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Breathing Zone Concentration Variations in the Reinforced Plastic Industry; Field Measurements in a Boat Manufacturing Plant

R. F. Malek,¹ J. M. Daisy,² and B. S. Cohen

Nelson Institute of Environmental Medicine, New York University School of Medicine, Tuxedo, New York

Breathing zone samples are used to estimate worker exposure to airborne contaminants by collecting air from a vaguely defined zone surrounding the head. This zone is considered to have an airborne chemical concentration equivalent to the concentration breathed by the worker. It has been generally assumed that vapor is uniformly mixed in the breathing zone; therefore, samplers are placed on either lapel or on the chest of the worker. An extensive field investigation in a boat manufacturing plant was conducted where styrene air concentrations were measured by mounting four 3M one-stage diffusion samplers around the worker's breathing zone. Two job classes were studied: the spray gun operators and the rolling and tucking operators. Styrene air concentrations detected at the nose were significantly different than those concentrations detected at the other three locations and represented 90 percent, 84 percent, and 76 percent of the left lapel, right lapel, and chest samplers, respectively. This research revealed that the chest sampler provides a consistent relationship to the concentrations measured at the nose for a given job category. Additionally, this research identified the possible factors which could contribute to breathing zone concentration variations.

Keywords Breathing Zone Concentrations, Breathing Zone Samplers, Occupational Exposure Monitoring, Monitoring Inhalation Exposure, Personal Sampler Placement Bias, Lapel Samplers, Chest Sampler, Nose Sampler, Styrene, Reinforced Plastic Industry

The common goal behind industrial hygiene air sampling is the quantitation of airborne contaminants in the work environment to evaluate employee exposure to such contaminants.

Breathing zone samples are used to estimate worker exposure by collecting air from a vaguely defined zone surrounding the head. This zone is considered to have an airborne chemical concentration equivalent to the concentration breathed by the worker. There is no universal definition of the breathing zone. The Occupational Safety and Health Administration (OSHA)⁽¹⁾ considers the breathing zone to be a hemisphere forward of the shoulder, with a radius of approximately 6–9 inches. OSHA instructs its compliance officers to collect air samples as close as practical to the nose and mouth of the worker. In most cases, lapel or chest samples are utilized to collect "breathing zone samples." Therefore, it is obvious that the breathing zone samplers play an important role in estimating the worker's inhalation exposure.

Despite the importance of the breathing zone concentration measurements, the subject has not been thoroughly investigated to understand the factors that can influence the accuracy of the collected samples. There is not even a standard procedure for collecting air samples in the breathing zone. Samples collected in this zone may not provide true exposure estimates due to concentration variations within that zone, a phenomenon that is not uncommon in workplaces having a point emission source.⁽²⁾

There are just a few reports in the literature that deal with the breathing zone concentration variations. Chatterjee et al.⁽³⁾ investigated variations of lead concentrations in a battery factory by attaching two filter heads to the upper left chest of the worker, one about 5 inches below the other. The mean concentration of the filter heads in the upper position was 22 percent less than that obtained with the filter heads in the lower position. In an experiment to measure radioactive airborne dust, Butterworth and Donoghue⁽⁴⁾ attached three sampling devices, one at the helmet and one at each side of the chest. In most cases, there were no significant differences between samples taken on the left and the right chest, however, samples taken at the head were significantly lower than those taken at the chest. Donaldson and Stringer⁽⁵⁾ have confirmed the National Institute for Safety and Health (NIOSH) observation that lapel samplers for beryllium gave results that are different from a composite of breathing zone and general area samples. Martinelli et al.⁽⁶⁾ reported on

¹Current address: Rhodia Inc., Winder, Georgia.

²Current address: Lawrence Berkeley Laboratories, Berkeley, California.

workers' exposure to beryllium-copper aerosol (Be-Cu) during the melting and casting of Be-Cu alloy. The field measurements made of the aerosol concentration at the forehead, nose, and lapel of the workers showed considerable concentration variations at different locations within the breathing zone. Cohen et al.⁽⁷⁾ reported on bias and air sampling techniques used to measure inhalation exposure for Be, and found that dust resuspended from work clothing into the lapel monitor is generally the most important bias factor.

