

Determination of the Sampling Rate Variation for SKC UME_x 100 Passive Samplers

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Chemist: Mary Eide

Methods Development Team
Industrial Hygiene Chemistry Division
OSHA Salt Lake Technical Center
Sandy UT 84070-6406

Introduction

The purpose of this study was to determine the sampling rate variation (SRV) for SKC Inc. UME_x 100 Passive Samplers (SKC UME_x). These samplers are intended by the manufacturer for use to measure the amount of formaldehyde present in workplace air. The sampler uses 2,4-dinitrophenylhydrazine chemistry to produce a stable aldehyde derivative.

SRV has been established by OSHA as a measure of sampling rate error for diffusive samplers.¹ SRV is the diffusive sampler equivalent of the often cited $\pm 5\%$ sampling pump error used for active samplers. It is a unique number that is experimentally determined for each individual design of diffusive sampler, because SRV is presumed to be a function of sampler design. SRV provides the sampling error component of the Sampling and Analytical Error (SAE) calculations.²

SRV has been defined as the pooled relative standard deviation of sampling rates obtained in a modified version of the 16-run factor test described in the NIOSH testing protocol for diffusive samplers.³ This test is based on determination of diffusive sampling rates of test atmospheres containing five different aldehydes. The test requires sample collection from 16 different combinations of high and low analyte concentrations, short and long sampling times, high and low face velocities, high and low relative humidities, and parallel and perpendicular sampler orientations to air flow direction in a sampling chamber.

The formaldehyde atmosphere was generated from a solution of formaldehyde in water freshly prepared from paraformaldehyde. Formaldehyde slowly forms paraformaldehyde when in a formaldehyde-water solution, if it is not stabilized with methyl alcohol, so most commercial solutions of formaldehyde are stabilized with methyl alcohol. Methyl alcohol reacts with the formaldehyde forming methoxymethanol and/or dimethoxymethane.⁴ The methoxymethanol and dimethoxymethane (nonformaldehyde species) are unstable and readily decompose back to formaldehyde and methanol.⁵ These nonformaldehyde species readily react with the derivatizing agent, whether DNPH or 2-(hydroxymethyl)piperidine, to form the formaldehyde derivative. The paraformaldehyde test atmospheres, including formaldehyde water solution, contain mostly formaldehyde, while the methyl alcohol stabilized atmospheres contain formaldehyde and nonformaldehyde species. The sampling rates of the nonformaldehyde species are different from the formaldehyde, causing lower loadings of formaldehyde derivative on the passive samplers when compared to the active samplers taken from the same test atmosphere. This difference could result in formaldehyde results for the diffusive sampler which are as much as 35% lower than the active samplers.⁶ Diffusive

samplers, with sampling rates determined using test atmospheres prepared from paraformaldehyde, give analytical results similar to active samplers. This study employed formaldehyde test atmospheres generated with formaldehyde solution prepared from paraformaldehyde to establish sampling rates for SKC Inc. UME_x 100 Passive Samplers. Therefore, sampling rates shown here are for formaldehyde alone. Formaldehyde atmospheres in the workplace could result from formaldehyde stabilized with methyl alcohol, and would contain the nonformaldehyde species, causing formaldehyde results, which would be lower than an active sampler, if the samples were taken side-by-side.

Reagents

Acetaldehyde, Aldrich Chemical Company, 99.5+%, lot CO 02962AO
Benzaldehyde, Aldrich Chemical Company, 99.5+%, lot 00208TI
Butyraldehyde, Aldrich Chemical Company, 99.5+%, lot BO 03519DI
Glutaraldehyde, Aldrich Chemical Company, 50% in water, lot 01907 CI
Paraformaldehyde, Aldrich Chemical Company, 95+%, lot 08710 AA
Acetonitrile, Fisher Chemical Company, 99.9%, lot 031027
Phosphoric acid, JT Baker, Baker-analyzed, 85.9%, lot D25821
2,4-Dinitrophenylhydrazine (DNPH), Aldrich Chemical Company, lot 7627JK (DNPH is light sensitive, so all solutions and samples should be protected from the light in light-impervious containers.)
Toluene, Alfa-Aesar, 99.8%, lot K06M13
N,N-Dimethylformamide (DMF), Aldrich Chemical Company, 99.8%, lot 04643LA

A freshly prepared solution of formaldehyde in water was prepared by heating paraformaldehyde at 80 °C, and bubbling the vapor through deionized water. These mixtures were quantitated by titration⁷ before use in the vapor generation system.

