0.039). Both the study by Yang (2002) and this study (Tables 1 and 2) demonstrate that more than 50% of workers wore gloves during their working hours; this indicates that controlling the escape of evaporating solvents and encouraging the good habit of wearing gloves will help to reduce the exposure of workers to EGBE.

2. Use of lower toxicity solvents can reduce exposure to EGBE. In the results of the questionnaire, shown in Table 4, 62% of the workers mentioned using PGEs in their work, which was the same percentage as used EGEs (62%). These results indicate that this factory widely uses PGEs, which have a lower toxicity than EGEs. If the use of PGEs to replace EGEs can be increased, the workers' level of exposure to EGEs could be further reduced. The decreasing trend in the airborne EGBE concentration, as indicated by the reports of different researchers over the last two decades (Fig. 3), seems to coincide with points 1 and 2 of our considerations.

3. Low-level EGBE exposure can still damage health. Many studies of the past decade have suggested that, there is a correlation between air EGBE exposure and the levels of EGBE metabolite 2-butoxyacetic acid, and that EGBE exposure has a blood toxicity effect in humans. There is also evidence to suggest that EGBE may be carcinogenic, though the relevant studies used animal models in which the animals were exposed to high EGBE doses, or acute cases of human exposure to high EGBE concentrations (Gift, 2005). The current study demonstrates a case of workers' chronic exposure to low concentrations of EGBE in an ink factory, although we did not study whether or not exposure affects the 2-butoxyacetic acid concentration in the urine. However, the studies by Haufroid et al., (1997) and Yang (2002) demonstrated that there was a significant correlation between low EGBE exposure from the air to workers and the 2-butoxyacetic acid concentration in the urine after work (Haufroid, et al., (1997): r=0.55, P=0.0012; Yang: r=0.74, no p value described). In addition, Haufroid et al., (1997) pointed out that the hematocrit levels of the exposed workers were lower (3.3%, P=0.03) than those of the workers in the control group, and their mean corpuscular hemoglobin concentration was higher (2.1%, P=0.02) than that of the control group. Yang (2002) also showed that the mean corpuscular hemoglobin concentration in the exposed workers was significantly higher (P=0.04) than that of the workers in the control group. The results from these studies reveal that even exposure to low EGBE concentrations could affect the health of workers.

Although the level of EGBE exposure from the atmosphere might be low, our study reveals that the workers are also exposed to several other volatile organic solvents (Table 4 and Fig. 4) during their working hours. Therefore, further study of the effects of co-exposure to these solvents on health might be necessary.

ACKNOWLEDGEMENTS

The financial support (Grants NSC93-2320-B-470-001 and NSC94-2314-B-470-001) of the National Science Council (NSC) of the Republic of China (R.O.C.) is gratefully acknowledged. We also thank Dr. Tzu-Chieh Chou of the Institute of Environmental Health, China Medical University, Taiwan for his invaluable suggestions and assistance in collecting the samples.

REFERENCES

Angerer, J., Lichterbeck, E., Begerow, J., Jekel, S., Lehnert, G., (1990). Occupational chronic exposure to organic solvents. XIII. Glycolether exposure during the production of varnishes. Int. Arch. Occup. Environ. Health, **62** (2): 123-126.

Baker, E., Smith, T., Quinn, M., (1985). Health hazard evaluation report HETA 82-212-1553, Screen Printing Shops, Boston, Massachusetts and Denton, Maryland areas. PB-86-105392/XAB; HETA-82-212-1553.

CLA, (2003). Permissible exposure limits standard in workplace. Taipei, Taiwan: Council of Labor Affairs (CLA), Executive Yuan, available from http://www.iosh.gov.tw/data/f4/law58.pdf.

Denkhaus, W., von Steldern, D., Botzenhardt, U., Konietzko, H., (1986). Lymphocyte subpopulations in solvent-exposed workers. Int. Arch. Occup. Environ. Health, **57** (2): 109-115.

