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THE FEASIBILITY OF USING AN AIR–PURIFIED RESPIRATOR AS AN INDUSTRIAL HYGIENE PERSONAL SAMPLING DEVICE*

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INTRODUCTION

The pulmonary air volume intake of an employee during an 8-hour working shift is influenced by many factors. A worker's age, sex, body mass, physical conditions, job, physical and mental demands, working environment, physical and chemical stresses, etc., can all affect respiration rate, and thus the total air volume intake. These factors suggest that workers exposed to identical concentrations of airborne contaminants may receive quite varied inhalation doses due to differences in pulmonary ventilation rates.[1] A healthy male individual's breathing rate can vary about 17 folds[2] from 6 l/min to 100 l/min. Traditional industrial hygiene practice has been to assume that the average worker consumes 10 m^3 of air during an 8-hour work period. Occupational dose has been estimated through known contaminant air concentration (e.g., eight hours time-weighted average concentration equals TWA8) and worker 8-hour air intake[3] (10 m^3). As a matter of fact, current occupational health standards are merely addressing certain time-weighted average worker breath-zone contaminant air concentrations; e.g., TWA8 permissible, short-term, and ceiling exposure limits.

This paper proposes that a more accurate and individualized inhalation dose can be estimated by fitting workers with air-purifying respirators equipped with an organic-vapor adsorption cartridge which functions as a collection media. The dose rate can then be calculated from the aliquot sample gas chromatograph (GC) analysis result. The dose rate is expressed as milligrams of organic-vapor uptake per kilogram of body weight per unit of time. This kind of expression for exposure is more accurate and more consistent with the concept of toxicological dose/response relationship from which the permissible exposure level was derived.[4]

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Some concerns that should be mentioned here are the pressure drop across a charcoal bed and the pulmonary dead space increase exerted on a respirator wearer; therefore, the total quantity of organic-vapor capture on the charcoal cartridge may require some correction for air volume intake loss.[5] Analysis of aliquot amounts of total charcoal obtained from a respirator could eliminate the problem of a large sample weight.

MATERIAL AND METHOD

Five male volunteers wearing fitted, half-face, air-purifying respirators with charcoal organic-vapor cartridges [Safety Products, American Optical Corporation, Southbridge, MA 01550; catalogue no. S4500; cartridge part no. R51A] were exposed to an air concentration of about 20 ppm of xylene vapor for 20 min. Respirators served as air samplers. Air contaminants were collected through a human breathing mechanism by moving air through respirator cartridges and trapping xylene vapor on the charcoal beds. The charcoal from two respirator cartridges (total weight about 100 g) was pooled together in a clean glass jar and mixed well before an aliquot amount was withdrawn for gas chromatography qualitative and quantitative analysis.

A breathing-zone air sample was also taken simultaneously from each individual during the experiment, using the conventional industrial hygiene pump and charcoal tube sampling method. The charcoal sample was desorbed by placing the aliquot weight charcoal granule into a screw-cap sample vial, with Teflon-lined septa (3.7 ml capacity). Two milliliters of methylene chloride were injected into the vial through septa using a precision HPLC syringe. The sample vial was shaken vigorously by hand for a minute and let set for 5 min. The supernatant of the extraction was withdrawn from the vial and injected into the GC without further preparation. A HNU Model 421 GC with a photoionization detector (HNU System Inc., Newton, MA) and a 10% SE–30 on 80/100 Supelcoport 8-ft stainless steel tube column (Supelco Inc., Bellefonte, PA) was used for xylene chemical analyses. Temperatures for GC oven, injector, and detector were 100°C, 150°C, and 150°C, respectively. All analyses included a blank sample at the beginning of the assay for checking the purity of the respirator cartridge charcoal and standard samples for GC response calibration curve.