Two different neat aldehyde mixtures were prepared. The first mixture was 1:1 (by volume) ratio of butyraldehyde:benzaldehyde, and the second mixture was 1:1:0.1 (by volume) of the formaldehyde solution:acetaldehyde:glutaraldehyde. These mixtures were used to generate the test atmospheres and prepare standards.

SKC UME_x 100 Passive Samplers and coated glass fiber filter extracting solution (DNPH solution). The solution was composed of 1-g DNPH and 5-mL phosphoric acid in 1-L acetonitrile. The same solution was used to prepare analytical standards. The DNPH was purified by recrystallization with hot acetonitrile.

Adsorbent tube extracting solution. The solution was composed of 0.2 µL/mL DMF in toluene.

Sampling Media

SKC UME_x 100 Passive Sampler (UME_x 100), lots 2527A, 2233C, and 2756, containing a silica tape coated with DNPH and phosphoric acid.

SKC 226-117 and 226-54 sampling tubes, lot 2952, containing XAD-2 coated with 10% (w/w) 2-(hydroxymethyl)piperidine (HMP XAD-2). These sampling tubes were packed with the same adsorbent, but contained differing amounts of the coated resin in the tubes, and thus have different amounts of formaldehyde background. The 226-54 has two sections containing 45- and 23-mg coated resin, and is used for short-term sampling. The 226-117 has two sections containing 150- and 75-mg coated resin, and is used for long-term samples. These sampling tubes were used to establish the concentrations of acetaldehyde, butyraldehyde, and formaldehyde in test atmospheres.

Glass fiber filters coated with 2-mg DNPH and 10-µL phosphoric acid (DNPH GFF). The cassette was loaded with three coated filters, with a spacer between each filter, and an extra spacer on the top to emulate open face sampling. These filters were used to establish the benzaldehyde and glutaraldehyde concentrations in the test atmospheres. The DNPH used was recrystallized from hot acetonitrile. The DNPH coated GFF were prepared by placing glass fiber filters on a clean glass plate and pipetting 0.5 mL of a

solution of 4-g/L DNPH and 20-mL/L phosphoric acid in acetonitrile.⁸ The filters were allowed to dry 20 minutes in a hood, then they were placed in a light impervious container (brown glass jar) loosely sealed with a lid, allowed to dry completely overnight in a drawer, and then the lid was tightly sealed and the jar was placed into a freezer for storage.

Apparatus

Shaker. A Eberbach shaker was used to extract the adsorbent tubes.

Rotator. A Fisher Roto Rack rotator was used to extract the SKC UME_x 100 Passive Samplers and coated glass fiber filters.

Gas chromatograph (GC) with a nitrogen-phosphorus detector. An Agilent 6890 gas chromatograph with a 7683 injector, and 3396 Series II integrator was used for analysis of HMP XAD-2 samplers. Separations were performed using a Restek Stabilwax DB capillary column (60-meter x 0.32-mm x 1- μ m df).

An electronic integrator or some other suitable means of measuring peak areas. A Waters Millennium32 Data System was used in this evaluation.

A liquid chromatograph equipped with a UV detector. A Waters 600 Controller and pump, with a Waters 2487 Dual wavelength absorbance Detector, and a Waters 717 plus Autosampler was used to analyze UME_x 100 and DNPH GFF. A 4.6- x 250-mm column packed with 5- μ m Pinnacle TO-11 (Bellefonte, PA) was used in this evaluation.

Humid air and air flow controller. A Miller-Nelson Model HCS-401 Flow-Temperature-Humidity Control System was used to generate humid air flows (for use with controlled test atmospheres) with a 500 L/min mass flow controller.

Relative humidity and temperature tester. An Omega Digital Thermo-hygrometer Model RH411 was used to test the relative humidity and temperature of the test atmospheres within the exposure chamber. The probe was calibrated by the manufacturer.

Gas test meter. An Equimeter no. 750 gas meter was used to measure dilution flow rates. This meter had been checked at several flows against a Singer DTM 115 gas meter (that had been tested by the local natural gas distributor and found to be accurate).