Gift, J. S., (2005). U.S. EPA's IRIS assessment of 2-butoxyethanol: the relationship of noncancer to cancer effects. Toxicol. Lett., **156** (1): 163-178.

Haufroid, V., Thirion, F., Mertens, P., Buchet, J. P., Lison, D., (1997). Biological monitoring of workers exposed to low levels of 2-butoxyethanol. Int. Arch. Occup. Environ. Health, **70** (4): 232-236.

HSE, (1997). Methods for the Determination of Hazardous Substances (MDHS): MDHS 88 Volatile organic compounds in air. Laboratory method using diffusive samplers, solvent desorption and gas chromatography. Sudbury, Suffolk, England: HSE Books, Health and Safety Executive (HSE), available from http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs88.pdf.

Hughes, K., Meek, M. E., Walker, M., Turner, L., Moir, D., (2001). 2-Butoxyethanol: hazard characterization and exposure-response analysis. J. Environ. Sci. Health C, **19** (1): 77-104.

Kullman, G. J., (1987). Health-hazard evaluation report MHETA 87-273-1866, Dalb, Inc., Ranson, West Virginia. PB-88-224696/XAB; MHETA-87-273-1866.

Lanigan, R. S., (1999). Special report: reproductive and developmental toxicity of ethylene glycol and its ethers. Int. J. Toxicol., **18** (4 supp 2): 53-67.

NIOSH, (1990). Criteria for a Recommended Standard: Occupational Exposure to Ethylene Glycol Monobutyl Ether and Ethylene Glycol Monobutyl Acetate. DHHS (NIOSH) Publication No. 90-118. Cincinnati, Ohio: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health (NIOSH).

NTP, (1989). Teratologic evaluation of ethylene glycol monobutyl ether (CAS No. 111-76-2) administered to Fischer-344 rats on either gestational days 9 through 11 or days 11 through 13. PB89-165849. Research Triangle Park, North Carolina: National Toxicology Program (NTP), U.S. Department of Health and Human Services, National Institutes of Health (NIH).

OSHA, (2007). Chemical sampling information: 2-butoxyethanol. Washington, DC: Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, available from http://www.osha.gov/dts/chemicalsampling/data/CH_222400.html.

Sakai, T., Araki, T., Masuyama, Y., (1993). Determination of urinary alkoxyacetic acids by a rapid and simple method for biological monitoring of workers exposed to glycol ethers and their acetates. Int. Arch. Occup. Environ. Health, **64** (7): 495-498.

Salisburg, S. A. and Bennett, D. E., (1987). Health-hazard evaluation report HETA 83-458-1800, Tropicana Products, Bradenton, Florida. PB-88-126636/XAB; HETA-83-458-1800.

Söhnlein, B., Letzel, S., Weltle, D., Rudiger, H. W., Angerer, J., (1993). Occupational chronic exposure to organic solvents. XIV. Examinations concerning the evaluation of a limit value for 2-ethoxyethanol and 2-ethoxyethyl acetate and the genotoxic effects of these glycol ethers. Int. Arch. Occup. Environ. Health, **64** (7): 479-484.

Veulemans, H., Groeseneken, D., Masschelein, R., van Vlem, E., (1987). Survey of ethylene glycol ether exposures in Belgian industries and workshops. Am. Ind. Hyg. Assoc. J., **48** (8): 671-676.

Vincent, R., Cicolella, A., Subra, I., Rieger, B., Poirot, P., Pierre, F., (1993). Occupational exposure to 2-butoxyethanol for workers using window cleaning agents. Appl. Occup. Environ. Hyg., **8** (6): 580-586.

Winder, C. and Turner, P. J., (1992). Solvent exposure and related work practices amongst apprentice spray painters in automotive body repair workshops. Ann. Occup. Hyg., **36** (4): 385-394.

Yang, C. M., (2002). 2-Butoxyethanol exposure assessment and biological monitoring of workers in a printed circuit board factory. Master Thesis (Chinese), Institute of Environmental Health Sciences, National Yang-Ming University. Taipei City 112, Taiwan (R.O.C.).