It has been generally assumed that vapor is uniformly mixed, consequently, information available on breathing zone concentration variations of organic vapors is even more limited than on particles. Capodagli et al.⁽⁸⁾ conducted an industrial hygiene survey on solvent during a manual gluing operation in a shoe factory. Samples were collected with passive dosimeters placed around the breathing zone: two at the collar (right and left), two at the nose and mouth level (right and left), and one at the forehead. Samples collected at the forehead showed 25–80 percent of the concentration detected at the collar. The variations were attributed to a strong concentration gradient near the breathing zone or even within the breathing zone. At present, this study appears to be the only published investigation on breathing zone concentration variations for organic vapor and, in this instance, the factors leading to such variations were not systematically investigated.

Exposure to organic contaminants is a problem that exists in many chemical industries in general and in the reinforced plastic industry in particular. The latter is a good example of manual operations with a high exposure to styrene and other organic compounds. The main ingredient used in that industry is unsaturated polyester resin solution. This solution consists of about 60 percent unsaturated polyester resin, and about 40 percent styrene which acts as a solvent at room temperature. The polyester resin is blended with small amounts (0.2–3%) of organic compounds called promoters, such as aromatic amines and organo-metallic compounds. The promoted polyester resin solution is catalyzed with organic peroxides and is then applied to fiberglass to produce reinforced hard plastic items such as boats. The promoter enhances the cleavage of organic peroxides which in turn catalyzes the exothermic reaction between styrene and the unsaturated polyester resin. The exothermic reaction is generally known as crosslinking and leads to the formation of hard plastic items. Tossavainen⁽⁹⁾ reported that as much as 10 percent of the styrene is lost into the air due to spraying and handling of polyester resin solution. Styrene has a permissible exposure limit (PEL) of 100 ppm as set by OSHA. Both the American Conference of Governmental Industrial Hygienists (ACGIH) and NIOSH recommend 50 ppm as a time-weighted average (TWA) exposure to styrene.

The International Agency for Research on Cancer (IARC) decided in March 1987, to reclassify styrene as "possibly carcinogenic to humans" (Group IIB) from its 1982 intermediate status, "not classified as to carcinogenicity in humans" (Group 3).^(10,11) This reclassification of styrene was based on data generated on styrene oxide which demonstrated carcinogenicity (stomach tu-

mors) in two rat studies.^(12,13) The reclassification was prompted by the fact that styrene may be converted to styrene oxide in an intermediate step of its metabolism by humans. Additionally, styrene oxide was identified in the blood and some tissues of mice injected with styrene.^(14,15)

The Styrene Information and Research Center (SIRC) was formed as a result of the IARC reclassification to pursue and sponsor research on styrene and its derivatives. SIRC has commissioned the Chemical Industry Institute of Toxicology (CIIT) to conduct toxicological studies to understand styrene metabolic pathway in rats and mice. Some results have been published,⁽¹⁶⁾ and additional research is still in progress. NIOSH estimated that about 30,000 workers are potentially exposed to styrene in the United States annually.⁽¹⁷⁾ The highest styrene exposures are observed in the reinforced plastic industry due to the specific operations of spraying and lamination. Two studies^(18,19) reported on styrene exposure in the fiberglass-reinforced plastic boat industries. Styrene exposure⁽¹⁸⁾ in one study ranged from 2 ppm to 183 ppm and, in the second study,⁽¹⁹⁾ 40 percent of all samples indicated exposures above the PEL of 100 ppm TWA. Both studies^(18,19) did not consider the breathing zone concentration variations. This research⁽²⁰⁾ was conducted to investigate the true inhalation exposure of styrene in the reinforced plastic industry, specifically to determine the magnitude of the variability in the breathing zone concentration in this industry and to begin to explore the preliminary factors leading to such variations, and to determine the most appropriate sample location within the worker breathing zone which correlates well with the air concentrations measured at the nose.