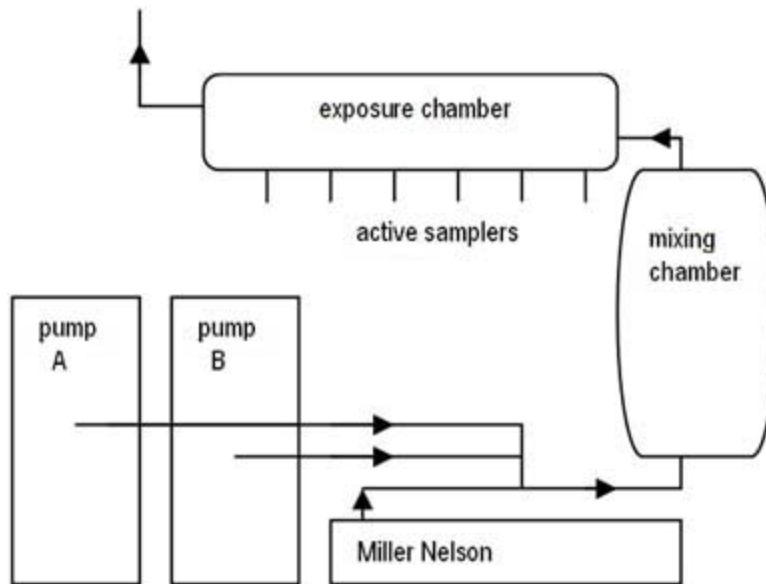


Figure 1. This is a diagram of the test atmosphere generation and sampling apparatus. The air stream of a known flow and humidity is introduced into the apparatus from the Miller Nelson Flow-Temperature-Humidity Control System. The aldehyde mixtures come from the ISCO syringe pumps and are teed into the air stream. The stream is heated to vaporize the aldehydes. The air and aldehydes flow into a glass mixing chamber to form a homogeneous test atmosphere. This test atmosphere then flows to the exposure chamber. The exposure chamber is large enough for the diffusive samplers to fit inside, and has side ports from which active samplers can be taken. The test atmosphere then flows out of the exposure chamber into the exhaust.

Syringe pumps. The two aldehyde mixtures were metered into the system using two Isco 100DM syringe pumps equipped with a cooling/heating jacket and an insulating cover. Both pumps were operated in the constant flow mode. The temperature of water in the cooling jacket was maintained at 19° C with a Forma Scientific Model RH411 Bath and Circulator.

The chemical vapors were generated by pumping the two aldehyde mixtures through a short length of 0.53-mm uncoated fused silica capillary tubing into a vapor generator where it was heated and evaporated into the dilution air stream (Figure 1). The entire apparatus was placed in a walk-in hood. The aldehyde mixtures were introduced into the air stream by a glass vapor generator consisting of a 15-cm length of 5-cm diameter glass tubing with a side port for introduction of the capillary tubing. Each of the two aldehyde mixtures were pumped into the vapor generator using an Isco syringe pump through the uncoated capillary column. The glass tube of the vapor generator was wrapped with heating tape to evaporate the chemicals in the mixture. The humidity, temperature, and volume of the dilution stream of air were regulated by use of a Miller Nelson Flow-Temperature-Humidity controller. The test atmosphere passed into a glass mixing chamber (76-cm x 30-cm) from the vapor generator, and then into a glass exposure chamber (76-cm x 20-cm). The humidity and temperature were measured at the exit of the exposure chamber with an Omega Digital Thermo-hygrometer. Face velocities of the test atmospheres were calculated by dividing the volumetric flow of each atmosphere by the cross-sectional area available for the air flow in each chamber. The cross-sectional area available for the air flow was the cross-sectional area of each chamber reduced by the cross-sectional areas of the samplers.

Experimental

Sample Analysis

The HMP coated XAD-2 adsorbent tubes were opened, each section placed into a separate 2-mL vial, and 1-mL of toluene with 0.2 µL/mL DMF internal standard was pipetted into the vial. The vials were sealed and were placed on a shaker for 1 hour. Standards were prepared by injecting microliter amounts of the spiking solutions into vials containing the 150-mg of the HMP coated XAD-2 resin for high standards, and for low standards a 45-mg portion was used. There were two different amounts of resin used to make the standards due to the amount of background formaldehyde on the resin. The standards were blank corrected before plotting the calibration curve. The standards were extracted in the same manner as the samples.

