

# A Passive Sampler with Improved Performance for Collecting Gaseous and Particulate Phase Polycyclic Aromatic Hydrocarbons in Air

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A passive sampler which can be used to collect both gaseous and particulate phase polycyclic aromatic hydrocarbons (PAHs) in air was previously developed and calibrated. The sampler was successfully used in a field study in North China Plain. However, the relatively low uptake rate for particulate phase PAHs prevented it from being applied in nonseverely contaminated environment. The sampler was redesigned to increase the uptake rate for particulate phase PAHs and calibrated in the field for individual PAH compounds of various molecular sizes. The effect of a fine-screen-mesh wrapping on the performance of the sampler was tested. It was found that the sampling efficiencies of the sampler for various PAH compounds were different depending on their molecular weights. For particulate phase PAHs, the uptake rates for high molecular weight compounds, which are favorably associated with fine particles, were generally lower than those for low molecular weight ones. Two calibration equations with molecular weight as an independent variable were developed to predict the ambient air concentrations of gaseous and particulate phase PAHs based on the results of the passive sampling. The uptake rates of the sampler were different for various PAH compounds. On average, the uptake rates of the sampler for gaseous and particulate phase PAHs were  $0.38 \pm 0.51$  m<sup>3</sup>/d and  $0.61 \pm 1.41$  m<sup>3</sup>/d, respectively. The latter was 2 orders of magnitude higher than the old model. The sampler was less efficient than active sampler for collecting fine particles in the air and such bias in sampled size distribution can be moderated by a fine-screen-mesh wrapping. However, the wrapping could also reduce the sampling efficiency.

## Introduction

Polycyclic aromatic hydrocarbons (PAHs) are among the categories of air pollutants that cause the most public concern in China. The emission of PAHs in China contributed to over 20% of the global total (1) and high PAH concentrations were often detected in various environmental media including air. For example, it was found that in Tianjin, a typical northern Chinese city, the entire population in the urban area exposed to a level of annual mean benzo[a]pyrene equivalent concentration exceeded the national ambient air quality standard of 10 ng/m<sup>3</sup> (2), which is 1 order of magnitude higher than the World Health Organisation (WHO) recommended guideline of 1 ng/m<sup>3</sup> (3). Similar or even higher levels of atmospheric PAHs were observed in many cities in China and other developing countries (4–6). Based on an extensive survey in North China Plain, it was reported that the atmospheric PAH pollution in rural villages in winter was as severe as that in urban area due to biofuel and coal combustion for heating (7).

Active samplers are widely used for monitoring PAHs and other semivolatile organic pollutants in air. Both gaseous and particulate phase PAHs can be collected. However, deployment of active sampler is not always convenient or feasible due to power and facility constraints. Moreover, long-term large-area monitoring using an active sampler is labor and time-consuming. Therefore, for a large-scale air quality investigation, use of a passive sampler is an attractive alternative which has been applied in a number of cases (8–11).

In a previous study, a passive sampler for collecting both gaseous and particulate phase PAHs simultaneously was developed and calibrated in our laboratory (12). The sampler (hereafter referred as PAS-GP-I) was successfully applied to study the seasonal and spatial distributions of gaseous and particulate phase PAHs in North China Plain (7). Although the PAS-GP-I can collect both gaseous and particulate phase PAHs, the average uptake rates were as low as  $0.10 \pm 0.014$  m<sup>3</sup>/d and  $0.007 \pm 0.001$  m<sup>3</sup>/d for gaseous and particulate phase PAHs, respectively, compared with 3–4 m<sup>3</sup>/d for gaseous phase pollutants of the conventionally used ones (10). For the field study in North China Plain covering 3 million km<sup>2</sup> in area and lasting for four seasons, meaningful information was obtained at such low uptake rates due to heavy pollution (7). However, in the places with relatively low contamination level of PAHs, the quantity of a sample collected by the sampler may not be enough for any accurate analysis. In fact, an effort for monitoring indoor PAH levels in the urban area of Beijing in summer using the PAS-GP-I sampler failed primarily because of the low sampling rate. Similarly, the sampler was tested without success in Pohang, Korea, where levels of PAHs in the ambient air were at least 1 order of magnitude lower than those in northern China, and the majority of particulate phase PAHs collected were lower than the detection limits.

