Simple ozone scrubber using a glass fiber filter impregnated with hydroquinone for the quantitative analysis of ambient air samples

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Abstract

As a standard method for measuring the concentration of carbonyl compounds in air, 2,4-dinitrophenylhydrazine (DNPH) derivatization followed by high-performance liquid chromatography (HPLC) is widely used. However, it is often plagued by interference issues related to the ozone content in ambient air samples. Although the use of a potassium iodide (KI) scrubber circumvents these problems, the combination of a DNPH-coated silica cartridge and KI scrubber often performs poorly, particularly in high humidity. The KI in the scrubber becomes wet under these conditions, trapping the carbonyl compounds under investigation before they can reach the DNPH cartridge; this ultimately results in inaccurate readings. In this study, a new type of ozone scrubber consisting of a glass fiber filter coated with hydroquinone (HQF), was developed. The HQF scrubber was placed in front of the DNPH-coated silica cartridge, allowing airborne carbonyl compounds to pass unimpeded through the HQF section before being trapped by the DNPH-coated silica. The subsequent reaction of the trapped carbonyls with DNPH produced carbonyl 2,4-DNPhydrazone derivative that is used as the basis for the quantitative and qualitative analyses of ambient air samples. The hydroquinone in HQF reacts with ozone to form benzoquinone with an efficiency of more than 95% under wide relative humidity range (8%–95%). The performance of our novel HQF scrubber was compared with those of potassium iodide (KI) and our previously developed trans-1,2-bis(2-pyridyl)ethylene (BPE)-coated silica scrubbers using ambient air samples, and the results showed that both HQF–DNPH and BPE–DNPH cartridges detected carbonyl compounds in the same concentration levels. Proposed method is superior to the KI-based and BPE-based technique for ozone removal because HQF is very small and can be easily attached to any commercially available DNPH cartridges.

Keywords: Ozone scrubber, Hydroquinone, Glass fiber filter, Carbonyl compounds
Introduction

Carbonyl compounds such as formaldehyde, acetaldehyde are formed through oxidation of hydrocarbons by ozone in the troposphere \(^1\) and by the reaction between ozone and terpenoid in indoor air. \(^2\) Long-term exposure to relatively high levels of formaldehyde and acetaldehyde increases the risk of asthma \(^3\)–\(^5\) and cancer. \(^6\)–\(^9\) Therefore, accurate aldehyde measurements are important both for determining the formation mechanism of aldehydes and for evaluating the implications for human health.

The detection of carbonyl compounds in ambient air samples is often achieved by a selective and sensitive method based on 2,4-dinitrophenylhydrazine (DNPH) derivatization and subsequent high-performance liquid chromatography (HPLC) separation procedures. \(^10\)–\(^13\) Unfortunately, ozone at high concentrations negatively impacts this detection method by reacting with both DNPH and its carbonyl derivatives (2,4-DNPhydrazones) in the DNPH cartridge. \(^14\),\(^15\) Positive ozone artifacts are observed for high molecular weight carbonyl compounds (C\(_8\)–C\(_{18}\)), particularly when C\(_{18}\) DNPH-coated cartridges are used, owing to the reaction between ozone and the C\(_{18}\) matrix. \(^16\) An ozone scrubber is often placed before the DNPH cartridge to circumvent this issue, with potassium iodide (KI) being the most widely used reagent in the scrubber owing to its ease of use and high efficiency. \(^18\),\(^19\) The reaction between ozone and KI is shown in Fig. 1.

However, at high humidity, the wet KI in the scrubbers absorbs the carbonyl analytes before they can reach the DNPH cartridge for subsequent separation and detection. Moreover, wet KI reacts with I\(_2\) to form KI\(_3\), which decomposes DNPH and DNPhydrazone derivatives in the cartridge. \(^20\),\(^21\) Therefore, when ambient air measurements are being conducted in a high humidity environment, the KI scrubber must be subjected to heat treatments to prevent water aggregation. This results in the added
burden of purchasing and maintaining an appropriate heating apparatus in addition to the associated energy costs.