PROCESS DESCRIPTION

Styrene breathing zone concentrations were measured in a boat manufacturing facility in the New England region of the United States. Boats in this facility are produced in two layers by two different molds. The two layers are produced separately, then bonded by injecting a two-component polyurethane resin between them. The process of producing both layers is similar, the only difference is the shape of the mold; a convex mold is used for the bottom layer and a concave mold is used for the upper layer. A mixture of two proprietary unsaturated polyester resins was utilized.

Production of either boat layer consists of applying a release agent to the mold, followed by an opaque gel coat layer. The gel coat serves as a barrier against external environmental factors. After the gel coat layer dries, lamination of the boat layer commences. The latter involves the spraying of alternating layers of catalyzed polyester resin solution and fiberglass over the gel coat layer. Each layer, after saturation with the resin, is rolled out to remove excess resin and expel air pockets. After the proper external layer thickness is achieved, structural support pieces are added and sprayed with polyester and fiberglass. The alternating layers, after crosslinking, provide the desired physical properties of the boat. The boat layers are then pulled out from their respective molds and bonded together.

Engineering Controls and Personal Protection Equipment

Dilution ventilation is utilized to remove styrene from the work environment. Air is supplied on both sides of the mold through slot openings, where air flows from the slots (600 ft/min \pm 50 ft/min; 3 m/s \pm .25 m/s) toward the worker's back, and around the worker into the mold area, then exhausted through various canopies mounted on the ceiling of the mold production area. Air velocities measured around the mold area ranged from 60–80 ft/min (0.3 m/s–0.4 m/s). Typically, each worker is provided with a hair cap, apron, rubber boots and gloves, and a half-mask respirator equipped with a high efficiency particulate filter (HEPA), followed by an organic vapor cartridge.

Industrial Hygiene Assessment of Potential Exposure to Styrene

Several styrene sources were identified in this manufacturing facility. However, spraying, rolling, and tucking operations of the polyester resin represented the most extensive source of styrene exposure. A large amount of polyester resin solution (400–600 lbs.) is sprayed in an interval of 55–80 minutes, depending on the boat size.

Two job classes were monitored for styrene exposure: the spray gun operator (gunner) and the rolling and tucking operator (roller). The intensity of the exposure is due to the large quantity of the sprayed resin, the close proximity of the worker to the sprayed mold or the gun, time required to build and laminate the boat layers, and the exothermic reaction which enhances styrene evaporation. The work crew consisted of one gunner and 3–5 rollers depending on the boat size.

EXPERIMENTAL METHODS

Styrene air concentrations were measured by mounting four 3M one-stage diffusion samplers around the worker's breathing zone; placing them at the nose, chest, left lapel, and right lapel. The duration for the diffusion samplers for any given worker was limited to the time required to build the alternating laminates of one boat. That time ranged from 55–90 minutes, depending on the boat size. A total of 21 workers (14 rollers and 7 gunners) were monitored for styrene breathing zone concentrations, with a total of 84 samples collected. Background area samples were also collected near the spraying area. The collected personal samples, background samples, and blanks were desorbed with 2ml CS₂ as recommended by 3M. The samples were analyzed utilizing a Hewlett Packard gas chromatograph equipped with a flame ionization detector (GC/FID). The column was 20 ft. \times 1/8 in. O.D., SS, 10% FFAP on 10% chromosorb W/AW, 80/100 mesh, and operating at 150°C isothermal. Helium was used as a carrier gas at 30 cc/min.

RESULTS

The styrene breathing zone concentrations of the 21 workers are presented in Table I. Clear and distinct air concentration variations in the breathing zone are evident as demonstrated by

TABLE I
Styrene breathing zone air concentrations mg/m³

Sample no.	Nose	Left lapel	Right lapel	Chest
1	375	385	449	510
2	298	369	368	549
3	762	687	800	815
4	157	206	180	251
5	352	386	386	451
6	263	306	269	341
7	200	232	232	245
8	248	300	438	474
9	367	415	486	565
10	362	381	356	491
11	262	290	292	280
12	311	340	340	359
13	284	333	360	346
14	325	354	394	400
15	144	345	367	356
16	506	533	558	600
17	314	298	348	337
18	247	280	293	340
19	449	506	531	533
20	346	368	355	402
21	303	343	368	381
\bar{x}^A	327	365	389	430
s^B	131	106	131	136

^A \bar{x} : sample mean.