To apply the passive sampling technique for collecting both gaseous and particulate phase PAHs in a variety of environments including the low-level background sites, the passive sampler was redesigned. The main objective of the new design was to improve the performance of the new sampler by increasing its sampling efficiency for particulate phase PAHs. The sampler was calibrated against active samplers in the field. The difference in uptake rate for various PAH compounds, size distribution of air particles collected by the passive sampler, and the effect of a fine-screen-mesh on the performance of the sampler were evaluated.

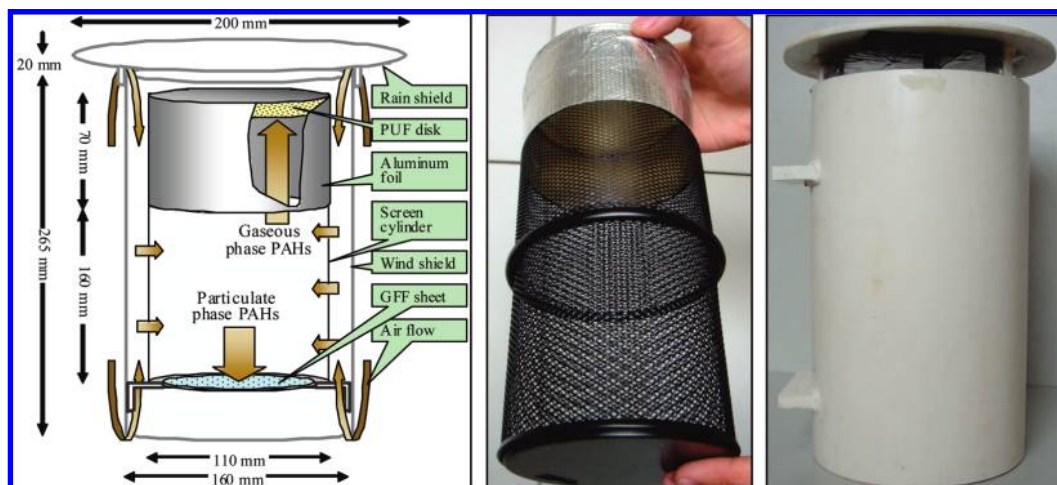
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**FIGURE 1.** Design of the PAS-GP-II passive sampler with a PUF disk and a GFF as the sampling media for collecting gaseous and particulate phase PAHs, respectively. The two photos are the assembled inside cylinder and the wind-rain shield, respectively.

## Materials and Methods

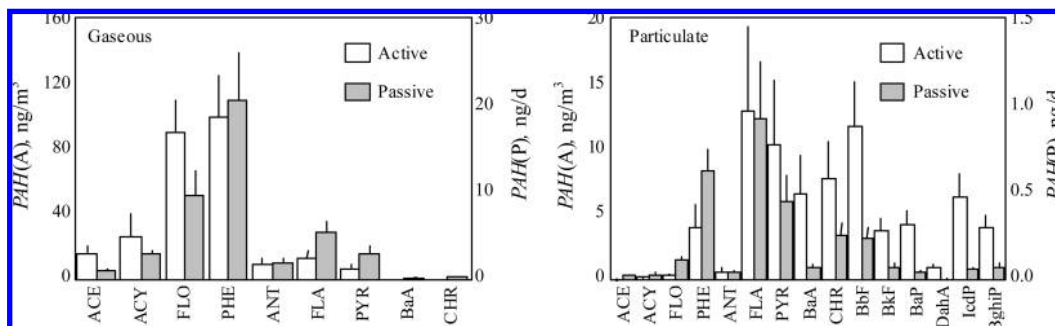
**Design of the Sampler.** The new design of the passive sampler (PAS-GP-II), aiming to increase the sampling efficiency for particulate phase PAHs, is shown in Figure 1 (more photos are provided in the Supporting Information). A polyurethane foam (PUF) disk (110 mm diameter  $\times$  15 mm thick, density 0.024 g/cm<sup>3</sup>) and a glass fiber filter (GFF, 110 mm diameter) were used as sampling media for gaseous and particulate phase PAHs, respectively. The sampling media were fixed in a metal cylinder (110 mm diameter  $\times$  230 mm length) with a mesh side face (2 mm aperture size). The upper part (70 mm) of the side face of the cylinder was sealed with aluminum foil to reduce the possibility of trapping fine particles by the PUF disk. The PUF disk was mounted to the ceiling of the cylinder while the GFF was laid at the bottom. The PUF disks were previously extracted by Soxhlet with dichloromethane, acetone and *n*-hexane sequentially for 12 h each reagent. The GFFs were preconditioned by heating in a furnace at 450 °C for 4 h. Direct air flow through the sampler, strong turbulence within the device and possible effect of wet precipitation were minimized by a wind shield (cylinder, 160 mm diameter  $\times$  265 mm length) and a rain shield (disk, 200 mm diameter) made of polyethylene. The inside of the wind shield and the bottom side of the rain shield were fully covered by aluminum foil. The samplers were assembled and disassembled on site while the sampling media were transported in sealed bags. Such a design was less encapsulated than the design of the PAS-GP-I and higher sample efficiency was thus expected.

