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EVALUATION OF STANDARD AND MODIFIED SAMPLING HEADS FOR THE INTERNATIONAL PBI SURFACE AIR SYSTEM BIOAEROSOL SAMPLERS

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This study substituted sampling heads with smaller holes to collect small particles with the International PBI Surface Air System (SAS) battery-powered, bioaerosol air samplers, which have proved inefficient in collecting small airborne particles such as free bacteria (e.g., < 2 μm). An Andersen six-stage (6-STG) sampler was used simultaneously with two SAS samplers (SAS high flow [SAS-HF] and Compact SAS [SAS-C]) to sample indoor air in two office environments. Discrepancies were observed in the flow rate results obtained using the manufacturer's Pitot Validation Kit (PVK). Air sampling results suggested no significant difference in the concentration of bacteria and fungi collected among the four sampling heads using either sampler model in a small sample (n = 5) at either site. However, with an additional 15 samples at Site B (n = 5 + 15 = 20), three of the four sampling heads statistically undersampled the 6-STG and the other sampling head. The field data were variable (geometric standard deviation [GSD] = 1.25–1.94 for bacteria; GSD = 1.18–3.51 for fungi), but within ranges previously observed. The manufacturer increased particle collection efficiency by decreasing the hole size; however, this increase was only noticeable after many replicates. The PVK may be used as an accurate flow rate measurement device with the SAS-HF sampler, though the Pitot tube measures only centerline velocity pressure. Because of the 10% decrease in flow rate resulting from the pressure drop across the PVK, the equation in the manufacturer's literature for calculation of average velocities (V_{AVG}) provides a reasonable estimate of flow rate through the SAS-C sampler.

Bioaerosol monitoring is a rapidly evolving area of industrial hygiene. It is used often for indoor environmental quality, agricultural health, infectious disease outbreak, and biotechnology containment investigations. The Andersen Six-Stage Viable (Microbial) Particle Sizing Sampler (6-STG, Graseby Andersen, Atlanta, Ga.) and the All-Glass Impinger-30 (Ace Glass, Vineland, N.J.) have been regarded as the samplers of choice for the enumeration of culturable microorganisms.[1–3] The International PBI (PBI) Surface Air System (SAS), portable, battery-powered, bioaerosol samplers (International PBI, Milano, Italy; Spiral Biotech, Inc., Bethesda, Md.) have been shown to be inefficient in the collection of small particles such as free bacteria.[4–5]

This study was initiated to support another group of National Institute for Occupational Safety and Health (NIOSH) investigators who were evaluating bioaerosols in indoor environments. The SAS samplers were selected because their multiple-hole impactors are portable and quiet. An effort was made to evaluate the efficacy of using sampling heads with smaller holes to collect small particles. In an attempt to increase the particle collection efficiency, the manufacturer had machined three different sampling heads. The three sampling heads had smaller holes (jets) than the standard sampling head. Also, a fourth sampling head, commercially available and having more of the same size holes than the standard sampling head, was used. Air was sampled during two different studies in office environments (Sites A and B). During these experiments, discrepancies were observed in the flow rate results obtained using the Pitot Validation Kit (PVK). The PVK is marketed by the manufacturer of the SAS samplers for instrument calibration to the manufacturer's flow rate specifications. Evaluation of the PVK under laboratory conditions illuminated limitations concerning the use of the PVK and application of the manufacturer's equations relating the PVK center line and average velocities (V_{AVG}), which are used to calculate the flow rate through the SAS samplers. In 1994 Spiral Biotech, Inc. of Bethesda, Md., developed and marketed a new airflow validation kit that uses a hot wire anemometer and a specially designed test assembly (not evaluated in this study).

EXPERIMENTAL MATERIALS AND METHODS

Evaluation of SAS Samplers and Sampling Head Combinations

Two models of the PBI SAS sampler were evaluated with four different types of sampling heads and compared to the Andersen 6-STG sampler. The air mover in SAS samplers is much quieter than the carbon vane pump provided with the 6-STG. The advantage of portability of the SAS samplers as well as their

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TABLE I. Theoretical and Actual Operating Characteristics and Sampling Parameters of the SAS-HF Samplers

Sampling Head[B]	Type Head	# Holes	d_j mm	Theoretical Q L/min	Theoretical V_j cm/sec	Theoretical d_{50} μm	Actual[A] Q L/min	Actual[A] V_j cm/sec	Actual[A] d_{50} μm
1	STD	219	1.00	180	1740	1.35	166	1610	1.41
2	STD	219	1.00	180	1740	1.35	170	1640	1.38
3	STD	219	1.00	180	1740	1.35	174	1680	1.38
4	STD-CAL	219	1.00	180	1740	1.35	160	1550	1.44
5	STD-MOD	219	0.75	180	3100	0.85	116	2000	1.08
6	STD-MOD	219	0.50	180	6980	0.43	55	2140	0.84
7	STD-MOD	219	0.25	180	27 900	0.11	15	2370	0.54
8	LRG	487	1.00	180	784	2.06	197	857	1.97
9	LRG	487	1.00	180	784	2.06	201	878	1.94
10	LRG-CAL	487	1.00	180	784	2.06	196	855	1.97
[C]	LRG-MOD	487	0.75	180	1390	1.31			
[C]	LRG-MOD	487	0.50	180	3140	0.68			
[C]	LRG-MOD	487	0.25	180	12 500	0.19			

[A] Property of Abbott Laboratories, Mountain View, CA

[B] The numbering system was used for identification purposes only.

