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Influence of meteorological factors on the atmospheric mercury measurement by a novel passive sampler

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HIGHLIGHTS

- Impact of meteorological factors on a passive mercury sampler was identified.
- Correction factor for the sampling rate calculation was obtained.
- The passive sampler was applied in Beijing and Tibet to test its performance.

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ABSTRACT

In recent years, an incentive for developing simple and cost-effective samplers that are capable of monitoring over an extended period and require nonattendance at remote locations was obvious. Compared to traditional active sampling approaches, passive samplers require no electric power and are more flexible in field deployment, thus they are more appropriate for screening applications and long-term sampling. However, the performance of passive samplers may be influenced by meteorological factors, therefore inducing bias for the result of passive sampling. In this study, the effects of temperature, relative humidity, and wind speed on the performance of a novel passive sampler for gaseous mercury were investigated. The meteorological factors were well controlled in an exposure chamber. The passive samplers were tested in different conditions: temperature ranging from −10 to 35 °C, relative humidity ranging from 25 to 90%, wind speed ranging from 0.5 to 5.0 m s^{-1}. The results showed that temperature and relative humidity had no significant influence on the performance of the passive sampler. However, wind speed was found to have significant impact on the sampling rate of the passive sampler. Wind correction should be considered when making comparisons among samplings with different average wind speeds. In the field application in Beijing and Tibet site, the passively measured data were well correlated with the active measurements.

1. Introduction

Mercury is a global atmospheric pollutant and attracts increasing attentions due to its inverse impacts on human health. Mercury in atmosphere is typically measured as three fractions: gaseous elemental mercury (GEM), particulate-bound mercury (PBM) and gaseous oxidized mercury (GOM) (Lyman et al., 2010). GEM is the prevalent form in the atmosphere, consisting of >90% of the total mercury (Ebinghaus et al., 2002; Huang et al., 2014). Due to its volatility and chemical stability, GEM can circulate in the atmosphere for 1–2 years, allowing its wide dispersion and long-distance transportation (Fang et al., 2009). In order to understand the sources, trends, and potential influence of mercury to the environment, it is important to evaluate the temporal and spatial patterns of atmospheric mercury (Lyman et al., 2010). Traditional automated instruments for measurement of gaseous mercury rely on electric power, a large financial investment and continuous

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operating costs, and require attendance of trained technical staff (May et al., 2011; Pirrone et al., 2013; Huang et al., 2012). Therefore, the active sampling technology has difficulties in assessing atmospheric mercury in remote sites. Additionally, concerns regarding the accurate and precise measurements of atmospheric mercury using active sampling instruments have also been raised. For example, for the Tekran 1130/1135/2537 system, the GOM measurements using KCl-coated denuders have been recently reported to underestimate GOM concentrations by 2–4 times (Huang et al., 2014). The measurement of total gaseous mercury by the Tekran system depends on how the instrument is deployed (Huang et al., 2014; Gustin et al., 2013).

In response to the limitations of active sampling, there has been a growing interest in the use of passive samplers (May et al., 2011). Passive samplers, with the advantage of low-cost, simple to use, and requiring no power, are developed as a cost-effective alternative to active samplers. In field applications, passive samplers would usually need a sampling time of more than one week. This allows them to record a time-average trend of atmospheric mercury. In addition, because of the flexibility in field applications, passive samplers can cover a large spatial area with deployment of large quantities across a broad geographic region simultaneously (May et al., 2011). Passive techniques are working well for the monitoring of a number of persistent organic pollutants (Pirrone et al., 2013). Nevertheless, one major disadvantage of passive samplers reported by many studies is that the sampling rate of passive samplers would be affected by meteorological factors and thus a systematic bias is induced. According to previous studies, temperature, humidity, and wind speed were discovered to have impacts on sampling rate, especially wind speed (Gustin et al., 2011; Plaisance et al., 2004; Tuduri et al., 2006; Pozo et al., 2004; Seethapathy et al., 2008). Literature reported that wind speed may influence the effective diffusion path length (Fan et al., 2006). For tube-type passive samplers, it was reported that a length:diameter ratio of 2.5–3 is sufficient to overcome the effects of wind turbulence (Harper and Purnell, 1987). However, Plaisance et al. (2004) showed that the magnitude of wind effect is very high and the rule of length:diameter ratio of 2.5–3 is incorrect.