**Field Calibration.** Four sites with very different levels of air pollution were selected for sampler calibration. They were an urban site in a large city (Peking University, Beijing), two rural sites in villages (Donghe, a village on Haihe Plain and Gubeikou, a village in mountain area of Hebei) and a background site in a national park (Xiaolongmen in Dongling mountain area of west Beijing). At each site, two PAS-GP-II passive samplers, two low-volume active samplers (GFF of 22 mm OD and PUF plug of 22 mm OD  $\times$  76 mm, 0.8~0.9 m<sup>3</sup>/min, TMP-1500, Jiangsu Eltong Electric Co., Ltd., China) and one high-volume sampler (GFF of 200  $\times$  250 mm<sup>2</sup>, 1.05 m<sup>3</sup>/min, KC-1000, Qingdao Laoshan Co., China) were deployed. Both gaseous and particulate phase PAHs were collected by the passive samplers for four seasons from 2007 summer to 2008 spring. For each season, integrated 24 h active samples were collected twice using the high-volume and the low-volume samplers for particulate and gaseous phase PAHs, respectively. Detailed information on the sampling locations and scheme are provided in the Supporting Information. After harvesting, all PUF plugs, PUF

disks and GFFs (only those from the high-volume sampler) were stored at -18 °C. PAHs of these samples were measured for calibration of the passive sampler. GFFs from the high-volume samplers were equilibrated in a desiccator (25 °C) for 24 h and weighed both before and after the sampling.

**Testing the Effect of Fine-Screen-Mesh.** The aperture size of the inside mesh cylinder was 2.0 mm. A set of experiments were conducted to evaluate the effect of fine-screen-mesh on the performance of the sampler. A total of 16 samplers were deployed on the outdoor platform at the sixth floor of the New Geoscience Building at Peking University for 50 days from April 28th to July 16th, 2007. The inside cylinder of 12 samplers were wrapped with stainless steel fine-screen-mesh of 20, 80, and 300 mesh, respectively. Among four samplers of each setting (without or with the fine-screen-mesh of various meshes), two were used for particulate size measurement and another two were used for PAHs and particulate quantity determination. Two duplicate glass slides (26  $\times$  76 mm<sup>2</sup> each) with vaseline-coating were set on the top of the GFF of each sampler for particulate size measurement. During the passive sampling period, samples were also collected actively for comparison. Duplicate 24 h active samples were collected three times in May 11, May 26, and June 17, 2007 using two low-volume air samplers (GFF of 22 mm o.d. and PUF plug of 22 mm o.d.  $\times$  76 mm, 0.8~0.9 m<sup>3</sup>/min, TMP-1500, Jiangsu Eltong Electric Co., Ltd., China). The samples were used to determine PAHs and the total mass of particulates. The sampling media were pretreated in the same way as those used for field validation. Together with the low-volume active sampling, size-fractionated airborne particulates were collected for 24 h using a low-pressure cascade impactor with a flow rate of 28.3 L/min (FA-3, Kangjie Co., China). The nine stage equivalent cutoff diameters at 50% efficiency were <0.43, 0.43~0.65, 0.65~1.1, 1.1~2.1, 2.1~3.3, 3.3~4.7, 4.7~5.8, 5.8~9.0, and 9.0~10.0  $\mu$ m, respectively. The samples of the nine stages were combined and measured for size distribution together with the passively collected particulates on the glass slides using a duel-channel particle size and shape analyzer (CIS-50, Ankersmid, Netherlands). The measurements were performed at video channel (ACM-4A cell or ACM10 cell, visual channel, lens A, range 0.1–150 mm, pixel resolution of 0.7 mm (13).

