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Validation of a radial diffusive sampler for measuring occupational exposure to 1,3-butadiene

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ABSTRACT

1,3-Butadiene (BD) is a major industrial chemical used in the manufacture of rubbers and latexes; it is also a ubiquitous environmental pollutant whose major source is traffic. Occupational exposure to (BD) can occur both during its production and during its use as a raw material. The objective of the study was the laboratory and field validation of a new diffusive sampler for BD. The nominal sampling rate of the Radiello® diffusive sampler filled with Carbopack X is 30.5 cm^3/min, at 0.177 mg/m^3, 20 °C and 50% relative humidity (RH), for an 8-h exposure time. A model can be used for calculating the sampling rate as a function of temperature, time and RH. The concentration does not affect the sampling rate above 30 μg/m^3. The measurement uncertainty ($k = 2$), calculated both by laboratory data and by field comparison according to International Standard Organization (ISO) 13752, satisfies the EN 482:2006 requirement for measurements between 0.1 and 0.5 times the threshold limit value—time weighted average (TLV–TWA) (uncertainty < 50%). For field validation study, 38 workers exposed to BD and 20 administrative employees, as the control group, underwent environmental and biological monitoring. Personal exposure to BD was measured by diffusive samplers (Radiello®) in comparison with active samplers. The BD exposure levels detected for the exposed subjects were low (mean 0.059, range <0.010–1.340 mg/m^3) but higher than the controls levels, all below 0.010 mg/m^3. The comparison between diffusive and active (pumped) air sampling showed a good correlation, with no systematic deviation from the ideal values of the intercept and slope of the optimized regression line. The concentrations of two biomarkers were also determined on urine samples, collected at the end of the work-shift: unchanged BD, by GC–MS, and the metabolite dihydroxybutylmercapturic acid (DHBMA), by HPLC–MS/MS. The urinary excretion of the biomarkers was on average higher in the exposed group (urinary BD: mean 8.8, range <1–48.1 ng/l; DHBMA: mean 0.232, range 0.016–0.572 mg/l) than in controls (urinary BD: mean 6.4, range 2.6–14.5 ng/l; DHBMA: mean 0.205, range 0.037–0.602 mg/l), but a statistically significant difference was achieved only for unchanged BD and not for DHBMA. In conclusion, the environmental monitoring measured by diffusive samplers (Radiello®) appears to be a reliable method for the assessment of exposure to low levels of airborne BD and a convenient alternative to the conventional active sampling.

1. Introduction

1,3-Butadiene (BD) is a major industrial chemical used in the manufacture of rubbers and latexes and as a raw material for nylon production. Occupational exposure to BD occurs during its production, its use as a chemical feedstock in the manufacture of other chemicals, during the use of such chemicals, and in a wide variety of miscellaneous processes involving petroleum refining, secondary lead smelting and wastewater treatment.

BD is also a ubiquitous environmental pollutant whose major source is traffic; another non-occupational source of BD exposure is the inhalation of cigarette smoke: in mainstream cigarette smoke, BD levels ranged from 16 to 75 μg/cigarette and in sidestream smoke from 205 to 361 μg/cigarette [1,2]. Long-term exposure of humans has been associated with a wide variety of toxic responses,

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including lymphohematopoietic cancers [3–8]. Several national organizations and agencies have classified BD as a carcinogen or probable carcinogen to humans and have established occupational exposure limits ranged between 1 and 2 ppm [9–13]. A recent paper measured hemoglobin adducts of BD epoxides as biomarkers of exposure and BD-induced DNA mutations as biomarkers of effect in mice, rats and occupationally exposed workers, concluding that BD induced cancer is related to the extent of BD metabolism to its epoxides and that rat is a more representative animal model to study human effects following BD exposure [14].

Inhalation is the main route of exposure: inhaled BD is partly eliminated unmetabolized in exhaled air or in urine, the remaining is metabolized through cytochrome P450-catalyzed oxidation processes to the hydroxy-metabolites and final conjugation with glutathione, leading to mercapturic acids, which are excreted in urine [2,15,16].The major BD-derived mercapturic acids are *R*,*S*-1-hydroxy-2-(*N*-acetylcysteinyl)-3-butene (monohydroxybutenyl-mercapturic acid) (MHBMA) and *R*,*S*-1,2-dihydroxy-4-(*N*-acetylcysteinyl)-butane [dihydroxybutyl-mercapturic acid (DHBMA)] [17,18]. The American Conference of the Governmental Industrial Hygienists (ACGIH) has proposed a biological exposure limit for DHBMA equal to 2.5 mg/l. Some authors have proposed the urinary BD as a biomarker to evaluate the BD exposure [19].