^B s : sample standard deviation.

the average styrene air concentration at each breathing zone location and its associated standard deviation: nose 327 mg/m³ \pm 131 mg/m³, left lapel 365 mg/m³ \pm 106 mg/m³, right lapel 389 mg/m³ \pm 131 mg/m³, and chest 430 mg/m³ \pm 136 mg/m³. The concentrations measured at the nose were consistently lower than those detected by the chest samplers.

In most of the workers (18 out of 21) the concentrations at the nose samplers were lower than both the left and right lapel concentrations. The relationships between the left lapel and the right lapel concentrations were somewhat mixed: in 13 workers the concentrations at the left lapel were lower than those at the right lapel, in five workers the left lapel concentrations were higher than those at the right lapel, and in three workers the concentrations at the left and right lapels were equivalent. On average, styrene air concentration detected at the nose represented 90 percent, 84 percent, and 76 percent of the left lapel, right lapel, and chest samplers, respectively. The overall average results indicated a certain trend in the breathing zone concentrations where the lowest concentrations were detected at the nose location, followed by the left lapel, the right lapel, and, the highest concentrations at the chest samplers.

The styrene breathing zone concentrations obtained on the 21 workers were sorted by job class: 7 gunners and 14 rollers. Tables II and III present the styrene breathing zone concentrations for

TABLE II

Styrene breathing zone concentrations of the spray gun operations mg/m³

Sample no.	Nose	Left lapel	Right lapel	Chest
2	298	369	368	549
4	157	206	180	251
7	200	232	232	245
11	262	290	292	280
13	284	333	360	346
15	144	345	367	356
18	247	280	293	340
\bar{x}^A	227	294	299	338
s^B	61	60	73	104

^A \bar{x} : sample mean.^B s : sample standard deviation.

the gunners and the rollers, respectively. The trend that has been previously observed (lowest concentrations at the nose, followed by the left lapel, the right lapel, and the chest), held for both job classes. The breathing zone concentrations experienced by the rollers were higher than those of the gunners. The gunners' average breathing zone concentrations at the nose, left lapel, right lapel, and the chest were 60 percent, 74 percent, 69 percent, and 71 percent, respectively, of the same samples collected on the rollers. Styrene background air concentrations are presented in Table IV, with an average concentration of 16 mg/m³ ± 6 mg/m³.

TABLE III

Styrene breathing zone concentrations of the roller operators mg/m³

Sample no.	Nose	Left lapel	Right lapel	Chest
1	375	385	449	510
3	762	687	800	815
5	352	386	386	451
6	263	306	269	341
8	248	300	438	474
9	367	415	486	565
10	362	381	356	491
12	311	340	340	359
14	325	354	394	400
16	506	533	558	600
17	314	298	348	337
19	449	506	531	533
20	346	368	355	402
21	303	343	368	381
\bar{x}^A	377	400	434	475
s^B	130	108	132	129

^A \bar{x} : sample mean.^B s : sample standard deviation.

TABLE IV

Styrene background air concentrations

Sample location	mg/m ³ styrene
30 ft. away from upper mold	12
10 ft. away from upper mold	20
10 ft. away from upper mold	17
30 ft. away from lower mold	5
10 ft. away from lower mold	20
10 ft. away from lower mold	21
\bar{x} = sample mean	16
s = sample standard deviation	6.2

STATISTICAL EVALUATION

Styrene breathing zone air concentrations presented in Table I were evaluated by the randomized blocks experiment. The results of this evaluation indicated that styrene air concentrations at various locations within the breathing zone are not equivalent. Further, multiple comparison testing among the means of various breathing zone sample locations was conducted utilizing the Tukey test. The results of the Tukey test indicated that the average styrene air concentration measured at the nose is significantly different when compared to the average styrene air concentrations measured at each of the other three locations within the breathing zone.