**Sample Extraction, Clean-up, and Analysis.** The same procedure used in our laboratory before was applied (12). In brief, the PUF disks and plugs were extracted by Soxhlet with a 1:1 mixture of *n*-hexane and cyclohexane for 4 h and the GFFs were extracted by Soxhlet using the same solvent mixture for 10 h. The extract was concentrated to 1 mL and



**FIGURE 2. Comparison in PAH composition profiles between the passive and active samples. Means and standard errors are shown based on the data collected at the four sites in the four seasons.**

solvent exchanged to *n*-hexane and purified on an alumina/silica column packed, from the bottom to top, with neutral silica gel (10 cm, 3% deactivated), neutral alumina (6 cm, 3% deactivated), and anhydrous sodium sulfate (1 cm). The silica gel, alumina and anhydrous sodium sulfate were baked at 450 °C for 4 h prior to use. The column was eluted with 50 mL of dichloromethane/hexane (2:3) at a rate of 2 mL/min to yield the PAHs fraction. The elute was concentrated on the rotary evaporator at below 38 °C to approximate 1 mL.

All samples were analyzed on a gas chromatograph (Agilent 6890) connected to a mass selective detector (MSD, Agilent 5973) and a 30 m HP-5MS capillary column. The column was programmed from 60 to 280 °C at 6 °C/min and then held isothermal for 20 min. The MSD was operated in electron impact mode at 70 eV, and the ion source temperature was 280 °C. The mass spectra were recorded using selected ion monitoring mode. Quantification was conducted by the internal standards of 2-fluoro-1,1'-biphenyl and *p*-terphenyl-*d*<sub>14</sub> (2.0 µg/mL, J&K Chemical, U.S.). Sixteen parent PAHs included in this study were naphthalene (NAP), acenaphthylene (ACY), acenaphthene (ACE), fluorene (FLO), phenanthrene (PHE), anthracene (ANT), fluoranthene (FLA), pyrene (PYR), benz[a]anthracene (BaA), chrysene (CHR), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), dibenz[a,h]anthracene (DahA), benzo[g,h,i]perylene (BghiP), and indeno[1,2,3-cd]pyrene (IcdP). The quantities of particulates were measured gravimetrically.

**Quality Control.** All the passive air sampling media were deployed and measured in duplicate to check for reproducibility. The average coefficients of variation of the duplicate samples were 18% (6~31%) for 13 PAHs from NAP to BaP sampled by the PUF disk, and 25% (3~44%) for all PAHs by the GFF. The measured analytical procedure blanks were generally more than 1 order of magnitude lower than the sample measurements. All of the results were blank corrected using arithmetic means of all procedure blanks. The method detection limits were 0.85 (NAP) ~ 6.8 (BghiP) ng/mL. Method recoveries were determined by spiking the sampling media with a working standard (the standard mixture of 16 PAHs from PH-10JM, Chem Service Inc., U.S.). For the 16 spiked individual PAHs, the recoveries from NAP to BghiP were from 66 to 114% for the PUF disk and from 60 to 115% for the GFF. Twenty percent of the samples were spiked with a range of deuterated PAHs (NAP-*d*<sub>8</sub>, ANE-*d*<sub>10</sub>, ACE-*d*<sub>10</sub>, ANT-*d*<sub>10</sub>, CHR-*d*<sub>12</sub>, and Perelyne-*d*<sub>12</sub>) to monitor the extraction and cleanup procedures. The recoveries for the deuterated PAHs were from 65 to 113% for the PUF disk and 89 to 112% for the GFF. All solvents used were analytical grade from Beijing Reagent, China and were purified by distillation. All glassware was cleaned using an ultrasonic cleaner (Kunshan KQ-500B) and heated to 400 °C for 6 h.

