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Field Study

Evaluation of Workers Exposed to Ethylene Glycol Monomethyl Ether and Ethylene Glycol Monomethyl Ether Acetate

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Abstract: Evaluation of Workers Exposed to Ethylene Glycol Monomethyl Ether and Ethylene Glycol Monomethyl Ether Acetate: Jiyoung Park, *et al*. Institute of Health and Environment, Department of Environmental Health, School of Public Health, Seoul National University, Korea—Objectives: Ethylene glycol monomethyl ether (EGME) and ethylene glycol monomethyl ether acetate (EGMEA) are widely used in industries as solvents for coatings, paint and ink, but exposure data are limited because they are minor components out of mixed solvents, as well as because of inconsistency in desorption solvent use. The objective of this study was to investigate the worker exposure profile of EGME and EGMEA. **Methods:** Our study investigated 27 workplaces from June to September 2008 and detected EGME and EGMEA in 20 and 13, respectively. Both personal and area sampling were conducted using a charcoal tube to collect EGME and EGMEA. Gas chromatography with a flame ionization detector was used to analyze these compounds after desorption using a mixture of methylene chloride and methanol. **Results:** The arithmetic mean concentrations of EGME and EGMEA during periods of full work shifts were 2.59 ppm and 0.33 ppm, respectively. The exposure levels were lower than the Korean Ministry of Labor (MOL) OEL (5 ppm) but higher than the ACGIH TLV (0.1 ppm). **Conclusions:** In general, the working environments were poor and required much improvement, including the use of personal protective equipment. Only 50% of the workplaces had local exhaust ventilation systems in operation. The average capture velocity of the operating local exhaust ventilation systems was 0.27 m/s, which did not meet the legal requirement of 0.5 m/s. Educating workers to clearly understand the handling and use of hazardous chemicals and improving working conditions are strongly suggested.
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Key words: Ethylene glycol monomethyl ether (EGME), Ethylene glycol monomethyl ether acetate (EGMEA), Occupational exposure limit, Organic solvent

Ethylene glycol monomethyl ether (EGME) and ethylene glycol monomethyl ether acetate (EGMEA), commonly called methyl cellosolve and methyl cellosolve acetate, respectively, are widely used in the industrial sector as solvents for dyes, resins, lacquers, varnishes, wood stains and inks[1–3].

Glycol ether derivatives, including EGME and EGMEA, have been known to inhibit reproduction and hematopoietic functions[4–6]. Reproductive toxicity including developmental toxicity, regarded as a reproductive side effect, has been identified in both males and females. The high prevalence of spontaneous abortions and stillbirths in the semiconductor industry was reported to be related to these glycol ether derivatives[7]. Decreases in pregnancy rates and prolongation of gestation were observed in female rats. Additionally, increased embryonic and fetal death, reduced fetal body weight and malformations of fetuses were also found[8]. Hematological effects of subacute poisoning include decreased white blood cell count (mainly neutrophils), macrocytic anemia and abnormal leukocytes[9–11].

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Based on *in vivo* reproductive toxicity tests, the American Conference of Governmental Industrial Hygienists (ACGIH) lowered the threshold limit values (TLVs) of EGME and EGMEA from 5 ppm to 0.1 ppm in 2006[12]. The Japanese Society for Occupational Health and the US National Institute for Occupational Safety and Health (NIOSH) recommended the same values for both EGME and EGMEA as the ACGIH TLVs[13, 14]. However, the occupational exposure limits (OEL) for both EGME and EGMEA in Korea remain at 5 ppm, following the previous ACGIH TLV guideline.

Data on EGME and EGMEA exposures in the workplace are rarely published. The first reason for this is that the desorption solvent used varies. The US Occupational Safety and Health Administration (OSHA) recommends using a mixed solvent (95:5) of methylene chloride and methanol[15]. The NIOSH recommends the same solvent for EGME but suggests using CS_2 for EGMEA[16, 17]. The second reason for the dearth of exposure data is that EGME and EGMEA comprise a small percentage of the mixed organic solvents used in the workplace. Therefore, an industrial hygienist usually takes one charcoal sample from a worker and desorbs it with carbon disulfide to eliminate minor components such as EMGE. The objective of this study was to evaluate the exposure profile of workers to EGME and EGMEA.

