

Monitoring of styrene exposure in the polyester industry

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GUILLEMIN, M. P., BAUER, D., HOTZ, P. A., LOB, M. and GREUTER, W. F. Monitoring of styrene exposure in the polyester industry. *Scand. j. work environ. & health* 4 (1978): suppl. 2, 14—21. Obtaining reliable results of exposure to styrene in field studies requires an appropriate methodology not only for analytical methods but also for the main strategy of conducting the surveys. This paper briefly describes how and why analytical methods for styrene in air, for its main metabolites in urine (mandelic and phenylglyoxylic acids) and for critical biological function tests were either chosen from the literature or adapted or developed to fit our criteria of convenience and reliability. In a second step of the preparation of field studies, experimental exposures to styrene were carried out on volunteers so that the best indicators of exposure could be determined and data could be obtained on the elimination kinetics of the urinary metabolites and the quantitative relationships between exposure and the urinary concentrations of mandelic and phenylglyoxylic acids. Finally field investigations, including air and biological monitoring, complete industrial hygiene surveys and medical examinations, have been organized and are being carried out in the Swiss polyester industry. Preliminary results concerning biological monitoring are given.

Key words: air monitoring, biological monitoring, field surveys, polyester industry, styrene.

Glass fiber reinforced styrene-polyester is used for many different products, such as containers, boats, swimming pools, car bodies and often special products difficult to produce mechanically. The work consists mainly of the manual application of resin and fiber glass. During the manufacturing, particularly during the handling of the styrene-containing resin and during tempering, exposure of workers can be significant.

Due to the possible extent of exposure and the question still unanswered regarding some aspects of toxicity and hazards,

it was decided to initiate a rather large investigation in the Swiss polyester industry. This field study has the following objectives:

1. Evaluation of styrene exposure in the polyester industry taking into account individual work practices, general ventilation and other important factors.
2. Setting up of a basis for future follow-up studies in the Swiss polyester industry.
3. Proposal of a suitable air and biological monitoring program (occupational hygiene and health) for the polyester industry.
4. Collection of epidemiologic data on possible dose-response relationships using selected biological exposure and function tests.

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Such a project must have a solid, scientific basis and must employ reliable analytical methods. In this paper the systematic approach, the analytical criteria, and the general strategy chosen have been described. First, we adapted and developed suitable analytical methods for air and biological monitoring to comply with our criteria (accuracy and precision, suitability for field use, automation, etc.). Second, we conducted human experimental exposures to obtain the pharmacokinetic information necessary for biological monitoring. Finally, after these preparatory experiments and with tested, reliable analytical methods at hand, we started the field-survey study.

PREFIELD-SURVEY PROGRAM

Development and testing of analytical methods

Air monitoring. Air monitoring allows eventual uptake by inhalation to be determined.

For styrene and occasionally for other pollutants usual methods were tested and sometimes used with slight modifications. Table 1 summarizes the type of sampling and the analytical methods that can be used for styrene. For continuous monitoring, a total hydrocarbon analyzer (flame ionization detector) cannot be used in field surveys due to the presence of other solvents (acetone especially), but it is quite convenient for monitoring the concentration in an exposure chamber.

The infrared analyzer may be used in field surveys, but the optical system may be damaged by the aerosol of polymerizing plastic, and precautions have to be taken. Styrene has a broad band of absorption at 254 nm, which is the mercury absorption wavelength, so mercury detectors can quite conveniently be used.

For spot samples a portable or at least a small gas chromatograph is useful and can be used with airtight syringes or gas sampling loops. Indicator tubes on the other hand give only rough semiquantitative information.

Biological monitoring. Biological monitoring allows the true total uptake to be determined or approximated independently of the route of entry. Styrene in breath or in blood can be analyzed by gas chromatography, but it represents only a very small fraction of the dose absorbed, which is a severe limitation for a good biological indicator. Breath analysis often gives erroneous results, mainly due to the difficulty in obtaining a reproducible and representative sample. Contamination of the sample by the dead space of the expiratory volume during exposure and adsorption of styrene on the mucous membrane of the trachea or throat (after exposure) are a few examples of difficulties which can be encountered when one tries to obtain a reliable sample (4). Technical problems also arise from the sampling device where adsorption or contamination may occur. Several apparatuses were developed, but none proved to be absolutely satisfactory. Carbon dioxide can be analyzed in each breath sample by gas chromatography or by infrared absorption and can be a very useful indicator of the representativity of the sample. Finally, physiological factors such as the modification of pulmonary ventilation when a mouthpiece is used may also play an important role. This will

Table 1. Sampling and analytical methods for the monitoring of styrene in air.

Sampling	Analytical method
Personal sampling pumps (sequential changes)	Slightly modified NIOSH ^a gas chromatographic method (9)
Sequential sampling at fixed locations	Slightly modified NIOSH gas chromatographic method (9)
Continuous monitoring	Infrared (gas cell with long optical path) Ultraviolet (portable mercury vapor analyzer)
Spot samples	Gas chromatography Indicator tubes

^a NIOSH=National Institute for Occupational Safety and Health.