## Results and Discussion

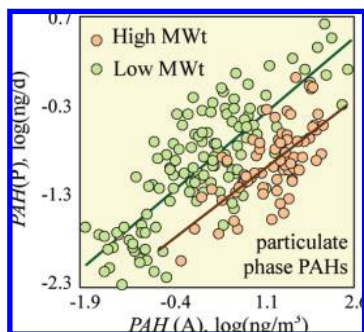
**Composition of the field sampled PAHs.** In practice, 16 PAHs on the U.S. Environmental Protection Agency priority pol-

lutant list, or 15 PAHs without NAP, are often measured simultaneously. All compounds in both gaseous and particulate phases are assumed to be fully collected by the active sampler. However, the sampling efficiencies of a passive sampler for individual PAH compounds depend primarily on their partition between gaseous and particulate phases and their diffusion and precipitation behaviors in the sampler. These behaviors are primarily associated with physicochemical properties of the sampled PAH compounds, which are often different drastically. For example, the vapor pressures of the 16 PAHs at room temperature varied 9~10 orders of magnitude (14). Therefore, the low molecular weight PAHs were predominately in gaseous phase, whereas the high molecular weight PAHs were mainly associated to particulates (15, 16). Consequently, the PAH composition profiles of gaseous and particulate phases in the atmosphere were considerably dissimilar. In Figure 2, the PAH composition profiles actively and passively sampled in this study, as PAH(A) and PAH(P), respectively, are compared and the results are presented as means and standard errors for data collected at the four sites in the four seasons. For gaseous phase, only nine compounds were presented because the other seven high molecular weight compounds were predominately sorbed on airborne particles (15, 16) and had relatively low detectable amounts.

In general, the measured composition profiles of both active and passive samples agree with those reported for the same area in the literature (12, 17). The similarities between the passive and active samples as well as the dissimilarities between the gaseous and particulate phases are demonstrated. Still, detailed differences between the active and the passive samples can be seen. For the gaseous phase PAHs, the relative sampling efficiencies of the passive sampler for the two-ring compounds were relatively lower than those of the active sampler. It is likely that turbulence diffusion rather than molecular diffusion dominated the process of the passive sampling media catching gaseous phase PAHs, otherwise, the lower molecular weight compounds would have more chance to be adsorbed (18). A very similar pattern was found when PAS-GP-I was tested (12). The difference in the composition of particulate phase PAHs between the active and passive samples was more significant than that of gaseous phase PAHs. It appears that the passive sampler collected high molecular weight particulate phase PAHs less efficiently than the active sampler. Such a difference is illustrated in Figure 3 in which the passively measured individual compounds (PAH(P)) are plotted against the actively measured ones (PAH(A)) for the four sites and the four seasons. Low (128~202) and high (228~276) molecular weight PAHs are shown in different colors, indicating apparent difference between them.

Significant correlations ( $p < 0.001$ ) of the log-transformed measurements between the active and passive samples are revealed for both low ( $r = 0.809$ ) and high ( $r = 0.665$ ) molecular weight PAHs. This is also the case for the previously





**FIGURE 3.** The relationship between the actively and passively sampled particulate phase PAHs in the field at the four sites for the four seasons. The results are log-transformed and the high (orange, MWt 228~276) and low (green, MWt 128~202) molecular weight compounds are marked in different colors.

used passive sampler (PAS-GP-I) (12). One reasonable explanation for the different sampling efficiencies between the high and low molecular weight PAHs is that the sampling media (GFF) of the passive sampler for particulate phase PAHs depended on free precipitation of particles and can catch coarse particles more effectively than catching fine ones, while the high molecular weight PAHs were preferred to associate with fine particles (19). Such a size distribution dependence is to be further addressed in this paper.

