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Relation of Average and Highest Solvent Vapor Concentrations in Workplaces in Small to Medium Enterprises and Large Enterprises

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Abstract: The present study was initiated to examine the relationship between the workplace concentrations and the estimated highest concentrations in solvent workplaces (SWPs), with special references to enterprise size and types of solvent work. Results of survey conducted in 1010 SWPs in 156 enterprises were taken as a database. Workplace air was sampled at ≧5 crosses in each SWP following a grid sampling strategy. An additional air was grab-sampled at the site where the worker's exposure was estimated to be highest (estimated highest concentration or EHC). The samples were analyzed for 47 solvents designated by regulation, and solvent concentrations in each sample were summed up by use of additiveness formula. From the workplace concentrations at ≧5 points, geometric mean and geometric standard deviations were calculated as the representative workplace concentration (RWC) and the indicator of variation in workplace concentration (VWC). Comparison between RWC and EHC in the total of 1010 SWPs showed that EHC was 1.2 (in large enterprises with>300 employees) to 1.7 times [in small to medium (SM) enterprises with ≦300 employees] greater than RWC. When SWPs were classified into SM enterprises and large enterprises, both RWC and EHC were significantly higher in SM enterprises than in large enterprises. Further comparison by types of solvent work showed that the difference was more marked in printing, surface coating and degreasing/cleaning/wiping SWPs, whereas it was less remarkable in painting SWPs and essentially nil in testing/research laboratories. In conclusion, the present observation as discussed in reference to previous publications suggests that RWC, EHC and the ratio of EHC/WRC varies substantially among different types of solvent work as well as enterprise size, and are typically higher in printing SWPs in SM enterprises.

Key words: Enterprise size, Exposure concentration, Organic solvent, Workplace concentration

Introduction

The regulation in Japan takes two types of strategy in evaluating solvent vapor concentrations in solvent workplaces (SWPs); one follows the grid sampling trategy to take samples at ≧5 crosses in the SWP, and a geometric mean and a geometric standard deviation of the concentrations were figured out as representative parameters of solvent concentrations in the workplace. The other approach is to take one grab air sample at the site where the worker's vapor exposure concentration is empirically estimated to be the highest (the estimated highest concentration or EHC) in the SWP[1, 2].

Both of the two approaches, the grid sampling for a geometric mean and a geometric standard deviation and the grab sampling for EHC, are important because the geometric mean and the geometric standard deviation indicate the representative workplace vapor concentration (RWC) for the SWP and the sampling site-dependent variation in the concentrations (VWC) within the SWP, respectively, whereas EHC suggests the possible highest exposure condition for a worker, e.g., a foreman in the

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SWP. It may be possible to expect empirically that better industrial hygiene would be practiced in large enterprises with sufficient resources, so that not only RWC would be lower but VWC also would be smaller (i.e., closer to 1), and thus, EHC would be lower and the ratio of EHC over RWC would be also closer to 1. Nevertheless, relationships among RWC, VWC and EHC[3–5] and the possible effects of enterprise size on the relationships[6] have been examined only on limited occasions. In addition, experiences suggest that occupational hygiene condition may vary subject to types of solvent work[6, 7].

The present study was initiated to examine if such assumptions are valid to what extent and on what quantitative bases, and what would be the exceptions. For this purpose, data from over 1000 SWPs were compiled on various types of solvent work in small to medium (SM) enterprises and large enterprises, and statistical analyses were conducted for verification. The results will be presented in this communication in references to previous publications.