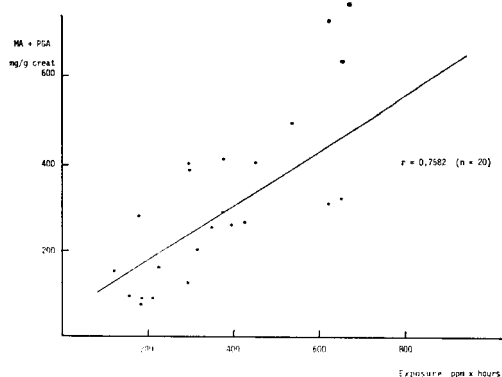


Fig. 2. Correlation between total concentration of the metabolites [mandelic acid (MA) + phenylglyoxylic acid (PGA)] in the "next morning" sample and the time-weighted average exposure to styrene. (Results from four different factories)

For all these technical, analytical and psychophysiological reasons this kind of monitoring was abandoned.

The analysis of styrene in blood was not retained either for the reasons already mentioned.

The urinary metabolites (mandelic acid + phenylglyoxylic acid) were analyzed in every urine sample of the volunteers, sometimes up to 4 d after exposure. Nine volunteers participated in 25 experimental exposures, and it was found (7) that the best sample to correlate with exposure was the "next morning" sample, in other words, the sample taken 14 h after exposure, at the beginning of the next workday. In all cases the sum of mandelic acid and phenylglyoxylic acid was a better index than either acid alone. However mandelic acid in the end of exposure (end of shift) sample was also found to be good, but probably much too sensitive to the last period of exposure.

Kinetic data. The study of the elimination of mandelic and phenylglyoxylic acids during and after exposure allows important information to be obtained, e.g., half-lives, probable accumulation during the week, ratio of mandelic acid/phenylglyoxylic acid at different times, etc. Fig. 1 shows the typical elimination curves of mandelic acid and phenylglyoxylic acid after different exposures. It is not possible

to evaluate the half-lives of these acids in industrial situations since the preceding exposure cannot be accounted for accurately enough.

Tentative biological threshold limit values. Finally, experimental exposures can serve as a basis for the estimation of tentative biological threshold limit values. The following values were tentatively proposed from the results obtained with the volunteers exposed at rest: concentrations of the metabolites mandelic acid and phenylglyoxylic acid in the next morning sample: 150 and 200 mg/g of creatinine, respectively (assumed pulmonary ventilation 6–7 l/mn).

These values for individuals at rest were estimated from the mean results obtained after a single exposure corrected for an assumed accumulation during the whole week (half-lives having been taken into account). Values corresponding to a certain type of work can simply be extrapolated from the mean corresponding pulmonary ventilation (1).

Biological function tests were not used during the human experimental exposures since they relate to long-term (chronic) effects.

It is clear that experimental exposures cannot answer a lot of questions concerning the kinetic evolution of styrene in real industrial conditions. They only help to propose hypotheses that have to be tested in the field.

FIELD INVESTIGATIONS

Plant visits were organized in the middle of the week, when the production was considered representative. The adopted program for the first part of the field investigations is the following.

Air monitoring

Each worker is asked to carry a personal sampler connected to a charcoal tube located close to his breathing zone. Four

tubes (2 in the morning, 2 in the afternoon) are used per worker.

Fixed sampling at different representative locations takes place in the same sequence (4 tubes per day).

Peak values are measured with air samples directly injected into a gas chromatograph and with indicator tubes.

Semicontinuous monitoring is run with a mercury vapor detector at different workplaces.

Selected air analyses such as total dust, fiber glass counting, acetone, peroxides, and amines are carried out episodically.

The activity of each worker is recorded and sometimes pictures or films complete the visual observation. This procedure is necessary for the recognition of situations in which percutaneous contact with styrene or acetone occurs.

Biological monitoring

We decided to use the following four different urine samples for the monitoring: (a) urine sampled before the shift, (b) urine sampled throughout the whole shift, (c) urine sampled at the end of the shift, and (d) urine sampled the next morning (before the next shift). Portions of all these urine samples are reduced with zinc immediately in the factory (transformation of the unstable phenylglyoxylic acid into the stable mandelic acid).

Industrial hygiene surveys

Temperature, pressure and relative humidity together with ventilation, air displacement, noise (if necessary), safety measures, personal hygiene, etc., are always recorded during the industrial hygiene survey. These determinations allow an overall assessment to be made of the situation and of the particular features of each plant visited.

Medical examination

Each subject is given a complete medical examination (medical and occupational history, physical examination, blood and urine analysis).

Field surveys are now in progress. Therefore only a few preliminary results can be given.