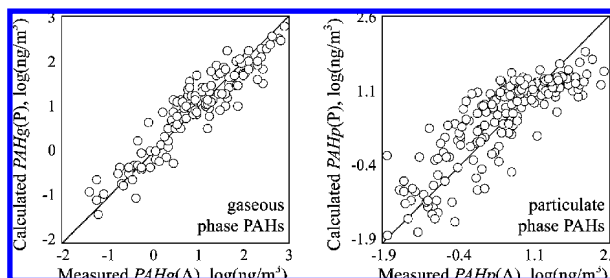
**Calibration of the Passive Sampler.** Based on the measured gaseous and particulate phase PAHs using both passive and active samplers, the passive sampling media for gaseous and particulate phase PAHs were calibrated individually. As discussed in the previous section, a general linear correlation between the passively and the actively sampled gaseous phase PAHs and the dependence of the sampling efficiency on the molecular size were observed. Accordingly, a regression model was developed to predict the log-transformed gaseous phase concentration of an individual PAH in air ( $\log\text{PAH}_g(\text{A})$ ,  $\text{ng}/\text{m}^3$ ) based on the total quantity of the gaseous PAH measured using the passive sampler ( $\log\text{PAH}_g(\text{P})$ ,  $\text{ng}/\text{d}$ ) and the molecular weight of the particular compound (MWt).

$$\log\text{PAH}_g(\text{A}) = 0.7676 \log\text{PAH}_g(\text{P}) - 2.167 \times 10^{-9} \text{MWt}^{3.776} + 1.6202, \quad r^2 = 0.878.$$

The passive sampler was also calibrated against the active sampler for particulate phase PAHs. Unlike gaseous phase PAHs, the relationship between the active and passive sampling methods could not be characterized by a simple linear function, even with a log-transformation. Instead, a nonlinear least-squares fitted calibration equation was developed to predict the particulate phase concentration of an individual PAH in air ( $\text{PAH}_p(\text{A})$ ,  $\text{ng}/\text{m}^3$ ) with two dependent variables of the measurement by the passive sampling method ( $\text{PAH}_p(\text{P})$ ,  $\text{ng}/\text{d}$ ) and molecular weight of the PAH (MWt).

$$\text{PAH}_p(\text{A}) = \frac{\text{PAH}_p(\text{P})}{e^{3.701 - 0.0314 \text{MWt}}}, \quad r^2 = 0.877.$$

For both gaseous and particulate phase PAHs, the models accounted for approximately 88% of the variations in the measurement. The nonaccountable variation (12%) can be explained by the following reasons: the active samples were only collected for eight individual days during the year, while PAH concentrations varied considerably day by day (20). Meantime, the passive samplers were continuously exposed for months. Figure 4 presents the relationship between the directly observed PAH concentrations using the active samplers and the predicted PAH concentrations based on the results of the passive sampling for both gaseous (left



**FIGURE 4.** Comparison between the observed (active samplers) and predicted (passive samplers) concentrations of gaseous (left panel) and particulate (right panel) phase PAHs in air.

panel) and particulate (right panel) phase PAHs, indicating a satisfactory prediction, particularly for gaseous phase PAHs.

A ratio between the passively ( $\text{ng}/\text{d}$ ) and actively ( $\text{ng}/\text{m}^3$ ) measured individual PAHs was often defined as uptake rate ( $\text{m}^3/\text{d}$ ) of a passive sampler (10). The uptake rate for a particular PAH is constant if only the amount of the PAH collected by a passive sampler is linearly proportional to the concentration in the air (or actively collected) in a given concentration range. However, in case of PAS-GP-II sampler, the calibration equations suggested that the sampling efficiencies for both gaseous and particulate phase PAHs depended on both the concentration (log-transformed) and molecular weight of the PAH. Therefore, only average uptake rates of the passive samplers could be calculated for given concentration ranges based on the measurements at the four sites for the four seasons. With all detected PAHs included, the calculated average uptake rates were  $0.38 \pm 0.51 \text{ m}^3/\text{d}$  and  $0.61 \pm 1.41 \text{ m}^3/\text{d}$  for gaseous and particulate phase PAHs, respectively. In comparison, the uptake rates of the previously developed PAS-GP-I, based on the results of an indoor calibration, were  $0.10 \pm 0.014 \text{ m}^3/\text{d}$  and  $0.007 \pm 0.001 \text{ m}^3/\text{d}$  for gaseous and particulate phase PAHs, respectively (12). It appears that the uptake rate of the PAS-GP-II was approximately 4 times of that of the previous model for gaseous phase PAHs and was almost 2 orders of magnitude higher than that of the PAS-GP-I for particulate phase PAHs. Although the uptake rates were still lower than those of the other types of passive samplers reported in the literature ( $3\sim4 \text{ m}^3/\text{d}$ ) (8–10) and the uptake rates for low molecular weight gaseous phase PAHs and for high molecular weight particulate phase PAHs were much lower than the mean values (Figure 5), simultaneous collection of both gaseous and particulate phase PAHs allowed it to be an attractive alternative for monitoring semivolatile pollutants, such as PAHs, in air.