Adsorbent tubes were analyzed by a gas chromatograph (GC) using a nitrogen-phosphorus detector. Separations were performed using a Restek Stabilwax DB capillary column (60-meter x 0.32-mm x 1-µm df). The injection volume was 1 µL with a 1:10 split. The GC temperature program was 60° C for 4 min then 7° C/min to 220° C and hold for 2 min. The hydrogen carrier gas was 2.5 mL/min, hydrogen detector gas was 2 mL/min, the nitrogen auxiliary gas was 10 mL/min, and the detector air was 60 mL/min. The injector temperature was 220° C and the detector temperature was 260° C.

UMEx 100 were opened, each section of coated silica tape was placed into a separate 4-mL amber vial, 2-mL of a solution of acetonitrile containing 1 g/L DNPH and 5 mL/L phosphoric acid was added, and they were capped. They were extracted for 1/2 hour on a Fisher Roto Rack. The supernatant from the SKC UMEx 100 Passive Samplers was immediately removed and placed into a separate vial for analysis. It is important to either dynamically extract the SKC UMEx 100 Passive Samplers or to transfer the supernatant to a separate vial immediately after shaking. The concentration of DNPH derivatives decreases in solution, with time, when left in contact with the silica tape.

DNPH GFF cassettes were opened, each filter placed into separate 4-mL amber vials, 2 mL of the DNPH extraction solution was added, and they were capped. They were extracted for 1/2 hour on a Fisher Roto Rack.

UMEx 100 and DNPH GFF were analyzed by a liquid chromatograph equipped with a UV detector. A 4.6-x 250-mm column packed with 5-µm Pinnacle TO-11 were used in the evaluation. The injection volume was 10 µL. The mobile phase was 65:35:0.02 (v:v:v) acetonitrile:water:phosphoric acid pumped at 1 mL/min. The wavelength was 365 nm.

Extraction efficiency

It was not necessary to perform an extraction efficiency study of the aldehydes from HMP coated XAD-2 tubes, as the same medium was spiked with the aldehydes in the mixture to make the analytical standards.⁹

The extraction efficiency study of the DNPH GFF was performed by spiking the five aldehydes onto the DNPH GFF, in light amber vials, and allowing them to react overnight in a drawer. Six filters at each of six levels were spiked. The loadings studied were: acetaldehyde 1 to 86.4 µg/sample; benzaldehyde 1 to 208.4 µg/sample; butyraldehyde 1 to 141.6 µg/sample; formaldehyde 0.3 to 22 µg/sample; and glutaraldehyde 0.2 to 9.8 µg/sample.

The extraction efficiency study of the UMEx 100 was performed by opening the samplers, removing the coated silica tape, placing the coated silica tape in amber vials, spiking the five aldehydes onto the coated silica tape, and allowing them to react overnight in a drawer. Six samplers at each of six levels were spiked. The loadings studied were: acetaldehyde 1 to 40 µg/sample; benzaldehyde 1 to 58.8 µg/sample; butyraldehyde 1 to 46.8 µg/sample; formaldehyde 0.5 to 12.6 µg/sample; and glutaraldehyde 0.3 to 5.6 µg/sample.

Sampling rate and capacity

The sampling rate and capacity of UMEx 100 for each of the aldehydes was determined by exposing sets of three passive samplers to the aldehyde test atmosphere for increasing time periods. The test atmosphere

contained a target concentration of acetaldehyde (2 ppm or 3.6 mg/m³), benzaldehyde (2 ppm or 8.82 mg/m³), butyraldehyde (2 ppm or 5.9 mg/m³), formaldehyde (0.75 ppm or 0.92 mg/m³) and glutaraldehyde (0.2 ppm or 0.8 mg/m³). These levels will be referred to as the 1 x, and the 1/10 of this level as 0.1x in this study. Unless otherwise noted, the sampler orientation was parallel to the flow direction of the test atmosphere. The average relative humidity, temperature, and face velocity of the test atmospheres, except in the factor tests, was 77%, 30° C, and 0.4 m/s respectively. Six active samplers were collected with each set of three passive samplers; the six active samplers consisted of three DNPH coated GFF and three HMP coated XAD-2 tubes. The sampling rates were 100 mL/min for DNPH coated filters, and 50 mL/min for HMP coated XAD-2 tubes.

Reverse diffusion tests were performed by sampling the 1 x concentration for one-half the total sampling time, and then sampling clean humid air for the remainder of the sampling time. Eight passive samplers were exposed for 2 hours, four were removed and analyzed, and then the other four were exposed for 2 hours to clean, humid air and then analyzed. The relative humidity, temperature, and face velocity were 76%, 29° C and 0.4 m/s respectively.