To resolve these problems, we have already developed BPE-scrubber\textsuperscript{20,22} and HQ-scrubber\textsuperscript{20} which consist of silica particles impregnated with \textit{trans}-1,2-di(2-pyridyl)ethylene (BPE) and hydroquinone (HQ), respectively. BPE reacts with ozone to form pyridine-2-aldehyde (PA) and HQ reacts with ozone to form benzoquinone (BQ) (Fig. 1). Using these ozone scrubbers, DNPH and DNPhydrazone derivatives do not decomposed by ozone at a wide range of relative humidities.\textsuperscript{22,20} However, these ozone scrubbers have some demerits caused from silica base. For example, they need a specific cartridge packed with HQ or BPE impregnated silica particles. Additionally, in the case of BPE-scrubber, the large PA-DNPhydrazone peak overlaps a part of the acetaldehyde-DNPhydrazone peak, and it might affect analysis under high concentration of ozone.

In this study, we developed a new simple ozone scrubber, HQ filter (HQF), using a glass fiber filter instead of silica. It is very small and can provide a compact system to measure carbonyls. It is easy to install HQF to any commercially available DNPH cartridges.

**Experimental**

\textit{Apparatus and reagents}

The HPLC system (Shimadzu, Kyoto, Japan) used in this study included two LC-10AD pumps, an SIL-10AD autosampler, and SPD-M10A photodiode array detector. The analytical columns were 150 mm length × 4.6 mm i.d. stainless steel tubes (Supelco Inc, Bellefonte, PA) packed with Ascentis RP-Amide (3 \(\mu\)m particle size). Solution A of the mobile phase mixture was acetonitrile/water (50/50 v/v) containing 10 mmol/L ammonium acetate, and Solution B was acetonitrile/water (80/20 v/v). HPLC elution was
conducted using 100% Solution A for 5 min, followed by a linear gradient from 100% A to 100% B in 50 min, which was then held constant for 10 min. The flow rate of the mobile phase was 0.9 mL/min. The column temperature was 35 °C, and the injection volume was 10 μL.

The environmental test chamber, supplied by Ohnishi Netsugaku Co., Ltd., Tokyo, Japan, was used for the sampler exposure tests. The test chamber had a volume of 34.8 m³ (4.2 × 3.6 × 2.3 m) and was equipped with an adjustable constant temperature and humidity controller. Ozone gas was generated using an Ozone Generator (TGO-1, Funatech Ltd., Tokyo, Japan). The humidity and temperature of standard ozone gas were recorded using a TR-72U data logger (T&D Corporation, Japan).

For the collection of indoor and outdoor air samples, air pumps (MP-Σ30N, Shibata Scientific Technology Ltd., Tokyo, Japan) and wet gas meters (WS D-1A; Shinagawa Co., Tokyo, Japan) were used. Thermal mass flow meter (TSI 4100 Series, TSI Inc., Shoreview, MN) was used for measuring the pressure drop of DNPH-cartridge system with ozone scrubbers.

The water used for HPLC analysis and sample preparation was deionized and purified using a Milli-Q water system equipped with a UV lamp (Millipore, Bedford, MA, USA). Acetonitrile (HPLC grade, >99.9%), hydroquinone (HQ, >99%), 2-pyridinecarboxaldehyde (pyridine-2-aldehyde, 99%), and ammonium acetate (99.999%) were purchased from Sigma-Aldrich Inc. (St. Louis, MO, USA). Phosphoric acid (85% solution in water) and p-benzoquinone (BQ, >98%) were purchased from Fujifilm Wako Pure Chemical Corporation (Osaka, Japan). 2,4-dinitrophenylhydrazine hydrochloride (>98.0%) and trans-1,2-di(2-pyridyl)ethylene (>98.0%) were purchased from Tokyo Chemical Industry Co. Ltd. The InertSep mini AERO ozone scrubber used as the standard KI-based ozone scrubber in this study was purchased from GL Sciences Inc. (Saitama,
Japan). Empty Rezorian tube kits and BPE–DNPH cartridges \textsuperscript{21,22} were purchased from Supelco Inc. (Bellefonte, PA, USA). The 2,4-dinitrophenylhydrazine-coated silica gel was obtained from Hitachi Chemical Techno Service Co. Ltd. (Ibaraki, Japan). Pyridine-2-aldehyde (PA) 2,4-DNPhydrazone was synthesized according to the previously reported method.\textsuperscript{22}

**Synthesis of the p-benzoquinone 2,4-DNPhydrazone derivative**

2,4-Dinitrophenylhydrazine hydrochloride (5 g) was dissolved in concentrated sulfuric acid (50 mL) and added to an ethanol/water mixture (250/70 v/v). One gram of BQ was dissolved in ethanol (100 ml), and then the DNPH solution (350 mL) was added with continuous stirring. The resulting precipitate was recovered via filtration and washed sequentially using water (3000 mL) and methanol (500 mL), followed by vacuum drying to a constant weight.