Such an improvement in uptake rate is critical in practice. In this study, particulate phase PAHs were detectable for almost all compounds in all seasons at a control site in Xiaolongmen where the average total concentrations of 16 particulate phase PAHs were as low as  $3.6 \pm 2.0 \text{ ng}/\text{m}^3$ ,  $3.5 \pm 1.2 \text{ ng}/\text{m}^3$ ,  $4.4 \pm 1.3 \text{ ng}/\text{m}^3$ , and  $0.79 \pm 0.48 \text{ ng}/\text{m}^3$  for fall, winter, spring, and summer, respectively, compared with the annual mean concentrations of  $267 \pm 161 \text{ ng}/\text{m}^3$  for the entire North China Plain (21). An attempt for monitoring indoor air PAHs in Beijing urban area in summer using PAS-GP-I conducted by our laboratory failed to obtain meaningful information on particulate phase PAHs because of the relatively low uptake rate. The improvement allows the PAS-GP-II to be used in indoor environment. In fact, the sampler was tested indoor in an apartment in Beijing suburban area, and 12 PAH compounds in particulate phase were detected for a relatively short sampling period of 30 days.

**Size Distribution of the Collected Particulates.** Accumulative size distributions of the particles sampled actively (cascade impactor) or passively with or without the fine-screen-mesh are presented in Figure 6. It appears that the

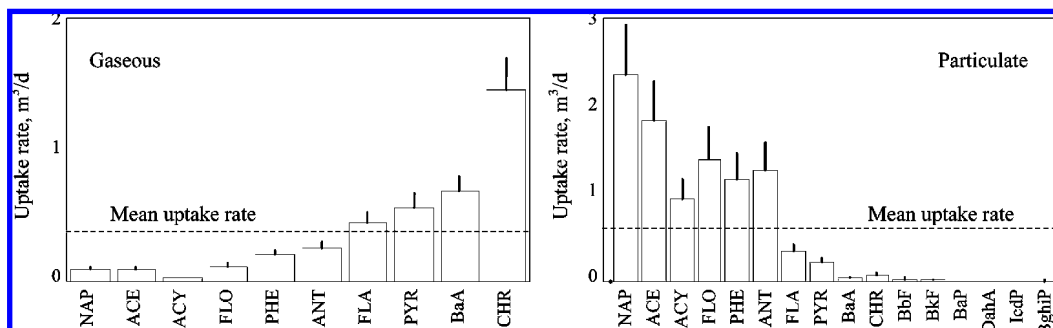


FIGURE 5. Difference in uptake rates of the PAS-GP-II passive sampler for various PAH compounds in gaseous (left panel) and particulate (right panel) phases.

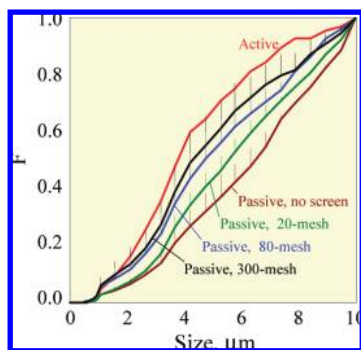


FIGURE 6. Accumulative size distributions of the particles sampled by a cascade impactor (active) and the PAS-GP-II passive samplers with or without the fine-screen-mesh (20, 80, and 300 mesh) wrapping. The data presented are arithmetic means (polygonal lines) and standard errors (vertical bars).