Fig. 2 shows the first results obtained for the correlation of air and biological monitoring. The concentrations of the metabolites in the next morning sample correlate better with exposure ($r = 0.758$ $N = 20$) than the concentrations in the end-of-shift sample ($r = 0.654$ $N = 25$), which confirms the experimental results (7).

For the qualitative evaluation of the skin contact with styrene, washing of fingers with ethanol and further analysis of styrene by gas chromatography has proved useful. Even after careful washing of the hands with soap and water, styrene may be extracted in ethanol; this result confirms (10) that styrene is stored in the skin (probably in subcutaneous fats) and that this route of entry is of concern. It also proves, as previously mentioned, that capillary blood samples cannot represent total exposure.

The biological function tests are, for the moment, not complete enough to be statistically validated and interpreted.

This combined industrial hygiene and medical survey will hopefully help to clarify the situation in the polyester industry and to evaluate the adequacy of the present threshold limit value. Possible influencing factors will probably also be demonstrated and help the future monitoring of such situations.

This article describes a general strategy for conducting occupational health studies which can be applied to solvents other than styrene. In our opinion all important exposures to solvents should be monitored in such a way in order to obtain the most reliable scientific bases for the prevention of adverse effects.

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QUESTIONS AND ANSWERS

Questions to Dr. GUILLEMIN

- Dr. RANTANEN: Have you detected half-times for mandelic acid in urine at various levels of exposure?
- Dr. GUILLEMIN: With human experimental single exposures we did not find a significant difference in the half-life for mandelic acid between "low exposure" (400 ppm × h) and high exposure (800 ppm × h). In field studies we calculated the "apparent" half-life from the "end-of-shift" sample and the next "morning" sample and could not find any difference, but the range of exposure was rather narrow (20—90 ppm, TWA concentrations).
- Prof. IKEDA: The proposal of using a mercury analyzer to detect styrene concentrations appears to be very interesting. Is there any possibility of interference by other coexisting materials?

- Dr. GUILLEMIN: Mercury vapor detectors use the 254 nm absorption band, and styrene shows a good absorption in this range. The other pollutants we encountered in the field surveys (polyester industry) such as acetone, peroxide, etc., did not interfere. Glass fibers and dust should be filtered so that they do not deposit themselves in the optical system.
- Mr. PASMAN: In estimating exposure of hand-laminating workers to styrene, I used to take "after shift" urine samples. In your opinion the urine samples of the next morning give a better correlation. To what extent am I wrong with my estimation?
- Dr. GUILLEMIN: Both experimental and field exposures have shown a better correlation between exposure (concentration $\times$ time) and urinary metabolite concentrations (mandelic acid + phenylglyoxylic acid) by using the "next morning" sample than by using mandelic acid in the "end-of-shift" sample, which is a good indicator of exposure, but we feel that it is too sensitive to the last period of exposure.
- Prof. ÅSTRAND: When dealing with easily soluble substances like styrene, the uptake in the body may vary considerably between rest and work conditions. It means that the product of exposure in ppm and exposure time in hours is not a good estimate of the uphold. We know that the uptake lies fairly stable around 60 % during a day's exposure. Therefore it is possible to get a reasonably good estimate of the uptake by measuring pulmonary ventilation and concentration in respiratory air.
- Dr. GUILLEMIN: I quite agree with that. I think the concept of expressing exposure in ppm $\times$ hours is valid for a whole workday period. It may be a poor index for short exposures at high levels. We assume that the relative uptake (% of concentration inhaled) is constant at any pulmonary ventilation rate, at least in the ranges studied; so the uptake factor does not affect the concept of ppm $\times$ hour. One important factor then is the alveolar ventilation rate. We recommend multiplying the metabolite concentrations indicated for individuals at rest (ventilation assumed to be 6—7 l/min) by the factor: ventilation corresponding to the work (activity) considered/ventilation at rest.
- Dr. SMITH: One of your slides had "REDUCED ON SPOT SITE" in relation to mandelic acid concentrations. Does this imply reduction of phenylglyoxylic acid back to mandelic acid before analysis? If so, what reducing agent did you use? (LiAlH_4 ? SnCl_2 ?)
- Dr. GUILLEMIN: Here is exactly how we proceed: The total volume of the urine sample is measured, as well as its specific gravity. Ten milliliters is sampled into a test tube, and 1.0 ml of 10 N H_2SO_4 is added (this will serve for the analysis of mandelic acid). Into another test tube, which contains 500 mg of zinc, 10.0 ml of urine is added, followed by 1.0 ml of 10 N H_2SO_4 (this will be analyzed for total mandelic acid, the initial mandelic acid and the mandelic acid coming from the reduction of phenylglyoxylic acid). A third sample (untreated urine) is taken for the analysis of creatinine and sometimes glucaric acid. Complete reduction of phenylglyoxylic acid to mandelic acid takes place in less than 30 min under the action of the native hydrogen (H°) produced by the reaction between zinc and sulfuric acid.