Methods

Study design

Employers in Korea are required by the Ministry of Labor to evaluate hazardous agents in the workplace and report them to the Korean Occupational Safety and Health Agency (KOSHA). A total of 27 workplaces where EGME and EGMEA were handled, selected based on accessibility and concentrations previously reported to the KOSHA in 2005, were surveyed from June to September in 2008. The sampling strategy consisted of monitoring similar exposure groups including workers who directly handled organic solvents and whose exposure was expected to be high. Area samples as well as personal samples (i.e., samples assessing the exposure of individual workers) were taken. To characterize each worker and the corresponding workplace, the following workplace and worker parameters were recorded: temperature, humidity, ventilation, worker age, working hours per week, duration of work, use of personal protection equipment (PPE), smoking habit, and consumption of alcoholic beverages.

Sampling and sample analysis

All samples were collected and analyzed following OSHA method 79[15]. To determine the time-weighted average (TWA) and short-term exposure (STE) values, active sampling was conducted using a coconut shell charcoal tube (Cat No. 226-01, 100 mg/50 mg, SKC, Eighty Four, PA, USA) that gathered samples through a calibrated low pump (Gillian LFS-113, Sensidyne, Clearwater, FL, USA). Diffusive monitors (3M Organic Vapor Monitor 3500, 3M Company, St. Paul, MN, USA) were used during the full-shift workday. To measure personal TWA concentrations, active samplers were attached near the breathing zone (i.e., on the collar) of the workers during a full shift. Two consecutive active samplers were used for each worker (one in the morning and the other in the afternoon), and TWA was calculated. STE samples were taken every 10 to 15 min with the active sampler when high exposure for workers was expected during a specific task. Area samples were taken at the center of the working area during the full shift using diffusive and active samplers simultaneously.

Sample analysis was performed using a gas chromatography/flame ionization detector (GC/FID) for quantitative analysis, and methylene chloride/methanol (95:5) was used as the desorption solvent.

Data analysis

Statistical analyses of the exposure data were generated using an Industrial Hygiene Statistics Spreadsheet (Microsoft Excel) provided by the American Industrial Hygiene Association. A Shapiro-Wilk test (W-test) was performed to determine the data distribution at a significance level of 0.05[18]. Log-normal probability plotting was also used to determine data distribution. The arithmetic mean (AM), known to be a better predictor of dose than geometric mean (GM), was used to test the differences, though some data showed a log-normal distribution. STEs measured in this study were compared with the 8-hour ACGIH TWA data, as no STE limit values for occupational exposure in Korea were available.

Statistical tests, such as the *t*-test and correlation analyses, and graph construction were performed using Sigma Plot 9.0 and SAS Version 9.1 (SAS Institute, Inc., Cary, NC, USA).

Results

General characteristics of the workers and workplaces

Twenty companies handling EMGE and 13 companies handling EGMEA were chosen for this study out of 27 workplaces that had previously reported EGME and/or EGMEA measurement data to the KOSHA in 2005. The average temperature and humidity of the workplaces were 30.6˚C and 53.7%, respectively. Only 48% of workplaces (10 of the 20 EGME workplaces and 6 of the 13 EGMEA workplaces) had installed local exhaust ventilation systems. The range

of the control velocity was 0.14–0.39 m/s, with an average of 0.27 m/s in these systems. Most workers were male, and few wore PPE (Table 1). All workplaces used other organic solvents, and these were combined rather than used individually. Major processes performed in the workplace were coating, printing, mixing, and painting (Table 2).

Airborne concentrations of EGME and EGMEA

The TWA concentrations of personal EGME exposure, STE concentrations of both EGME and EGMEA, and concentrations of area samples of EGME and EGMEA were log-normally distributed, whereas TWA concentrations of EGMEA were not log-normally distributed (Fig. 1).