In order to identify the influence of meteorological factors on the performance of passive samplers, laboratory experiments with exposure chamber are used (Plaisance et al., 2004). Controlling the tested meteorological factor at the designed range, this approach can estimate the magnitude of the influencing factors and explore modifications of passive sampling technologies. In our previous study, a passive sampler for measurement of gaseous mercury in the atmosphere was developed (Zhang et al., 2012). In this study, the influence of temperature, humidity and wind speed on the performance of the passive sampler was investigated in an exposure chamber. The relationship between the meteorological factors and the sampling rate was studied, and the correction factor for the sampling rate calculation was obtained to improve the accuracy of the passive measurement. Application of the passive sampler was conducted in Beijing and Tibet to test its suitability and stability under various environmental conditions.

2. Materials and methods

2.1. The passive sampler

The passive sampler for gaseous elemental mercury consists of a diffusion tube, a rain shield and an adsorption carrier with a mesh screen (pore size of 75 μm). The mesh screen was used to further reduce the face air velocity effects and minimize the entrapment of large aerosol particles, however, diffusion of fine particles such as PM2.5 cannot be prevented. The cylindrical shelter is designed to reduce the turbulence of external air, and it is sealed with the rain shield on the top of the diffusion tube. It has 24 evenly distributed 5-mm diameter openings at its bottom for air exposure. The mesh screen of the adsorption carrier was designed to reduce the influence of deposition of the particulate matters in the air. The material carrier was fixed at the ceiling of the tube with pulverized sulfur-impregnated carbon (Calgon Carbon Corporation) in it with the size of 250–380 μm as adsorption material. The more specific configuration of the passive sampler is described in our previous paper (Zhang et al., 2012).

2.2. Exposure chamber experiment

In the laboratory experiments, an exposure chamber was used to investigate the impacts of meteorological factors (humidity, temperature, and wind speed) on the sampling rate of the passive sampler. The schematic of the exposure chamber is presented in Fig. 1. In the exposure chamber, the level of the meteorological parameters can be preciously controlled: temperature (−20 °C–50 °C, 0.1 °C), relative humidity (10%–90%, 1%), wind speed (0 m s^{-1}–5 m s^{-1}, 0.1 m s^{-1}). A series of laboratory experiments with the combination of the three meteorological parameters at different levels were carefully designed, and summarized in Table 1. The range of the parameters was set according to the common values of the natural environment. For example, the environmental relative humidity usually ranges from 30% to 90%. Thus, the impact of relative humidity the performance of the passive sampler was investigated in four batches ranging from 25% to 90%, and in each batch, the temperature was controlled at 25 °C and the wind speed was set at 0.5 m s^{-1}. Similarly, according to the common range of temperature in the environment, the impact of temperature was studied in five levels ranging from −10 °C to 35 °C in five experiment batches respectively. In each batch, the level of relative humidity and wind speed was controlled at 25% and 2.0 m s^{-1}, respectively. In previous studies, wind speed was suggested as a very possible meteorological factor affecting the sampling rate of diffusive passive samplers (Gustin et al., 2011; Zhang et al., 2012; Seethapathy et al., 2008; Fan et al., 2006). Therefore, in this study, the impact of wind speed was investigated ranging from 0.1 to 5.0 m s^{-1}. In each experiment for wind speed, the level of relative humidity and temperature was set at 35% and 25 °C respectively.

In each batch of experiment, five passive samplers were deployed in the chamber as replicates (the distance between samplers was approximately 8 cm). The mass of the adsorption material (sulfur-impregnated carbon) in each sampler was 0.946 ± 0.049 g (Mean ± SD). The deployment lasted 8 days for each batch. The mercury concentration within the exposure chamber

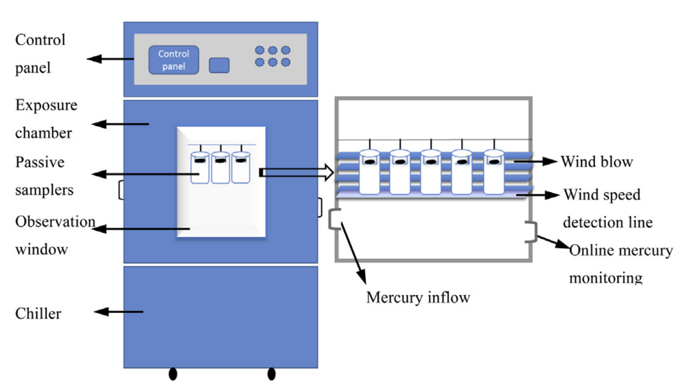

Fig. 1. Schematic of the exposure chamber.