Materials and Methods

Air sample collections, analyses for solvents, and the solvent database

The database employed was the results of survey conducted by Kyoto Industrial Health Association in the fiscal year 2004 in 1010 SWPs in 156 enterprises, which were mostly in Kyoto prefecture and its surroundings in Japan. When necessary, the enterprises were classified into small to medium (to be abbreviated as SM) enterprises and large enterprises, taking 300 employees as a cut-off value[8]. In each SWP, air samples were collected in Tedlar® bags at ≧5 crosses of a hypothetical grid and also at the site where the worker's exposure was estimated (through the experiences in the SWP) to be highest (EHC)[2, 9]. Vapor concentrations of 47 solvents (Table 1), i.e., 7 solvents in Group 1 and 40 solvents in Group 2[10, 11], in the air samples were analyzed by flame ionization detector-equipped gas-liquid chromatography (FID-GC). Seven solvents in Group 3 (Table 1) were not considered because they are natural solvent mixtures (mostly of petroleum origin), and therefore they give large numbers of peaks of unidentified fractions on the chromatograms. In FID-GC, two columns were employed as necessary. In one system of analysis (for general purpose), a 25 m-long mega-bore (inner diameter, ϕ=0.53 mm) capillary column (coated with PEG 2000 or 6000; film thickness, 1 μm) was maintained at 75℃. In the other system (for quantification), a 2.5 m-long (inner diameter, ϕ=3 mm) stainless steel column packed with 30% DOP on Selite 545) was kept at 100℃. By use of an airtight syringe, 0.5 ml or 2.0 ml air sample was injected per analysis to the former and the latter systems, respectively. Extra-pure nitrogen gas was employed as

Table 1. Organic solvents analyzed[a] in the present study

Group 1		Group 2				Group 3	
1	Carbon disulfide	1	Acetone	21	Isobutyl alcohol	1	Coal tar naphtha
2	Carbon tetrachloride	2	Butyl acetate	22	Isopentyl acetate	2	Gasoline
3	Chloroform[c]	3	1-Butyl alcohol	23	Isopentyl alcohol	3	Mineral spirit
4	1,2-Dichloroethane	4	2-Butyl alcohol	24	Isopropyl acetate	4	Petroleum benzine
5	1,2-Dichloroethylene	5	Chlorobenzene	25	Isopropyl alcohol	5	Petroleum ether
6	1,1,2,2-Tetrachloroethane	6	Cresols[c]	26	Methl ethyl ketone	6	Petroleum naphtha
7	Trichloroethylene	7	Cyclohexanol	27	Methyl acetate	7	Terpentine oil
		8	Cyclohexanone[c]	28	Methyl alcohol		
		9	o-Dichlorobenzene	29	Methyl butyl ketone		
		10	Dichloromethane	30	Methyl isobutyl ketone		
		11	N,N-Dimethylformamide	31	Methylcyclohexanol		
		12	1,4-Dioxane	32	Methylcyclohexanone		
		13	EG[b] monobutyl ether	33	Pentyl acetate		
		14	EG monoethyl ether	34	Propyl acetate		
		15	EG monoethyl ether acetate	35	Styrene[c]		
		16	EG monomethyl ether	36	1,1,1-Trichloroethane		
		17	Ethyl acetate	37	Tetrachloroethylene		
		18	Ethyl ether	38	Tetrahydrofuran		
		19	Hexane	39	Toluene		
		20	Isobutyl acetate	40	Xylenes		

[a] Group 3 solvents were not analyzed in the present study, but names are listed for information.
[b] EG; ethylene gylcol.
[c] Solvents for which the limit of detection was 0.1 ppm. The limits were 1 ppm for others.

carrier gas, and was allowed to flow at 4 and 40 ml/min in case of the capillary and packed columns, respectively. The FID was kept at 200 ℃ and 150 ℃ in the former and the latter, respectively. The results of GC analyses were confirmed with the information on solvent composition given on the side of each solvent or solvent preparation container. The limit of detection was 0.1 ppm for some solvents (those marked in Table 1), and 1 ppm for others. The quality of analysis was controlled internally.

When 2 or more solvents were present in the air sample, the ratio of the measured concentration over the administrative control level[12] was calculated for each solvent and the sum of the ratio (thus by use of the additiveness formula[12–14]) was calculated; the sum was taken as an integrated solvent concentration at the sampling site. In the present analyses, the same procedure was applied also to the case where only one solvent was detected (i.e., the ratio of the measured solvent concentration over the administrative control level in place of the measured concentration) for the uniformity in data processing. The 2001 version of the administrative control levels were employed in the present analysis because the surveys were conducted when the 2001 version was in effect. From the integrated vapor concentrations at the ≧ 5 crosses per SWP, a geometric mean and a geometric standard deviation were calculated as parameters of representative workplace concentration (RWC) and that of variation in concentrations within the workplace (VWC), respectively. Separately, the estimated highest concentration (EHC) was recorded for each SWP. Thus, 1010 sets of RWC, VWC, EHC and the EHC/RWC ratio were available for statistical analyses.