**Preparation of HQ coated glass fiber filter (HQF)**

For the preparation of the HQF system, HQ (0.5 g) was dissolved in acetonitrile (50 mL). Glass fiber filter was cut to a diameter of 9 mm and put it in this HQ solution. After 30 minutes, the filter is removed and dried at 50°C for 30 minutes. HQF made by this method contains 0.99 ± 0.08 mg of HQ. Hereby, 0.99 mg of HQ corresponds to 0.44 mg of ozone.

**Preparation of HQF-DNPH cartridge and collection of air samples**

For the preparation of the HQF–DNPH system, the end adapter with the cap of a DNPH cartridge was removed, and the HQF scrubber was placed in the DNPH cartridge (Fig. 2). The air sample was drawn through the HQF–DNPH system at a flow rate of 100
mL/min. After collection, the elution was conducted using acetonitrile in the reverse direction to afford a final volume of 5 mL. The eluate was analyzed by HPLC. The video S1 of the supporting information shows how to make HQF-DNPH cartridge, collection of air samples, and elution.

Results and Discussion

Ozone removal efficiency of HQF

Single or double HQFs containing various amounts of HQ were prepared and set to the BPE side of BPE-DNPH cartridges. Ozone (50 μg/m³) was generated using the ozone generator in the indoor test chamber, then the air sample was drawn through the HQF-BPE-DNPH cartridge system from the HQF scrubber to the BPE–DNPH cartridge at a flow rate of 100 mL/min for 24 h. After collection, the BPE–DNPH system was eluted using 25% dimethyl sulfoxide in an acetonitrile solution containing 0.1% (v/v) phosphoric acid to a final volume of 5 mL. After standing for 10 min, the eluate was analyzed by HPLC. Ozone detected in BPE-DNPH is equal to the amount passed through in HQF. The ozone removal efficiency of the HQF is calculated by comparing the amount of ozone collected in the BPE–DNPH system equipped with the HQF scrubber to that collected without it. Fig. 3 shows changes in the ozone removal efficiency with the HQ content of the scrubber. The ozone removal efficiency increased with content of HQ and when it exceeded 0.1 mg (0.91 μmol), collection efficiency showed almost 100%. Uchiyama et al. reported that the appropriate amount of HQ in the HQ-impregnated silica scrubber (130-mg silica) was more than 1.2 μmol 20; thus, our result agreed with the reported quantities. Considering the high ozone removal efficiency and ease of operation, we decided to conduct further experiments using only single layer of HQF containing
0.99 mg of HQ.

The reaction between ozone and hydroquinone is a dehydration reaction, so HQF-DNPH cartridge method may be affected by humidity. Ozone (50 μg/m³) was generated in the indoor test chamber set to various relative humidity (8%–95%), then the air sample was drawn through the HQF-BPE-DNPH cartridge system as described above. Fig. 4 shows changes in the ozone removal efficiency with relative humidity. Ozone removal efficiencies was ranged from 95–99% at all conditions and increased very slightly as the humidity increased. Uchiyama et al. reported that the HQ-impregnated silica scrubber showed no decomposition of DNPH and DNPhydrazones across a wide relative humidity range (3%–97%)⁴⁰, which is in line with our result.

If the ozone removal reaction rate is not high enough, the removal efficiency could decrease at a higher flow rate. So, the effect of the sampling flow rates on the ozone removal efficiency was measured. The experimental condition was the same as above except ozone concentration. Ozone concentration was 43 μg/m³, and sampling flow rates were 100 to 1000 mL/min. Fig. 5 shows changes in the ozone removal efficiency at the various volume flow rates. The ozone removal efficiency was ranged from 94–98%.