Table 3 shows the descriptive statistics for the charcoal tube samples of the 20 and 13 workplaces handling EGME and EGMEA, respectively. In the case of the EGME-exposed workplaces, 92 airborne samples ranged from 0.03 to 17.24 ppm. The arithmetic and geometric means (AM and GM, respectively) of the TWA in the personal samples were 2.59 ppm and 0.99 ppm, respectively. Of these samples, 20.8% exceeded 5 ppm, which is the occupational exposure limit (OEL) of the Ministry of Labor (MOL) in Korea, and 96.2% of samples exceeded 0.1 ppm, which is the ACGIH TWA. In the case of the EGMEA-exposed workplaces, 56 airborne samples ranged from 0.01 to 14.50 ppm. The AM and GM of the TWA in the personal samples were 0.33 ppm and 0.19 ppm, respectively. None of the samples exceeded 5 ppm, which is the MOL OEL in Korea, and 68.8% of the samples exceeded 0.1 ppm, which is the ACGIH TWA.

Table 1. General characteristics of workers

	EGME-exposed	EGMEA-exposed
Number (%)	68 (100)	48 (100)
Gender		
Male (%)	65 (96)	46 (96)
Female (%)	3 (4)	2 (4)
Mean age	39	38
Working duration (yr)	4.9	5.1
Exposed hours (h/day)	7.1	7.1
Wearing PPE		
Gas mask (%)	18 (26)	17 (35)
Protective gloves (%)	22 (32)	15 (31)

PPE: Personal protective equipment.

Discussion

In this study, we evaluated the characteristics of

Table 2. General characteristics of workplaces handling ethylene glycol monomethyl ether (EGME) and ethylene glycol monomethyl ether acetate (EGMEA)

Company	Main product	EGME and/or EGMEA using process	Potentially exposed workers*	EMGE No. of samples			EGMEA No. of samples			Ventilation	Other solvents used
				Personal TWA	Personal STE	Area TWA	Personal TWA	Personal STE	Area TWA		
A	Copper wire coating	Coating	20	4	3	1	4	3	1	Dilution	Cresol, xylene, phenol
B	Boxes	Printing	2	2	2	1	2	2	1	Dilution	Toluene, IPA[a], EA[b]
C	Tanks	Painting	5	5	2	0	5	2	0	Dilution	Xylene, toluene, IPA
D	Pressers	Painting	2	2	2	0	2	1	0	Dilution	–
E	Car parts	Painting	8	5	8	0	5	8	0	Local exhaust	Xylene, c-hexanone, BA[c]
F	Gaskets	Mixing	5	5	2	0	5	0	0	Local exhaust	Toluene
G	UV spray	Mixing	13	1	1	0	1	1	0	Local exhaust	Ethanol, butyl ether
H	Iron plates	Coating	12	3	4	0	2	2	0	Local exhaust	Hexane, acetone, styrene
I	Colored steel plate	Painting	8	1	0	0	1	0	1	Local exhaust	Paint
J	Ship parts	Painting	2	1	0	0	1	0	0	Dilution	Toluene, acetone, BC[d]
K	Paint	Mixing	11	3	0	2	3	0	2	Local exhaust	EB[e], acetone, hexane
L	Ship parts	Painting	2	2	0	2	1	0	0	Dilution	Hexane, MEK[f]
M	Paint	Painting	30	5	0	0	2	0	0	Dilution	Toluene, xylene, MIBK[g]
N	Wooden furniture	Painting	7	4	3	0	–**	–	–	Dilution	Toluene, EB[e] butyl acetate
O	Tape	Mixing	5	3	1	0	–	–	–	Local exhaust	EA[b], toluene, 2-buthanol
P	Slitters	Painting	1	1	0	1	–	–	–	Dilution	Toluene, xylene, MEK[f]
Q	Muffler	Coating	1	1	0	1	–	–	–	Local exhaust	TCE[h], xylene, EB[b]
R	Paint	Mixing	4	2	0	0	–	–	–	Local exhaust	Toluene, BA[c], EA[b]
S	Paint	Mixing	6	1	0	3	–	–	–	Dilution	Xylene
T	Machines	Painting	8	2	0	0	–	–	–	Local exhaust	BC[d], methanol
Total			152 (120)	53	28	11	34	19	5		

The numbers of workers exposed to EMGE and EGMEA were 152 and 120, respectively. **: EGMEA was not used, so there are no measurements for EGMEA. a: Isopropyl alcohol. b: Ethyl acetate. c: Butyl acetate. d: Butyl cellosolve. e: Ethyl benzene. f: Methyl ethyl ketone. g: Methyl isobutyl ketone. h: Trichloroethylene.