Statistical analysis

A PC software of StatView Version 5 was employed for statistical analyses. The distributions of the four parameters, RWC, VWC, EHC and the EHC/RWC ratio, skewed with clustering in lower value regions and tailing toward higher values (e.g., Fig. 1). A preliminary analysis with chi-square test showed that RWC and EHC fit with normal distribution after logarithmic conversion, whereas the distributions of log VWC and log the EHC/RWC values were still not normal. Nevertheless, it was thought appropriate to assume log-normal distribution for all four parameters in common because of uniformity and practicality in data processing. Accordingly, parametric analyses after logarithmic conversion of the parameters were generally employed. Non-parameteric Mann-Whitney test was also applied for evaluation of the difference when considered appropriate. Differences in slopes, intercepts and correlation coefficients of two regression lines were examined according to Ichihara[15].

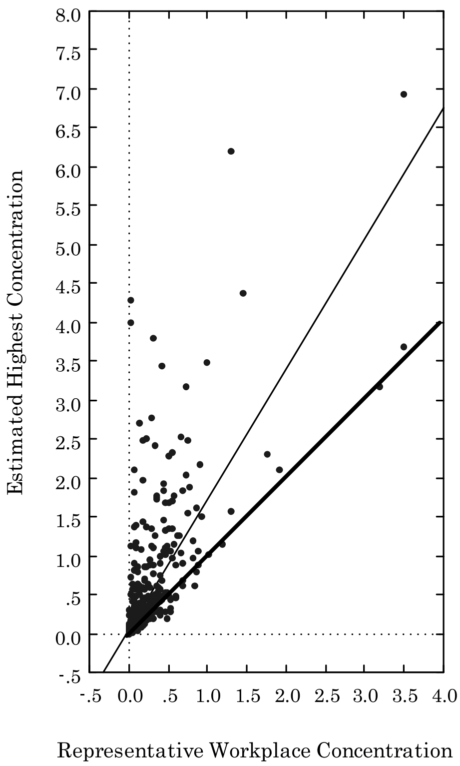

Fig. 1. Correlation between representative workplace concentrations and estimated highest concentrations.

In total, 1010 solvent workplaces (SWPs) were investigated. Each dot represents a SWP. The line in the middle is a calculated regression line, with an equation of Y=0.06+1.68X (where X is the RWC and Y is EHC; r=0.73, P<0.01). The thick line shows Y=X.

Results

Size of enterprises surveyed and available number of solvent work places

The number of employees in the 156 enterprises distributed in a wide range of<50 to>1000. When the 1010 SWPs were divided into two groups of nearly equal sizes taking together the enterprise size into consideration, 524 SWPs out of a total of 1010 cases belonged to 126 SM enterprises (with ≦ 300 employees in an enterprise; Small and Medium Enterprise Agency 2000), whereas remaining 486 SWPs were in 30 large enterprises (with >300 employees in an enterprise).

Distribution patterns of RWC and EHC, and the relation between the two parameters

When EHC was plotted against RWC on an ordinary scale (Fig. 1), and the relation between the two parameters was examined by linear regression analysis, a regression line of Y=0.06+1.68X (where X is RWC and Y is

EHC) was obtained with a significant correlation coefficient (r=0.73, P<0.01). The slope (1.68) coupled with a very small intercept (0.06) suggests that EHC would be 1.6 to 1.7 times greater than corresponding RWC. The figure also shows that EHC was smaller than the corresponding RWC value in some cases (104/1010 or 10%), possibly due to the practice that workers there were instructed to serve avoiding the sites of dense vapor concentrations. The differences of EHC from RWC in these 104 cases were however generally minute.

There was a heavy clustering near the origin, suggesting non-normal distribution of the two parameters as previously described in the Materials and Methods section. Accordingly, further analyses were conducted after logarithmic conversion.