Factor tests

A 16-run factor test was performed using a modified version¹⁰ of the NIOSH Factor Test.¹¹ NIOSH has identified six factors that can affect the performance of diffusive samplers: analyte concentration, face velocity, relative humidity, exposure time, interferant, and sampler orientation. Sixty-four experimental runs (26) would be required to fully evaluate combinations of each factor at two levels. NIOSH recognized that this would be an excessive number of tests, and has devised a 16-run fraction of the full factorial that is capable of revealing any of these factors having a significant effect, free of two-factor interactions, on sampler performance. Some two and three-factor interactions can also be screened by this design. The test is based on comparison of each factor effect to experimental error so that the significance of that effect can be determined. Experimental conditions are shown in Table 1. Interferant was provided by the components of the aldehyde mixture, for example if formaldehyde was examined, then acetaldehyde, benzaldehyde, butyraldehyde, and glutaraldehyde were the interferents, and the levels were either high or low.

Table 1
Experimental Design of the Factor Test

run no.	analyte concn	RH (% , ° C)	inter level	time (min)	face vel (m/s)	sampler orien
1	0.1x	21,30	low	120	1.9	perp
2	1x	19,29	low	30	0.2	perp
3	0.1x	80,30	low	30	2.0	paral
4	1x	80,30	low	120	0.2	paral
5	0.1x	21,30	high	120	0.2	paral
6	1x	20,30	high	30	1.8	paral
7	0.1x	79,30	high	30	0.2	perp
8	1x	79,30	high	120	1.8	perp
9	1x	80,29	high	30	0.2	paral
10	0.1x	77,30	high	120	1.8	paral
11	1x	20,30	high	120	0.2	perp
12	0.1x	21,31	high	30	1.9	perp
13	1x	77,30	low	30	1.8	perp
14	0.1x	78,30	low	120	0.2	perp
15	1x	21,29	low	120	1.8	paral
16	0.1x	20,29	low	30	0.2	paral

concn = concentration; inter = interference; face vel = face velocity; orien = orientation; perp = perpendicular; paral = parallel

Results and Discussion

Extraction efficiency

A summary of the average extraction efficiencies is in Table 2. The extraction efficiencies were high and constant over the ranges studied.

Table 2
Extraction Efficiency (%)

medium	acet	benz	buty	form	glut
DNPG GFF	100.0	100.1	100.0	100.0	100.0
SKC UME _x	100.1	100.0	100.2	99.8	100.0

where: acet = acetaldehyde; benz = benzaldehyde; buty = butyraldehyde; form = formaldehyde; and glut = glutaraldehyde

Sampling rate and capacity

Sampling rates were calculated by dividing mass collected (corrected for extraction efficiency) by sampling time multiplied by the actual concentration of the test atmosphere (sampling rate = $\mu\text{g}/(\text{min} \times \mu\text{g}/\text{L})$). Sampling rate, in L/min, was converted to mL/min, the same units often used for adsorbent tubes. Theoretical concentrations were calculated from the test atmosphere generator apparatus operation parameters. The actual test atmosphere was determined from the active sampler results. The actual test atmosphere concentrations were about 98% of the theoretical amounts ((syringe pump rate x concentration in solution) ÷ dilution air volume). The selection of active medium used to establish actual test atmosphere concentrations was based on the existence of validated methodology and on technical considerations. Adsorbent tube results were used for acetaldehyde, butyraldehyde, and formaldehyde. DNPH GFF results were used for glutaraldehyde and benzaldehyde. The same sampling time was used for the active and passive samplers for each test run. All samples were analyzed as soon as possible after collection. Sampling rates and capacity results are shown in Table 4 and Figure 2. The sampling rates were determined at ambient temperature and pressure and converted to their equivalent at 25° C and 760 mmHg.