The Randomized Block Analysis of Variance

Styrene breathing zone air concentrations presented in Table I were evaluated by the randomized blocks experiments, as presented in Brown and Hollander.⁽²¹⁾ In the randomized blocks experiment, Treatments [T] (i.e., styrene air concentration measurements) were obtained for different units or blocks [U] (i.e., workers exposed to styrene).

The sum of squares for treatments in randomized block design with k treatments and n blocks is:

$$\begin{aligned} SS(\text{treatment}) &= \sum [(T_i^2/n) - (T^2/nk)] \\ &= [(T_1^2 + T_2^2 \dots + T_k^2)/n] - [T^2/nk] \end{aligned}$$

Where T = T₁ + T₂ ... T_k; and in this case T₁ denotes the total (sum) for styrene air concentrations at the nose sample location. Similarly, T₂, T₃, and T₄ denote the total for styrene air concentrations at left lapel, right lapel, and the chest sample locations, respectively. The number of treatments (k) equals four corresponding to the four locations within the breathing zone. The number of blocks or workers (n) equals 21 corresponding to the number of workers who participated in this study.

The sum of squares for blocks is calculated in a parallel manner by obtaining the total (sum) of styrene air concentrations (U)

TABLE Va*
Analysis of variance of randomized blocks experiment

Source of variation	Sum of squares SS	Degree of freedom DF	Mean square
Sample location (treatment, T)	$\frac{\sum T_i^2}{n} - \frac{T^2}{nk}$	k - 1	$\frac{SS(\text{sample location})}{k - 1}$
Individuals (blocks, B)	$\frac{\sum U_j^2}{K} - \frac{T^2}{nk}$	n - 1	$\frac{SS(\text{individual})}{n - 1}$
Residual	SS(total) - SS(blocks) - SS(treatment)	(k - 1)(n - 1)	$\frac{SS(\text{residual})}{(k - 1)(n - 1)}$
Total	$\frac{\sum x^2 - T^2}{nk}$	nk - 1	

F Statistics:

$$F_T = \frac{MS(\text{sample location})}{MS(\text{residual})}$$

*The terms listed in the above table are explained in "The Randomized Block Analysis of Variance" section.

for each worker, and is given by:

$$\begin{aligned} SS(\text{blocks}) &= \sum [(U_j^2/k) - (T^2/nk)] \\ &= [(U_1 + U_2 \dots + U_n)/(k - T^2/nk)]; \end{aligned}$$

where U_1 is the total styrene air concentrations for worker number one ... etc., and again:

$$T = U_1 + U_2 \dots + U_n = T_1 + T_2 \dots + T_k$$

The total sum of squares is given by:

$$SS(\text{total}) = \sum (X^2 - T^2)/(nk);$$

where X^2 is obtained by squaring each styrene air concentration measurement and summing the nk squared values.

The sum of squares attributed to random variations within blocks, that is, not due to or explainable by differences among blocks or among treatments, can be obtained by subtraction. This sum of squares is called the sum of squares due to "error" or the sum of squares of the residuals:

$$SS(\text{residual}) = SS(\text{total}) - SS(\text{blocks}) - SS(\text{treatment})$$

The analysis of variance table of randomized blocks experiment is given in Table Va. The analysis of variance of the styrene breathing zone air concentrations data presented in Table I is given in Table Vb. The ANOVA Table Vb. yields a test of the omnibus hypothesis:

H_0 : The styrene air concentrations at various locations within the breathing zone are equivalent.

The test statistic is the ratio of the mean square for measurements

to the mean square for residuals:

$$F_T = \frac{MS(\text{treatments})}{MS(\text{residuals})}$$

The α level test rejects H_0 if $F_T \geq F_{\alpha, K-1, (K-1)(n-1)}$. Referring to F percentiles table, an $F_{.0005, 3, 60}$ value of 6.81 is obtained. The observed F_T value is 26.6, thus H_0 can be rejected at α values below .0005, that is the P value is less than .0005, therefore, there is strong evidence of differences of styrene air concentrations among various locations within the breathing zone.