Relation among the four parameters and possible effects of enterprise size

In order to examine quantitative relationship among the four parameters, linear regression analysis was conducted between pairs among the four parameters, taking log RWC or log VRC as an independent variable (i.e., X) and the logarithm of another parameter [i.e., log VWC, log EHC, or log (EHC/RWC)] as a dependent variable (i.e., Y). Analysis was conducted for all enterprises in combination, and also for SM enterprises and large enterprises separately to examine if the relation, in terms of the slope and the correlation coefficient in particular, might be modified by enterprise size (Table 2). The relation of log VWC with log RWC was such that VWC became larger for larger RWC as the positive slope (>0) indicated, and the effect was more evident among SM enterprises than large enterprises as the slope was significantly (P<0.01) larger for the former (0.37) than for the latter (0.23).

It was quite conceivable that EHC was larger when RWC was larger. A correlation coefficient of 0.91 between RWC and EHC for total enterprises after logarithmic conversion was significantly (P<0.01) larger than the coefficient without conversion (r=0.73; Fig. 1). The observation is on line with the fitness of the two parameters to log-normal distribution as discussed in the Materials and Methods section.

The correlation of log (EHC/RWC) with log RWC was not close when the cases were classified into two groups of SM enterprises and large enterprises ($P \geqq 0.05$). Statistical significance of the correlation for the total group (P<0.01) was essentially due to doubling in the number of cases.

Of particular interest is the relation of EHC with VWC.

Table 2. Relation between solvent concentration parameters by size of enterprises

X / Y	Size of enter-prises[a]	No. of SWPs	Regression parameters[b]				P[c]	
			α	β	r	P	α	β
log RWC	Total	1010	0.23	0.087	0.42	<0.01		
log VWC	SM	524	0.25	0.090	0.37	<0.01	<0.01	<0.01
	Large	486	0.13	0.042	0.23	<0.01		
log RWC	Total	1010	0.24	1.06	0.91	<0.01		
log EHC	SM	524	0.26	1.03	0.87	<0.01	<0.01	ns
	Large	486	0.08	1.00	0.91	<0.01		
log RWC	Total	1010	0.24	0.06	0.12	<0.01		
log (EHC/RWC)	SM	524	0.26	0.03	0.06	ns	<0.01	ns
	Large	486	0.08	−0.00[d]	−0.00[d]	ns		
log VWC	Total	1010	−1.54	2.98	0.53	<0.01		
log EHC	SM	524	−1.27	2.58	0.54	<0.01	<0.01	<0.05
	Large	486	−1.68	1.90	0.31	<0.01		
log VWC	Total	1010	0.05	0.99	0.43	<0.01		
log (EHC/RWC)	SM	524	0.06	1.08	0.46	<0.01	ns	<0.01
	Large	486	0.05	0.61	0.24	<0.01		

[a] Small to medium (SM) enterprises and large enterprises with ≦ 300 or >300 employees, respectively.
[b] α and β are parameters of calculated regression lines of $Y=\alpha+\beta X$, in which X and Y are as shown in the table. r is s a correlation coefficient, and P shows the statistical significance of the coefficient. For more details of variables, see the Materials and Methods section.
[c] P for significance of the difference in the intercepts (α) and slopes (β) for the SM enterprises and large enterprises (examined after Ichihara[15]); ns for $P \geqq 0.05$.
[d] −0.002 for β, and −0.004 for r.

The slope was positive (>0) with a difference of weak statistical significance (P<0.05) dependent on enterprise size, i.e., being greater in SM enterprises and smaller in large enterprises. The observation suggests that EHC would be greater when VWC was wider, especially in SM enterprises. Such findings are well in agreement with expectation, because EHC by definition is the worker's highest exposure concentration in the SWP and should be higher as the variation in concentrations within the SWP are greater. Similarly, the ratio of EHC/RWC would be greater in SWPs where VWC was larger.

Effects of enterprise size and types of solvent work on the four parameters

The 1010 SWPs were classified by the size of enterprise and also by the types of solvent work. As the numbers of SWPs were rather small for some types of solvent work, the types with more than 100 SWPs were selected for inter-type comparison (Table 3). In practice, they were printing, surface coating, degreasing/cleaning/wiping, painting, and testing/research SWPs.