Table 3
Sampling Rate and Capacity Test Atmosphere (ppm)

source	acet	benz	buty	form	glut
theoretical concn	2.13	2.01	2.09	0.76	0.21
DNPH GFF results	1.83	1.98	2.01	0.72	0.20
HMP XAD-2 results	2.11	1.88	2.04	0.75	na

na = not applicable

Table 4
Sampling Rate and Capacity (mL/min)

time (min)	acet	benz	buty	form	glut
5	22.11	12.37	14.94	27.11	13.03
10	22.37	12.55	15.27	27.29	13.23
15	22.52	13.26	15.69	27.67	13.41
30	22.91	13.49	15.99	28.47	13.88
60	22.88	13.72	16.03	28.66	13.99
120	23.13	13.89	16.29	28.69	14.32
180	23.02	13.72	16.16	28.58	14.13
240	23.15	13.91	16.25	28.45	14.31
360	22.54	13.24	15.58	28.67	13.81
480	22.25	13.01	15.27	27.14	13.55

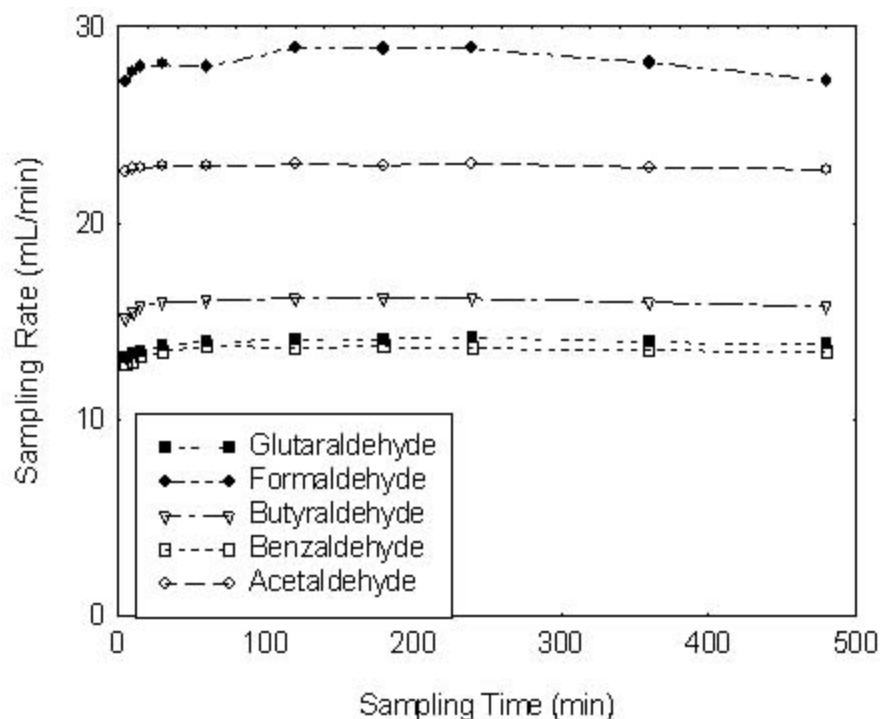


Figure 2. This is a plot of the data presented in Table 4.

The sampling rates were constant from 30 to 240 minutes, the range normally averaged by OSHA to obtain the average diffusive sampling rate.¹⁴ The capacity of the sampler for a component is presumed to be exceeded when the apparent sampling rate for that component decreases rapidly. The test atmosphere contained acetaldehyde at 2 ppm, while the PEL is 100 ppm, so the capacity results for a sampler determined at the PEL will be lower than what appears in Table 5. The average sampling rates for 30 to 240 minutes are listed in Table 5, along with their RSD. The SKC sampling rates in Table 5 were obtained from SKC. The formaldehyde sampling rate determined by SKC Inc. is published on their website, and was determined experimentally with a RSD of 5.2%.¹⁵ The SKC sampling rate was determined by varying concentration, relative humidity, sample time, orientation, and face velocity, following a variation of the NIOSH protocol.

Table 5
Average Sampling Rate (mL/min) and RSD (%)

	acet	benz	buty	form	glut
30-240 min	23.02	13.75	16.14	28.57	14.13
RSD	0.54	1.26	0.82	0.34	1.37
SKC sampling rate ^{12, 13}	23.1	14.1	16.5	28.6	14.3

Reverse diffusion occurs when the compound is lost from the sampler following collection. All diffusive samplers have the potential for reverse diffusion. These DNPH aldehyde derivatives are not volatile, but loss could occur through other means so this experiment was performed. The recovery was calculated by dividing the average recovery after 4 hours by the average recovery after 2 hours. The results in Table 6 show that the recoveries for the two sampler sets were similar.