Multiple Comparison Using the Tukey Test

Multiple comparison of styrene mean concentrations at the four locations of the breathing zone was conducted by the Tukey test as presented by Zar.⁽²²⁾ Because the randomized block analysis of variance rejects H_0 that styrene air concentrations at various locations within the breathing zone are equivalent, a multiple comparison test is called for to determine between which population (sample location) means differences exist. The first step in the analysis is to arrange and number all four sample means (from Table I) in order of increasing magnitude. Then pairwise

TABLE Vb
Analysis of variance for the data of Table I

Source of variation	SS	DF	MS	F
Sample location	116,493	3	38,831	26.2
Subject	1,194,583	20	59,729	
Residual	87,621	60	1,460	
Total	1,398,698	83		

TABLE VI
Multiple comparison test

Sample location:	<i>Nose</i>	<i>Left lapel</i>	<i>Right lapel</i>	<i>Chest</i>	
Ranked sample mean in mg/m ³ :	327	365	389	430	
Samples ranked by mean:	1	2	3	4	
SE = (S ² /n) ^{.5} = (1460/21) ^{.5} = 8.34					
The critical value of q _{.05,60,4} is found from q distribution tables ⁽²²⁾ = 3.74					
<i>Comparison of</i>					
<i>two locations</i>	<i>Differences</i>	<i>SE</i>	<i>q</i>	<i>q_{.05,60,4}</i>	<i>Conclusion</i>
4vs.1	103	8.34	12.35	3.74	Reject H ₀ :μ ₄ = μ ₁
4vs.2	65	8.34	7.79	3.74	Reject H ₀ :μ ₄ = μ ₂
4vs.3	41	8.34	4.92	3.74	Reject H ₀ :μ ₄ = μ ₃
3vs.2	24	8.34	2.88	3.74	Accept H ₀ :μ ₃ = μ ₂
3vs.1	62	8.34	7.43	3.74	Reject H ₀ :μ ₃ = μ ₁
2vs.1	38	8.34	4.56	3.74	Reject H ₀ :μ ₂ = μ ₁
<i>Overall Conclusion:</i>					
μ ₁ ≠ μ ₂ ≠ μ ₄ : mean styrene concentrations at nose ≠ mean concentration at left lapel ≠ mean concentrations at chest.					
μ ₁ ≠ μ ₃ : mean concentrations at nose ≠ mean concentrations at right lapel.					
μ ₂ = μ ₃ : mean concentrations at left lapel and right lapel are not significantly different.					

differences between the means, $\bar{X}_B - \bar{X}_A$, are tabulated. The test statistics is given by:

$$q = (\bar{X}_B - \bar{X}_A) / (SE);$$

where:

$$SE = (s^2/n)^{.5};$$

s² is the error (residual) mean square from the randomized block ANOVA presented in Table Vb, and equals: 1460; and n is the number of samples within each of the four groups and it equals 21.

If the calculated q value is equal to or greater than the critical value, q_{α,v,k} then the H₀:μ_B = μ_A is rejected. The critical value in this test is known as a "Studentized range," and it is dependent on α (the significance level), v (the error degrees of freedom for the ANOVA = 60), and k (total number of means being tested = 4). The results of the multiple comparison test are presented in Table VI, and it rejects the H₀ at P < .05, and shows that styrene mean air concentration at the nose is significantly different from the mean air concentration at the other three locations within the breathing zone.

OBSERVATIONS AND DISCUSSIONS

This research clearly demonstrated the existence of statistically significant variations within the breathing zone. On average, concentrations measured at nose for all workers (gunners and rollers) were 76 percent to 90 percent of those concentrations measured at the chest, right lapel, and left lapel, respectively. Average styrene breathing zone concentrations for the gunner

were 68 percent of the same concentration for the roller, that is, the roller experienced higher styrene air concentrations compared to the gunner. However, the extent of breathing zone concentration variations was different for each job class as average styrene air concentrations measured at the gunner's nose were 67 percent to 77 percent of those measured at the chest, right lapel, and left lapel, respectively. On the other hand, the average styrene air concentrations measured at the roller's nose were 79 percent to 94 percent of those measured at the chest, right lapel, and the left lapel, respectively. The worker's average styrene breathing zone concentrations and the extent of variation within that zone seemed to be related to the distance between the worker and the styrene source.