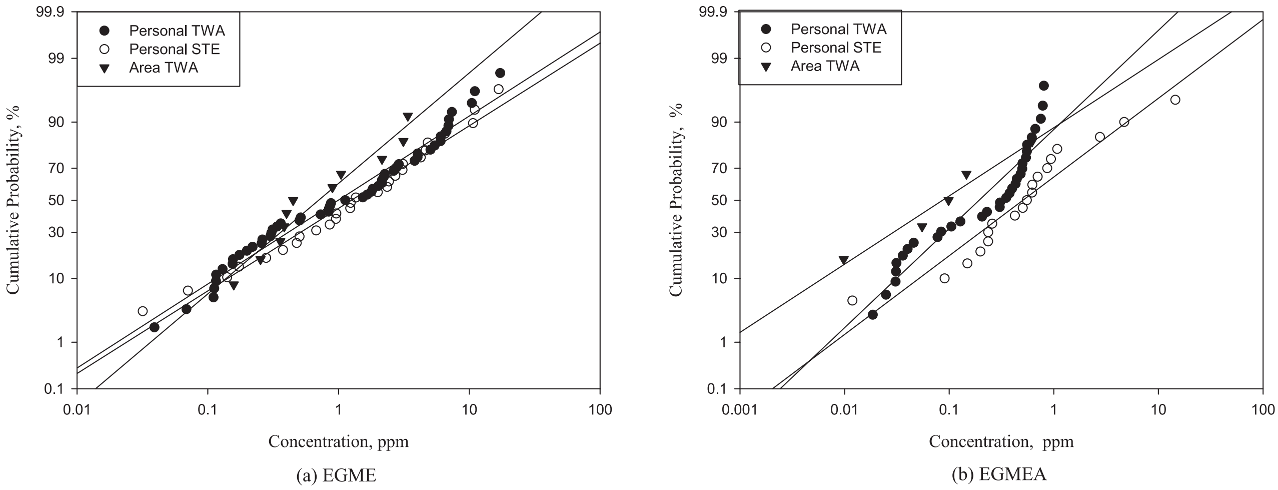

Fig. 1. Distribution of airborne samples of EGME (a) and EGMEA (b).

Table 3. Descriptive statistics of airborne exposure to ethylene glycol monomethyl ether (EGME) and ethylene glycol monomethyl ether acetate (EGMEA)

	Samples		n	AM (SD)	GM (GSD)	% above OEL	
						MOL*: 5 ppm	ACGIH: 0.1 ppm
EGME	Personal	TWA	53	2.59 (3.42)	0.99 (4.75)	20.8	96.2
		STE	28	2.99 (3.95)	1.25 (4.64)	14.3	92.9
	Area	TWA	11	1.15 (1.19)	0.70 (2.92)	0	100
EGMEA	Personal	TWA	32	0.33 (0.25)	0.19 (3.46)	0	68.8
		STE	19	1.55 (3.33)	0.51 (4.57)	5.3	89.5
	Area	TWA	5	0.19 (0.25)	0.09 (4.53)	0	40

*MOL: Ministry of Labor in Korea.

several workplaces and workers who handle EGME and EGMEA. The arithmetic mean of personal EGME and EGMEA concentrations using charcoal tubes were 2.59 ppm and 0.33 ppm, respectively. As shown in Table 3, the TWA of personal exposure and STE and TWA of area samples of EMGE were higher than those of EGMEA. For EGME, 20.8% of personal TWA exposures and 14.3% of STEs were higher than the Korean OEL value of 5 ppm, and 96.2% and 92.9% of those were above the ACGIH TLV of 0.1 ppm. For EGMEA, 5.8% of personal STEs were higher than the Korean MOL OEL, and 89.5% of STEs were above the ACGIH TLV. All area TWA concentrations of EGME and EGMEA samples were below the Korean OEL, whereas 100% of EGME and 40% of EGMEA area samples were above 0.1 ppm.