Table 6
Reverse Diffusion

	acet	benz	buty	form	glut
recovery (%)	98.6	100.1	99.7	100.2	99.3

The effects of increasing face velocity, on the sampling rates, are shown in Figure 3. The most dramatic effects occur at low to medium velocities. The overall effect is similar to the ones observed for 3M 3520 OVMs and SKC 575-002 passive samplers.¹⁶

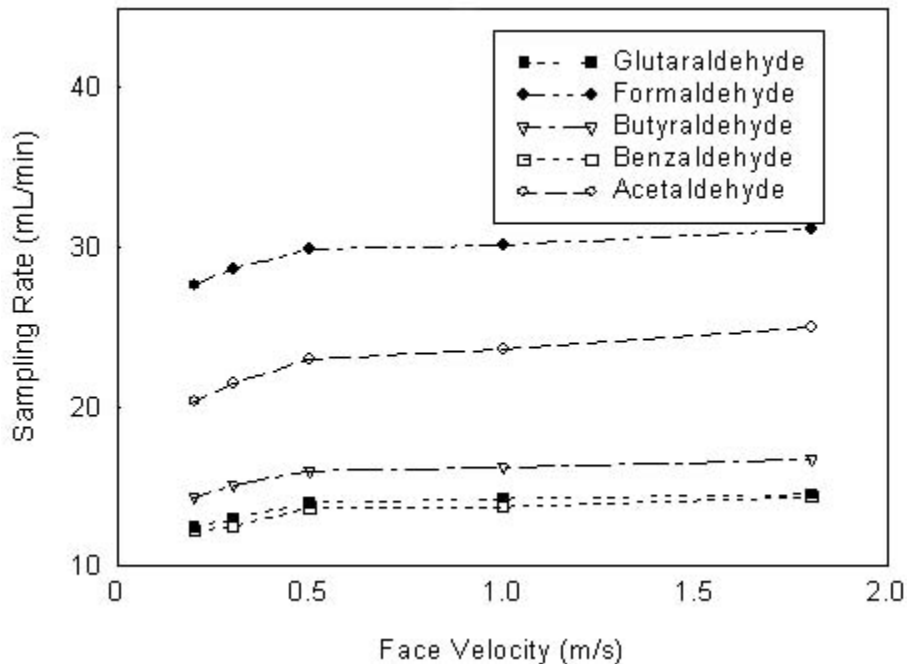


Figure 3. This is the plot of the face velocity (m/s) versus sampling rate (mL/min) for the five aldehydes studied. The points on the graph for acetaldehyde are: 0.2 m/s, 20.38 mL/min; 0.3 m/s, 21.45 mL/min; 0.5 m/s, 22.99 mL/min; 1.0 m/s, 23.62 mL/min; and 1.8 m/s, 24.96 mL/min. The points for benzaldehyde are: 0.2 m/s, 12.25 mL/min; 0.3 m/s, 12.54 mL/min; 0.5 m/s, 13.66 mL/min; 1.0 m/s, 13.72 mL/min; and 1.8 m/s,

14.35 mL/min. The points for butyraldehyde are: 0.2 m/s, 14.36 mL/min; 0.3 m/s, 15.10 mL/min; 0.5 m/s, 15.99 mL/min; 1.0 m/s, 16.20 mL/min; and 1.8 m/s, 16.70 mL/min. The points for formaldehyde are: 0.2 m/s, 27.60 mL/min; 0.3 m/s 28.66 mL/min; 0.5 m/s, 29.90 mL/min; 1.0 m/s 30.14 mL/min; and 1.8 m/s, 31.14 mL/min. The points for glutaraldehyde are: 0.2 m/s, 12.45 mL/min; 0.3 m/s, 13.00 mL/min; 0.5 m/s, 13.99 mL/min; 1.0 m/s, 14.24 mL/min; and 1.8 m/s, 14.52 mL/min.

Factor Test

The results of the factor test are presented in Table 7. The sampling rates were determined at ambient temperatures, but are expressed at 25 ° C and 760 mm Hg.

Table 7
Factor Test Results (mL/min)

test	acet	benz	buty	form	glut
1	24.59	14.57	17.11	31.25	15.13
2	20.88	12.25	14.32	26.48	12.49
3	24.91	14.67	17.15	31.55	14.82
4	21.38	12.96	14.59	27.05	12.44
5	20.49	12.26	14.24	26.89	12.39
6	24.69	14.97	16.88	30.05	14.99
7	20.93	12.85	14.75	26.58	12.78
8	25.01	14.79	17.29	31.40	15.11
9	21.95	12.94	15.43	27.66	13.3
10	24.89	14.09	16.69	31.34	14.84
11	21.39	12.68	14.66	27.42	12.65
12	22.52	13.72	15.25	28.18	13.55
13	24.98	14.88	17.08	31.32	15.14
14	21.34	12.31	14.65	27.38	12.66
15	24.96	14.61	17.14	31.34	15.03
16	20.72	12.18	14.38	27.15	12.53

Average sampling rates and their percent RSDs are shown in Table 8. These percent RSDs were found to be homogenous by the Cochran Test.¹⁷ The pooled percent RSD, 8.06%, is the sampling rate variation for SKC UME_x 100 Passive Samplers as determined by this work.