In addition to the confirmed breathing zone concentration variations, it was consistently observed that a clear correlation exists between the chest sampler and the nose sampler. In all 21 workers, the concentrations measured at the chest were consistently higher than those at the nose. Thus, the chest sampler is a good location because it helps to avoid biases due to right- or lefthandedness. Additionally, the chest sampler will provide a more conservative estimate of the worker inhalation exposure, so if it is biased, it will provide more protection to the worker.

In addition to these findings, limited investigation was conducted in the boat manufacturing plant while monitoring workers' exposure to styrene, to determine the factors that could control the breathing zone concentration variations. The following factors were identified as possible causes for the variations:

1. styrene general air concentrations,
2. changes in the ventilation rate,

3. the role of turbulent airflow in the breathing zone,
4. re-volatilization of styrene from work clothing, and
5. the distance between the styrene source and the breathing zone.

Styrene general air concentrations in the boat facility are presented in Table IV. Those concentrations are much lower compared to the workers' styrene exposure. Therefore, it is unlikely they will contribute significantly to the breathing zone variations.

Changing the ventilation rate might be a significant factor in this investigation. The average air velocity in the workers' breathing zone was between 60–80 ft/min. (0.3–0.4 m/s). The plant relies on general ventilation systems to remove airborne styrene away from the breathing zone. Changing the ventilation rate was not achievable without interfering with the production process. Therefore, further investigation of this factor was deferred. However, the ventilation pattern in the breathing zone was studied by visual techniques. A worker held a smoke tube in front of the lower mold to simulate a spray gun. The smoke visualization showed small swirls rotating slowly and emanating from the smoke tube toward the workers' breathing zone, indicating a turbulent airflow pattern in that zone. Actual polyester solution spraying was discontinued during smoke visualization due to the flammability of the resin solution.

An investigation of styrene re-volatilization from work clothing in the boat facility was not feasible due to the lack of a clean room and was deferred to future laboratory study.

The distance between styrene source and the workers was determined to be a controlling factor as evident by the breathing zone concentration for the spray gun operator and the roller operator. The styrene emission sources are the spray gun and the sprayed mold. However, for simplification purposes the spray gun was assumed to be the only styrene source for the gunner and the sprayed mold was assumed to be the only source of exposure to the roller. Each operator assumed a different posture with respect to the styrene source. The gunner was observed to hold the gun in an upright position away from his breathing zone but the roller had to lean over the mold to perform his task. In other words, the styrene source was closer to the roller than the gunner. Breathing zone concentrations presented in Tables II and III indicated that the gunners' breathing concentrations were about 68 percent of those of the rollers, which is consistent with an inverse relationship between the distance from the source and the breathing zone concentrations.

SUMMARY AND RECOMMENDATIONS

Breathing zone concentration variations must be expected in workplaces such as those of the reinforced plastic industry due to the presence of a strong directional emission source and turbulent airflow conditions. In this research breathing zone concentration variations were confirmed in the two job classes studied, the gunner and the roller.

The traditional industrial hygiene method of measuring breathing zone concentrations by placing a sample at the worker's lapel might not provide a true estimate of the worker's exposure. Correlation between concentrations measured at the left lapel and right lapel were not consistent due to the worker's orientation with respect to the emission source. On the other hand, it was observed that a clear correlation exists between the chest sampler and the nose sampler. Therefore, it is recommended that industrial hygiene samples should be placed at the worker's chest. The air concentrations measured at the worker's chest were consistently higher than those detected at the nose. Thus, the chest is a good location because it helps to avoid biases due to right- or lefthandedness.

Additionally, the chest sampler will provide a more conservative estimate of the worker inhalation exposure, so if it is biased, it will provide more protection to the worker. On the other hand, because the correlation between the chest and nose samplers is always consistent, then one can develop an empirical relationship between the two locations to estimate air concentrations at the nose for a given workplace.

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