Most concentrations were between 0.1 and 5 ppm (Table 3). For example, 75.4% and 78.6% of personal TWA and STE for EGME were between 0.1 and 5 ppm. For EGMEA, 68.8% and 84.2% of personal TWA and STE were between 0.1 and 5 ppm.

The Korean MOL OEL for both EGME and EGMEA is currently 5 ppm, which reflects the ACGIH TLV of 5 ppm from the early 1990s, even though the ACGIH lowered the TLV to 0.1 ppm in 2006 based on evidence of reproductive toxicity. Korea should also adjust the OEL to the new, lower level in recognition of the impact of EGME and EGMEA on health and working conditions. Neither the MOL in Korea nor the ACGIH has set values for STEL and C (Ceil) for EGME and EGMEA. In the present research, however, STE was measured considering work characteristics such as the blending of raw materials and short work time. The measured value of STE for EGME showed a slight difference from the TWA, whereas that for EGMEA was approximately five times higher because the TWA was relatively low. The reasons for these differences are uncertain, but EGMEA was not used as frequently as EGME. Therefore, the TWA concentration of EGMEA was much lower than that of EGME, but the STE value could have increased during the short time the EGME was handled. The analyzed concentration for each workplace was 0.01–17.20 ppm, which is very high, indicating that workers are exposed to high concentrations.

The workplaces handling EGME and EGMEA were small in size and characterized by poor working conditions, and EGME and EGMEA were usually used for printing, painting, and mixing processes. Only 48% of these workplaces had local exhaust facilities operated during working hours, and the remainder either had no local exhaust ventilation or staff did not know how to operate if they were present; instead, they depended on dilution ventilation. Odors were severe in these areas because of the use of various mixed solvents, reflecting the processes involved. However, the workers were not notably aware of the odors, and the rates of gas mask use were very low (EGME 26%, EGMEA 35%). This may be due to the season (summer) in which the study was performed. However, in many cases, cotton masks were worn because of the inconvenience of wearing gas masks and the workers' poor understanding of their importance. EGME and EGMEA characteristically show high dermal absorption[19], yet only 32% of the workers wore appropriate protective gloves. Many (43%) of the workers wore cotton gloves, but dermal absorption is still possible through the cotton gloves, especially when the gloves are wet due to direct contact with the solvents and due to perspiration resulting from the high temperatures during the time of the study. Some workers used cloth soaked in organic solvents for wiping purposes without using any gloves. Containers for materials were left open for long periods, and the cloths used for solvents were also left lying around, both of which resulted in volatilization of the organic solvents. In some cases, workers refused to wear PPE for reasons such as inconvenience. In summary, there was no appropriate management of these workplaces. Therefore, changes must occur in the understanding of the use and handling of hazardous organic solvents through the education of workers and improvements in the work environment by managers.

Comparison of the concentrations between active sampler and passive sampler were published elsewhere[20]. Passive sampling should be applied in EGME- and EGMEA-exposed workplaces very carefully because of the possibility of underestimation, even though Pearson's correlation coefficients between passive and active collection were 0.86 and 0.75 for EGME and EGMEA, respectively[20].

The selection of the workplaces for the present research was made based on the results collected in 2005 by KOSHA. However, the managers and workers in these workplaces had a poor understanding of the use and handling of EGME and EGMEA. This may be due to the small amounts used as additives in solutions, especially as many workplaces did not have material safety data sheets (MSDS).

Conclusions

This research evaluated 20 and 13 workplaces handling EGME and EGMEA, respectively, in an effort to determine the exposure characteristics and overall working environment in EGME- and EGMEA-handling industries. The measured concentrations of EGME (TWA 2.59 ppm and STE 2.99 ppm) were higher than those of EGMEA (TWA 0.33 ppm and STE 1.55 ppm). The concentrations of most samples were at levels between the ACGIH TLV (0.1 ppm) and the Korean OEL (5 ppm).

The rates of workers wearing PPE, such as gas masks and protective gloves, were very low. The working conditions were very poor due to a lack of operating ventilation facilities and inappropriate maintenance. Improvements in working conditions, education of workers and modifications in the understanding of the use and handling of hazardous chemicals are strongly needed.

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