Nowadays the sampling step is affected by more error sources than the analytical step. Therefore, the availability of validated sampling devices is fundamental for a reliable exposure assessment. This study was aimed at the validation of a high-sensitivity and easy-to-use method for measuring the workplace airborne concentration of BD. A new diffusive sampler was validated in a laboratory study. In a following step the method was validated in field in parallel with a pumped method, for the measurement of workers' personal exposure to BD in a chemical plant. For completeness, the same workers were also requested to provide a urine sample at the end of the work-shift, on which biological monitoring was performed. The selected biomarkers were one metabolite, namely DHBMA, the biological indicator suggested by ACGIH, in order to verify the compliance with the ACGIH biological exposure index (BEI), and unmetabolized BD that proved to be significantly correlated with personal BD exposure [20].

2. Materials and methods

2.1. Diffusive sampler

The diffusive sampler developed for measuring BD in workplace air is the radial-symmetry sampler Radiello® (Fondazione Salvatore Maugeri—Centro di Ricerche Ambientali, Padua, Italy). The sorbent, a thermally desorbable graphitized carbon (Carbopack X, Supelco, Bellefonte, PA), is contained in a stainless steel net tube (3×8 μm mesh opening, 4.8 mm diameter). The net tube filled with the sorbent medium, which is referred to as the adsorbing cartridge, can be introduced into 1/4 in. stainless steel tubes provided with commercially available thermal desorbers.

For diffusive sampling, the adsorbing cartridge is inserted into the yellow porous polyethylene membrane (5 mm thickness). The Radiello® diffusive sampler (Fig. 1) is described elsewhere [21]; this sampler was already evaluated, both in laboratory and in field, for 7-day ambient air BD measurements [22,23]

2.2. Laboratory validation

The validation of a diffusive sampler involves the determination of the diffusive sampling rate (SR), that is the rate at which the sampler collects the target compounds by gaseous diffusion from the atmosphere. The Radiello® diffusive sampler for BD was validated according to the protocol of the European standard EN 838:1995 [24]. Briefly, the rather complex experimental procedure is aimed at assessing the performance of the device, by measuring SR under typical values of the environmental conditions and its variations in dependency of exposure concentration, time, temperature and relative humidity (RH).

Fig. 1. Radiello® diffusive sampler for 1,3-butadiene. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The experimental tests were performed in standard atmospheres, generated in a dynamic exposure chamber that allows the simultaneous exposure of up to 24 samplers at a time. The general description of the standard atmosphere generation system can be found elsewhere [21]. Depending on the target concentration in the exposure chamber, pure BD or a gaseous mixture in nitrogen were fed from a cylinder into a small mixing chamber and then, after dilution with air, into the main gaseous stream conveyed to the exposure chamber. All gaseous flow-rates were continuously measured by mass flow meters (Bronkhorst, Ruurlo, NL or Sierra Instruments, Monterey, CA).

Taking into account that BD is classified as carcinogenic for humans [9,11,12], we have decided to set the validation range well below the occupational exposure limit, which ACGIH sets at 2 ppm, equal to 4.42 mg/m^3 [10]. Therefore, the test concentrations ranged from 0.001 to 1.3 ppm (from 0.002 to 2.873 mg/m^3).

2.3. Field validation

The field validation study was carried out in a chemical plant (Polimeri Europa-ENI) in Ravenna (northern Italy), where BD was used. In this site the BD exposure was formerly measured by means of the method no. 56 of the Occupational Safety and Health Administration (OSHA) [25], which involves drawing air by a personal sampling pump through an adsorbing tube, extracting it by solvent and analysing it by gaschromatography. This method is called hereafter "active" as it relies on the forced movement of air, while the diffusive method does not and is therefore a "passive" method.

Sixty workers were enrolled for the study, of which 40 were employed in the production unit (exposed group), while 20 had administrative jobs (internal controls). The study included both environmental (active and diffusive) and biological (urinary BD and