Application for the analysis of real ambient air samples

Ambient air was collected using the HQF–DNPH-coupled cartridge system during August to November, 2020 at Wako-shi, Saitama, Japan. The air sample was drawn through the HQF–DNPH system at a flow rate of 100 mL/min for 24 h. After collection, the elution was conducted using acetonitrile in the reverse direction to afford a final volume of 5 mL. The eluate was analyzed by HPLC. For comparison, three different kinds of DNPH-coupled cartridge systems, namely, BPE–DNPH system, KI-DNPH system (equipped with a KI ozone scrubber), and DNPH system, were subjected to the same
testing conditions as our HQF–DNPH system. Fig. 6 shows the chromatographic profiles of the associated eluates. Herein, formaldehyde DNPhydrazone (FA–D) and acetaldehyde DNPhydrazone (AA–D) were detected in all the cases. When using HQF-DNPH, HQ reacts with ozone to form BQ and the peak of BQ DNPhydrazone (BQ–D) was detected. Similarly, when using BPE-DNPH, BPE reacts with ozone to form PA and the peak of PA DNPhydrazone (PA–D) was detected. BQ–D could be analyzed quantitatively via its synthesis in this study. While the peak associated with PA–D showed a slight overlap with the peak of the AA–D isomer, the BQ–D peak was completely different from the FA–D and AA–D peaks. Table 1 shows the concentrations of the ozone and aldehydes obtained from the samples. The weather conditions from a 24-h period average were as follows: temperature, 12°C–30°C; relative humidity, 56%–92%; and ozone concentration, 22–75 μg/m³. In the case of KI–DNPH system, sampling pump was stopped by wet KI in 5 (Aug. 31, Sep. 23, Oct. 5, Oct. 7, Oct. 12) out of 23 measurements. At these measurements, the KI in the KI scrubber gradually became wet and changed to a yellow color that was associated with the formation of KI₃. Moreover, liquid KI migrated into the DNPH cartridge. The HQF–DNPH, BPE–DNPH, and DNPH systems remained unchanged. Conditions of various DNPH cartridge systems after collection at wet condition are shown in Fig. S1 in the supporting information.

To compare the carbonyl concentrations measured by HQF–DNPH system with those measured by the other systems, a single linear regression analysis was applied to Table 1 data. Here, the well-known standard least-squares fitting approach for two-dimensional data assumes the only one variable (dependent variable) has statistical errors and is not appropriate for this analysis. Therefore, the standard major axis regression method used for data with statistical errors in both variables was applied. The method fits a set of data pairs \( \{x_i, y_i\}, i = 1, \cdots, n \) to a regression line \( y = ax + b \) by
minimizing the sum of areas of triangles:

\[
A = \min_{a,b} \sum_{i=1}^{n} \frac{1}{2} \Delta y_i \Delta x_i
= \min_{a,b} \sum_{i=1}^{n} \frac{1}{2} \{y_i - (ax_i + b)\}\left\{\left(\frac{y_i}{a} - \frac{b}{a}\right) - x_i\right\}
\]  

(1)

In this method, the slope \((a)\) and intercept \((b)\) of the regression line can be calculated from

\[
a = \pm \sqrt{\frac{\sigma_y^2}{\sigma_x^2}}
\]  

(2)

\[
b = \bar{y} - a\bar{x}
\]  

(3)

where \(\sigma_x^2\) and \(\sigma_y^2\) are the sample variances of data \(\{x_i\}\) and \(\{y_i\}\), and \(\bar{x}\) and \(\bar{y}\) are the means of data \(\{x_i\}\) and \(\{y_i\}\), respectively.

Letting \(x_i\) be formaldehyde concentrations measured by HQF–DNPH and \(y_i\) be those measured by another system, the calculated regression parameters for HQF–DNPH vs. BPE–DNPH, KI–DNPH, and DNPH were as follows: slope \((a)\), 0.99, 1.2, and 0.77; intercept \((b)\), 0.02, -0.45, and -0.17; and Pearson's correlation coefficient, 0.92, 0.88, and 0.87 (the scatter diagrams are shown in Fig. S2 in the supporting information, and all the parameters for HQF–DNPH vs. KI-DNPH were calculated omitting 5 measurements which were interrupted by pump stops). The results indicated that formaldehyde concentrations measured by HQF–DNPH and BPE–DNPH were almost equal. In contrast, when using DNPH without an ozone scrubber, formaldehyde concentrations showed the lowest levels of the lot due to the decomposition of FA–D by ozone. Using KI-DNPH, some lower concentrations data could be seen and the performance of KI-based scrubber seemed to be influenced by humidity and various other conditions.