Comparison (on the horizontal direction in Table 3) between SM enterprises and large enterprises among a total of 1010 SWPs made it clear that not only RWC and EHC were higher (P<0.01) in SM enterprises than in large enterprises, but VWC and therefore the EHC/RWC ratio were also greater (P<0.01) in the former than in the latter. Further perusal of the data by types of solvent work revealed that the enterprise-size dependent difference was significant (P<0.01) in surface coating and degreasing/cleaning/wiping SWPs for all of the four parameters, although it was less clear (P<0.05 to ≧ 0.05) in printing SWPs. The observation in combination with high RWC (0.102) suggests that the industrial hygiene conditions were less favorable in some types of solvent work especially in SM enterprises.

In contrast, size-dependent difference was either insignificant or not clear in painting (P ≧ 0.05) and testing/research SWPs (P<0.05 to ≧ 0.05). Although statistically significant (P<0.05), the differences in RWC and EHC (0.01 for both) in testing/research laboratories between SM enterprises and large enterprises were minute. It should also be taken into consideration that much more SWPs were available for large enterprises

Table 3. Difference between small to medium and large enterprises in solvent concentration parameters in workroom air

Type of solvent work[a]	No. of cases			RWC				VWC			
	Total	SM[c]	L[c]	Total	SM[c]	L[c]	P^d	Total	SM[c]	L[c]	P^d
All	1010	524	486	0.042	0.078	0.022	**	1.28	1.42	1.14	**
3 Printing	131	91	40	0.102 ↑	0.116	0.075	ns	1.32	1.35	1.23	ns
5 Surface coating	106	73	33	0.043	0.094	0.007 ↓	**	1.45	1.57	1.20	**
8 Degreasing, etc.[e]	314	115	199	0.022 ↓	0.059	0.012 ↓	**	1.25	1.47	1.13	**
9 Painting	161	129	32	0.082	0.078	0.104 ↑	ns	1.34	1.36	1.24	ns
11 Testing/research	164	21	143	0.028	0.020 ↓	0.029	*	1.09 ↓	1.02 ↓	1.10	ns
P^f				**	**	**		**	**	**	

Type of solvent work[a]	EHC				EHC/RWC ratio[b]			
	Total	SM[c]	L[c]	P^d	Total	SM[c]	L[c]	P^d
All	0.061	0.130	0.027	**	1.43	1.67	1.22	**
3 Printing	0.142	0.176	0.086 ↑	*	1.40	1.52	1.16	*
5 Surface coating	0.079	0.214 ↑	0.009 ↓	**	1.86 ↑	2.28	1.19	**
8 Degreasing, etc.[e]	0.032 ↓	0.104	0.016 ↓	**	1.45	1.75	1.31	**
9 Painting	0.113	0.111	0.122 ↑	ns	1.37	1.42	1.18	ns
11 Testing/research	0.030 ↓	0.019	0.032 ↓	*	1.08 ↓	0.98	1.10	ns
P^f	**	**	**		**	**	*	

RWC, VWC and EHC stand for representative workplace concentration, variation in workplace concentration, and estimated highested concentration, respectively. Values in the table are geometric mean values. For information on distribution patterns, see the Materials and Methods section.

[a] Solvent work as classified by regulation[10, 11].

[b] The ratio of EHC over RWC.

[c] Enterprise size by number of employees: small to medium enterprise (SM), 1-300; large enterprises (L), >300.

[d] P for the difference between SM enterprises and L enterprises; **, * and ns for P<0.01, 0.05 and ≧ 0.05, respectively by unpaired t-test.

[e] Degreasing, cleaning and wiping.

[f] P by ANOVA for the differences among the Groups 3, 5, 8, 9 and 11. Arrows show the values significantly (P<0.05) greater (upward) or smaller (downward) than three of other values.

(143 SWPs) than for SM enterprises (21 SWPs).

When compared on a total basis among the types of solvent work (comparison on vertical direction in Table 3), RWC was higher in printing SWPs (0.102) and lower in degreasing/cleaning/wiping SWPs (0.022). Although statistically insignificant, RWC tended to be lower also in testing/research laboratories (0.028). Correspondingly, EHC tended to be higher in printing SWPs (0.142; although statistically insignificant), and lower in degreasing/cleaning/wiping SWPs (0.032; $P<0.05$) and in testing/research laboratories (0.030; $P<0.05$). Thus, both RWC and EHC were greater in printing SWP typically in SM enterprises. Interestingly, VWC was smaller in testing/research laboratories (1.09) than others (1.25 to 1.45), indicating that the vapor concentration in testing/research laboratories was low and rather uniform among SWPs. As a result, the EHC/RWC ratio was also low in the laboratories (1.08) (Table 3).