size distributions of the particles sampled by the passive sampler shifted toward coarse fraction to various extents, suggesting that the passive sampler was less efficient for collecting fine particles than for collecting coarse ones. The relative efficiency for fine particles collection depended on the fine-screen-mesh used. For example, 50% of particles collected by the active sampler and the passive sampler without the fine-screen-mesh were smaller than 3.6 and 6.2  $\mu\text{m}$ , respectively. The performance of the passive sampler for collecting fine particles was improved significantly by covering the sampling cylinder with the fine-screen-mesh, which reduced the diffusion of coarse particles more effectively than that of fine particles. 50% of particles sampled by the passive samplers with the fine-screen-mesh of 20, 80, or 300 mesh were smaller than 5.3, 4.4, or 4.1  $\mu\text{m}$ , respectively. Even with the 300 mesh fine-screen, fine particles were not sampled as efficiently as coarse particles but the difference between the active and passive samplers was much less than the samplers without the fine-screen-mesh.

**Effect of the Fine-Screen-Mesh on PAH Uptake.** Because of the nature of the passive sampler, the sampling efficiencies for various PAHs depend on the partition of PAHs between gaseous and particulate phases, diffusion of gaseous phase PAHs and particles and free setting of the particles. The coverage of the fine-screen-mesh could affect PAH uptake by reducing the diffusion across the cylinder wall and the turbulence within the sampling cylinder. In Figure 7, the relationships between the passively sampled quantities ( $\text{ng/d}$ ) and the actively sampled concentrations ( $\text{ng/m}^3$ ) in the test for the fine-screen-mesh wrapping are presented for both gaseous (left panel) and particulate (right panel) phase PAHs. The passive samplers were either with (20 or 80 meshes) or without the fine-screen-mesh. With only a few exceptions, e.g., gaseous phase ACY and particulate phase FLO, linear correlation between the actively and the passively sampled individual PAH compounds are demonstrated. However, it

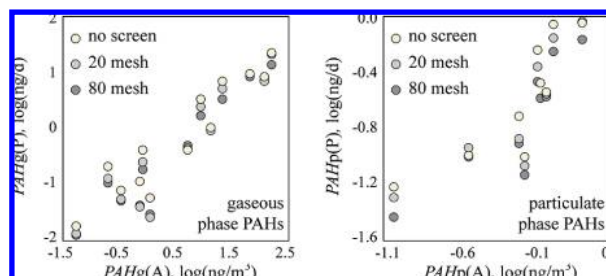


FIGURE 7. Relationship between the passively and the actively collected PAH compounds in gaseous (left panel) and particulate (right panel) phases. The passive samplers were either with or without the fine-screen-mesh (20 or 80 meshes) wrapping. All data are presented in log-scale.

is also shown in Figure 7 that the sampled PAHs by the passive sampler without the fine-screen-mesh were always higher than those sampled by the passive sampler with the fine-screen-mesh. Similarly, the sampled PAHs by the sampler with 20 mesh fine-screen-mesh coverage were always higher than those with the 80 mesh one. Obviously, the sampling efficiency of the passive sampler could be reduced by the coverage of the fine-screen-mesh. For the average of the 16 PAHs, the fine-screen-mesh coverage reduced the uptake rate significantly. The relative uptake rates of the passive sampler with 20 mesh fine-screen-mesh were 71 and 96% for gaseous and particulate phase PAHs, respectively, and the sampler with 80 mesh fine-screen-mesh were 61 and 81% for gaseous and particulate phase PAHs collected by the passive sampler without wrapping, respectively.

It appears that the fine-screen-mesh wrapping can provide better uniform sampling efficiencies for particles with various sizes and various PAH compounds at a cost of reducing the overall sampling efficiency for both gaseous and particulate phase PAHs. Therefore, the usage of the fine-screen-mesh wrapping should depend on the purpose and conditions of a specific study. For example, the passive sampler with the fine-screen-mesh coverage can be used when the ambient air PAH concentrations are relatively high and PAHs associated with fine particulates are of a particular concern. In case that the total concentrations are relatively low, the passive sampler without the fine-screen-mesh coverage is preferred. Fortunately, the difference in the sampling efficiencies for various PAH compounds can be corrected by using the calibration equation in which molecular weights of individual PAHs are taken into consideration.

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## Supporting Information Available

Photos of the passive sampler, sampling sites and sampling scheme for field calibration of the passive sampler. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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