Table 8
Percent RSDs of Average Sampling Rates

	acet	benz	buty	form	glut
ave (mL/min)	22.85	13.55	15.73	28.94	13.74
RSD (%)	8.28	8.04	7.93	7.26	8.70
pooled RSD (%)			8.06		

The data in Table 7 was further analyzed to detect factor effects, which gave an experimental error for each component of the mixture, following the NIOSH protocol for diffusive samplers.¹⁸ The minimum significant effect (MSE) was calculated for each component by multiplying experimental error of the factor test by the appropriate t statistic for the nine degrees of freedom (2.26 is the t statistic at the 95% confidence level for nine degrees of freedom). The MSE for each aldehyde is found in Table 9. The analysis gave a numerical factor effect result for each aldehyde component for each of the seven factors. The absolute value of the normalized ratio of effect/MSE is shown in Table 10. Any ratio above 1 is significant at the 95% confidence

level, and that effect should be studied further in additional experiments. The results for interferant may be somewhat equivocal because the remainder of the mixture was considered the interference, such as acetaldehyde, benzaldehyde, butyraldehyde, and glutaraldehyde were interferents for formaldehyde. Face velocity had the most significant effect on the sampling rates.

Table 9
Analysis of Factor Test Data

	acet	benz	buty	form	glut
error	0.28	0.16	0.25	0.38	0.22
MSE	0.63	.037	0.57	.085	.050

Table 10
Analysis of Factor Data Effect Results

	acet	benz	buty	form	glut
conc	0.96	1.16	0.70	0.35	0.61
RH	1.02	.076	0.80	0.81	0.58
interfer	0.38	0.04	0.27	0.59	0.16
time	0.49	0.06	0.25	0.75	0.16
face vel	5.45	5.36	3.85	4.39	4.34
orient	0.47	0.21	0.30	0.44	0.21
interaction	none	none	none	none	none

none = none significant

Precision

The relative standard deviations were calculated for each aldehyde from the factor tests. The precision data of the passive and active samplers for each component were comparable. While data is presented in Table 11 for both types of active samplers, the active sampler for acetaldehyde, butyraldehyde, and formaldehyde was HMP coated XAD-2 tubes, and the active sampler for benzaldehyde and glutaraldehyde was DNPH coated glass fiber filters.

Package integrity

Formaldehyde and acetaldehyde are common components in the air, especially in urban areas, as they are natural by-products of combustion engines. The integrity of unopened UME_x 100 (lot 2233C) was checked by placing them in the exposure chamber, for 100 hours, while the factor tests were performed. The results in Table 12 are not blank corrected.

Conclusions

The sampling rate variation for UME_x 100 is $\pm 8.06\%$ as determined by this work. Sampling rate variation is a function of the design of the diffusive sampler, and is not dependent on the sorbent inside, or the chemical tested. This sampling rate variation may be used for other chemicals collected on this passive sampler under conditions that approximate conditions of these tests. This sampling rate variation would also apply if a different sorbent was placed inside this design of diffusive sampler for sampling other chemicals.

Sampling rate variation is used by OSHA as the sampling error component of the SAE (Sampling and Analytical Error).¹⁹ The analytical error component is periodically updated from the analysis of quality control samples. Each analyte will have a unique SAE.

Table 11
Precision Data (Percent RSD)

	acet	benz	buty	form	glut
HMP XAD-2	2.6	4.8	2.2	2.5	na
DNPH GFF	5.2	2.1	3.3	4.1	2.4
UMEX 100	3.1	2.5	2.3	2.7	2.8

na = not applicable

Table 12
Package Integrity Test

	acet	benz	buty	form	glut
found (µg)	1.38	<DL	<DL	0.53	<DL
blank (µg)	0.21	<DL	<DL	0.33	<DL
DL	0.1	0.1	0.1	0.1	0.1

DL = detection limit

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