Discussion

The present analysis of solvent concentrations in more than 1,000 solvent workplaces made it clear that the estimated highest concentration (EHC) in workplaces will be 1.6 to 1.7 times higher than the representative workplace concentration (RWC; calculated as the geometric mean of $\geqq 5$ determinations in the workplace (calculation without logarithmic conversion; Fig. 1). When log-normal distribution was assumed, the ratio was 1.5 (=0.061/0.042), 1.7 (=0.130/0.078) and 1.2 (=0.027/0.022) for total enterprises, SM enterprises and large enterprises, respectively (Table 3), with a higher ratio for SM enterprises than for large enterprises. Both RWC and EHC were significantly higher ($P<0.01$) in SM enterprises than in large enterprise (Table 3). When examined by various types of solvent work, the trend of lower RWC and EHC in large enterprises as compared with the levels in SM enterprises was more marked in printing, surface coating and degreasing/cleaning/wiping SWPs, whereas it was less remarkable in painting SWPs, and was essentially nil in testing/research laboratories (Table 3).

Difficulties in the practice of good industrial hygiene in SM enterprise have been discussed world-wide. For example, Park *et al.*[16] in Korea, Su *et al.*[17] in China, Derlicka and Shahnavaz[18] and Michalak[19] in Poland reported further needs of support for better industrial hygiene conditions in SM enterprises. Similarly, less availability of human and financial resources for occupational health activities in SM enterprises were stressed also in Japan[20, 21].

Through comparison of RWCs among the various types of SWPs, Ikeda and Ohtsuki[7] observed less effective industrial hygiene in printing SWPs in the sense that RWC in this type of SWPs was higher than others. Ukai *et al.*[22] also found that EHC was higher in printing SWPs in particular. The present observation of higher RWC and EHC in printing SWPs especially in SM enterprises is on line with the finding in the previous studies[7, 22], which suggests that the problems are still persisting even at present.

Of particular interest is the ratio of EHC over WRC, because the ratio gives the possibility to estimate the relation of the worker's highest exposure concentration with the average workplace concentration. The present analysis with EHC and RWC (without logarithmic conversion) in total enterprises gave 1.6–1.7 (Fig. 1), whereas it was 1.5 for total, 1.6 for SM enterprises and 1.2 for large enterprises, respectively, when logarithmic distribution was assumed for EHC and RWC (Table 3). Early in 1980s, Ikeda et al.[3] observed in a FRP boat production plant that the ratio was close to 1 during the lamination work on the boat hull whereas it was close to 2 when the work was carried out on other parts of the boat; the difference depended on the ventilation conditions. Yasugi *et al.*[4] obtained even higher ratios of 2.0 to 3.0 in adhesive spreading and adhesion SWPs, and 1.8 to 4.5 in painting SWPs; the ratio tended to be higher in SWPs of poorer hygienic conditions in both types of solvent work. The ratios observed by Yasugi *et al.*[4] were substantially greater than the present observation of 1.2–1.7. It should be taken into account however that the ratios observed by Yasugi *et al.*[4] were the division of geometric mean EHC by the geometric mean RWC, whereas the ratio in the present analysis was the geometric mean of the individually calculated ratios, and therefore the ratio observed in the present analysis should be theoretically smaller than the ratio based on the procedures of Yasugi *et al.*[4] The results of the two studies agree with each other however in the sense that the ratio tends to be higher in association with higher RWC in SWPs. Recently, Hori *et al.*[5] measured personal exposure concentrations and workplace concentrations of ethylene oxide in sterilization facilities in hospitals. In one sterilization room where the results of both measurements were available, the results of the two measurements were close to each other, suggesting a ratio close to 1. Over-all evaluation, therefore, is such that the ratio of EHC/WRC, or the ratio of the highest personal exposure concentration over the workplace concentration, varies substantially from the level close to 1 to the level over 4 subject to variation in solvent work, but may be higher in SWPs of poorer hygienic conditions.

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