In the case of acetaldehyde, the regression parameters for HQF–DNPH vs. BPE–
DNPH, KI–DNPH, and DNPH were as follows: slope (a), 1.0, 1.1, and 0.95; intercept (b), 0.06, -0.31, and -0.19; and Pearson's correlation coefficient, 0.92, 0.94, and 0.97 (the scatter diagrams are shown in Fig. S2 in the supporting information, and all the parameters for HQF–DNPH vs. KI-DNPH were calculated omitting 5 measurements as aforementioned). Unlike formaldehyde, there was little difference among the concentrations measured by these methods. It was suggested that AA-D decomposition by ozone was much less than FA-D under these conditions.

*Airflow resistance of HQF-DNPH cartridge*

The airflow resistance of the DNPH cartridge system puts a load on the pump and affects the analytical value. Pressure drops of airflow across the DNPH cartridge with ozone scrubber systems were measured using a thermal mass flow meter at the same flow rates as Fig. 5. Figure 7 shows changes in the pressure drops for DNPH cartridge systems with various volume flow rates.

In general, the slow flow of fluids through porous media is described by Darcy’s Law:

\[
\Delta p = \frac{\mu L}{K A} Q \tag{4}
\]

where \(\Delta p\) is the pressure drop, \(Q\) is the volume flow rate, \(\mu\) is the fluid viscosity, \(K\) is the permeability, \(L\) and \(A\) is the length and cross-sectional area of the sample respectively. The results showed the pressure drops were proportional to the volume flow rates, which agreed with Darcy’s Law. Regarding the slope in Fig. 7, that is, flow resistance, the tendency of “DNPH = BPE-DNPH < HQF-DNPH <<< KI-DNPH” was observed. Since HQF-DNPH, BPE-DNPH, and DNPH cartridges are one-body products, it is thought that pressure drops are low.
Conclusions

A simple HQF ozone scrubber was developed as an alternative to traditional KI-based scrubber to analyze the carbonyl compounds of ambient air samples. HQF offers the advantages of being small and lightweight, having a low pressure drop, and being easily attachable to any commercially available DNPH cartridges. The ozone removal efficiency was more than 95% under the condition of a wide relative humidity range (8%–95%) when the hydroquinone content of HQF was 0.99 mg. As a result of measuring real ambient air, the BQ–D peak formed from hydroquinone with ozone was completely separated from the FA–D and AA–D peaks and does not interfere with the measurement of formaldehyde and acetaldehyde. Even under high humidity conditions, the concentration of carbonyl compounds measured by HQF–DNPH system agreed well with those measured by BPE–DNPH system. HQF–DNPH system has low flow resistance and low loading for sampling pump.
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Table 1. Concentrations (μg/m³) of ozone and carbonyl compounds detected in ambient air samples using the HQF–DNPH (HQ), BPE–DNPH (BPE), KI–DNPH (KI), and DNPH-coupled cartridge systems.