RESULT AND DISCUSSION

The side-by-side results of these two sampling methods indicated that under a light workload (e.g., reading and writing in an office), the difference between these two estimated inhalation doses averaged about 19%. Although the difference between each pair of the five observations is quite moderate, it is still statistically significant at 95% confidence intervals using a student "t" test and treating these five sets of data as paired observations. The estimated doses from the conventional industrial hygiene method in most cases are slightly lower (see Table 1). Under a heavy workload (e.g., moderate exercise using exercise machines in a room), the difference between the two estimated doses is more drastic—significant at both the 95% and the 99% confidence intervals using the same statistical method mentioned above.

The conventional method is on the average about 161% underestimated (see Table 2). These results are probably expected, since—from a human physiology point of view—respiration rate will increase drastically when higher body oxygen demand is needed under heavy workload.[1,2] The rates of respiration increase are quite different among the tested subjects and are difficult to predict. Using a respirator as an industrial hygiene sampling device can automatically adjust for these variables, making it suitable for personal exposure sampling.

Using charcoal as an adsorption media for organic solvent vapor air sampling is a well-established technology.[6] Any place able to use a charcoal tube for industrial hygiene air sampling probably could also apply a respirator with charcoal cartridge for the same air sampling. Charcoal can adsorb from 5% to 55% of its weight, depending on the solvent's chemical and physical properties.[6] The equilibrium between the vapor and the charcoal adsorbent is practically instantaneous and should not be a problem in the flow rate in the range of human breathing.[6,7,8]

Respirators can exert inspiration and expiration resistance to the wearer. These resistances are directly proportional to the respiration rate. This means that as resistance increases, the worker has to breath harder to compensate for the increased resistance, so the worker may not be able to wear a respirator for long periods of time (> 40 min) under a very heavy workload.[5] This physiological limitation may hinder the indiscriminate application of the respirator as a personal sampling device in the workplace.

Most charcoal cartridges with 12–20 mesh charcoal granule size, testing at 85 l/min of air flow, have a resistance about 50 mm of water. This breath rate is equivalent to a work rate of about 1300 kg m/min—considered a very heavy workload.[7,8] Since the respiration air-flow rate and the associated cartridge resistances are all varied in a sinusoidal wave,[8] correcting for the total air volume intake loss during the respirator air sampling may be difficult. However, the human pulmonary function has tremendous reserve capacity; the total air volume intake loss should be negligible even at a relatively heavy workload. The loss may become significant only when the workload is extremely heavy and the respiration rate has reached its peak limitation. This situation is quite rare at normal workplaces.

CONCLUSIONS

The preliminary results indicate that it is highly feasible to use a charcoal cartridge air-purifying respirator as an industrial hygiene personal sampling device. This method can compensate for environmental and physiological variables not accounted for by traditional sampling methods. The sampling method—accompanied by a good company respirator program, including a quantitative fit test—will further guarantee the quality of the result.

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TABLE 1.

This experiment was carried out under light workload conditions.

Test Subject ID	**A**	**B**	**C**	**D**	**E**
Xylene air concentration breathing zone (mg/m^3)	47.43	33.15	42.89	53.85	4349
Total xylene found on two respirator cartridges (mg)	25.31	18.44	16.1	24.37	20.52
Respirator method estimated dose (mg/kg/hr)	1.093	0.717	0.473	0.977	0.707
Conventional method estimated dose (mg/kg/hr)	0.853	0.537	0.524	0.898	0.623
Difference of estimation (%)	128	134	90	109	113

TABLE 2.

This experiment was carried out under heavy workload conditions.

Test Subject ID	**A**	**B**	**C**	**D**
Xylene air concentration breathing zone (mg/m^3)	81.25	71.51	78.2	70.25
Total xylene found on two respirator cartridges (mg)	69.35	67.2	119.64	72.35
Respirator method estimated dose (mg/kg/hr)	2.997	2.613	3.516	2.493
Conventional method estimated dose (mg/kg/hr)	1.461	1.158	0.957	1.008
Difference of estimation (%)	205	226	367	247