| Sampling date | Temp °C | R.H. (%) | formaldehyde, μg/m³ | acetaldehyde, μg/m³ | ozone, μg/m³ |
|---------------|---------|----------|---------------------|---------------------|--------------|
|               |         |          | HQ      | BPE     | KI    | DNPH | HQ      | BPE     | KI    | DNPH | BPE | ozone meter |
| Aug. 25       | 28      | 75       | 3.9     | 3.9     | 3.8   | 2.4   | 3.1     | 3.1     | 2.8   | 2.7   | 75  | 75            |
| Aug. 26       | 29      | 78       | 3.4     | 3.6     | 3.9   | 2.3   | 2.8     | 2.7     | 2.7   | 2.5   | 56  | 57            |
| Aug. 31       | 27      | 73       | 1.9     | 1.9     | *a    | 1.2   | 1.4     | 1.4     | *a    | 1.3   | 56  | 51            |
| Sep. 1        | 26      | 78       | 2.5     | 1.9     | 2.4   | 2.0   | 1.5     | 1.3     | 1.3   | 1.1   | 38  | 39            |
| Sep. 2        | 28      | 88       | 2.0     | 1.7     | 0.5   | 1.8   | 1.4     | 1.4     | 0.5   | 1.3   | 25  | 22            |
| Sep. 7        | 28      | 80       | 1.3     | 0.9     | 0.8   | 1.0   | 0.7     | 0.7     | 0.5   | 0.5   | 28  | 31            |
| Sep. 8        | 29      | 66       | 1.5     | 1.2     | 0.9   | 1.0   | 0.9     | 0.8     | 0.4   | 0.6   | 50  | 57            |
| Sep. 9        | 30      | 64       | 1.8     | 1.5     | 1.6   | 1.2   | 1.1     | 1.1     | 0.8   | 0.9   | 48  | 53            |
| Sep. 14       | 23      | 88       | 1.7     | 1.6     | 1.7   | 1.0   | 1.2     | 1.0     | 1.0   | 0.8   | 44  | 38            |
| Sep. 15       | 24      | 82       | 1.7     | 1.7     | 1.7   | 1.1   | 1.3     | 1.1     | 1.1   | 0.9   | 49  | 45            |
| Sep. 16       | 24      | 88       | 2.0     | 1.9     | 2.0   | 1.6   | 1.4     | 1.8     | 1.4   | 1.4   | 37  | 40            |
| Sep. 23       | 20      | 92       | 1.2     | 1.0     | *a    | 0.7   | 0.7     | 0.8     | *a    | 0.6   | 62  | 64            |
| Oct. 5        | 21      | 70       | 2.0     | 2.0     | *a    | 0.7   | 1.7     | 1.9     | *a    | 1.3   | 55  | 51            |
| Oct. 6        | 20      | 62       | 1.6     | 1.9     | 1.6   | 1.6   | 1.4     | 1.6     | 1.2   | 1.4   | 54  | 55            |
| Oct. 7        | 16      | 89       | 1.0     | 1.3     | *a    | 0.6   | 0.9     | 1.1     | *a    | 0.6   | *b  | 61            |
| Oct. 12       | 21      | 92       | 1.2     | 1.7     | *a    | 1.1   | 1.2     | 2.1     | *a    | 1.2   | 24  | 28            |
| Oct. 13       | 21      | 75       | 1.4     | 1.7     | 1.4   | 0.6   | 1.0     | 1.4     | 1.2   | 0.7   | 57  | 51            |
| Oct. 14       | 19      | 77       | 1.5     | 1.7     | 1.6   | 0.7   | 1.3     | 1.6     | 1.2   | 1.0   | 60  | 55            |
| Oct. 21       | 16      | 71       | 1.1     | 1.4     | 1.3   | 0.7   | 1.2     | 1.1     | 1.1   | 0.9   | 54  | 49            |
| Oct. 26       | 17      | 63       | 1.7     | 1.9     | 1.8   | 0.9   | 1.7     | 1.8     | 1.6   | 1.2   | 53  | 50            |
| Oct. 27       | 16      | 75       | 1.5     | 1.6     | 1.5   | 0.9   | 1.4     | 1.4     | 1.2   | 1.0   | 52  | 51            |
| Oct. 28       | 16      | 80       | 1.8     | 1.6     | 1.8   | 1.5   | 2.0     | 1.8     | 1.8   | 1.6   | 35  | 41            |
| Nov. 4        | 12      | 56       | 1.1     | 1.2     | 1.1   | 0.7   | 1.1     | 1.1     | 1.0   | 0.8   | 45  | 51            |
| mean          | 22      | 77       | 1.8     | 1.8     | 1.8*c | 1.2   | 1.4     | 1.5     | 1.3   | 1.2   | 48  | 48            |

*a, sampling pump was stopped; *b, no data, *c, without abnormal data (*b)
Figure Captions

Fig. 1. Reaction between ozone with KI and HQ.

Fig. 2. Preparation of HQF–DNPH cartridge.

Fig. 3. Changes in the ozone removal efficiency with the HQ content of the scrubber.

Fig. 4. Changes in the ozone removal efficiency with relative humidity.

Fig. 5. Changes in the ozone removal efficiency with various volume flow rates.

Fig. 6. HPLC chromatographic profiles of DNPH derivatives eluted using various cartridges.

Fig. 7. Changes in the pressure drops for DNPH cartridge systems with various volume flow rates.
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Graphical Index

Simple ozone scrubber using a glass fiber filter impregnated with hydroquinone.
Supporting Information

Video S1. Preparation of HQF-DNPH cartridge and collection of air samples
https://www.youtube.com/watch?v=dwq_favCDfI&list=PLQwECJHwocUIj_upfZ0KE9r5eXuz1P1

Fig. S1. Conditions of various DNPH cartridge systems after collection at wet condition.
Fig. S2. Comparison of the HQF-DNPH method with BPE-DNPH, KI-DNPH, and DNPH method for (A) Formaldehyde (left panels), and (B) Acetaldehyde (right panels).