[C] These sampling heads were not evaluated, but the data are presented for illustrative purposes.

inefficiency in collecting small particles were previously reported.[4]

The SAS samplers operate similarly in principle to the 6-STG sampler. The SAS high flow (SAS-HF) sampler has a nominal flow rate of 180 L/min and is powered by a portable 12-volt battery. The Compact SAS (SAS-C) has a nominal flow rate of 90 L/min and is powered by a 6-volt battery located in the central body of the sampler. The SAS samplers have a solid-state sampling timer. Users can select a sampling time of 20 to 300 sec in 20-sec intervals (also referred to as "aspirating units"). The standard sampling head has 219 1-mm holes (STD 1.00-mm). To collect particles 65-mm × 15-mm, Replicate Organism Detection and Counting (RODAC®, Becton Dickinson, Cockeysville, Md.) plates filled with approximately 13 mL of agar were used under the sampling head. Three of the modified sampling heads have the same hole pattern as the standard sampling head; however, the holes are 0.25-, 0.50-, and 0.75-mm in diameter (STD-MOD 0.25-mm, STD-MOD 0.50-mm, and STD-MOD 0.75-mm). The fourth modified sampling head has 487 1-mm holes (LRG 1.00-mm) and requires 91-mm × 19-mm RODAC-like plates (P/N 4474, International PBI/Spiral Biotech, Inc.) filled with approximately 17 mL of agar so that the agar formed a convex meniscus at the rim of the plates.[5] The holes in the STD 1.00-mm sampling head are approximately the same diameter as the second stage of the 6-STG sampler; however, the cut-diameter (d_{50}) is 4.7 μm. Because the nominal SAS sampling rate is either 90 or 180 L/min, the d_{50} for the STD 1.00-mm is either 1.94 μm or 1.35 μm, respectively.[4-5] Theoretical

TABLE II. Theoretical and Actual Operating Characteristics and Sampling Parameters of the SAS-C Samplers

Sampling Head[C]	Type Head	# Holes	d_j mm	Theoretical Q L/min	Theoretical V_j cm/sec	Theoretical d_{50} μm	Actual[A] Q L/min	Actual[A] V_j cm/sec	Actual[A] d_{50} μm	Actual[B] Q L/min	Actual[B] V_j cm/sec	Actual[B] d_{50} μm
1	STD	219	1.00	90	872	1.94	78	751	2.10	66	635	2.29
2	STD	219	1.00	90	872	1.94	79	769	2.08	68	656	2.25
3	STD	219	1.00	90	872	1.94	83	803	2.03	72	695	2.18
4	STD-CAL	219	1.00	90	872	1.94	85	820	2.01	74	715	2.15
5	STD-MOD	219	0.75	90	1550	1.24	48	824	1.72	45	771	1.78
6	STD-MOD	219	0.50	90	3490	0.64	24	932	1.31	17	659	1.57
7	STD-MOD	219	0.25	90	14 000	0.18	12	1860	0.62	12	1860	0.62
8	LRG	487	1.00	90	392	2.94	106	460	2.71	79	346	3.15
9	LRG	487	1.00	90	392	2.94	106	460	2.71	79	346	3.15
10	LRG-CAL	487	1.00	90	392	2.94	100	436	2.79	76	330	3.21
[D]	LRG-MOD	487	0.75	90	697	1.88						
[D]	LRG-MOD	487	0.50	90	1570	0.99						
[D]	LRG-MOD	487	0.25	90	6280	0.30						

[A] Property of California Department of Health Services, Berkeley, CA

[B] Property of NIOSH, Cincinnati, OH

[C] The numbering system was used for identification purposes only.

[D] These sampling heads were not evaluated, but the data are presented for illustrative purposes.

operating characteristics and sampling parameters of the SAS-HF and SAS-C samplers, using different sampling heads, were calculated and are shown in Tables I and II.

The STD-CAL 1.00-mm and LRG-CAL 1.00-mm sampling heads are identical to the STD 1.00-mm and LRG 1.00-mm sampling heads except for three threaded holes for the PVK. These sampling heads were not evaluated in the field studies. Because of the low power of the air mover in each sampler and its inability to maintain sufficient air flow through the STD-MOD 0.25-mm sampling head, only four heads (STD 1.00-mm, STD-MOD 0.75-mm, STD-MOD 0.50-mm, and LRG 1.00-mm) were evaluated in the field.

The SAS sampling heads were autoclaved for sterility, and aluminum foil envelopes (around the samplers) were maintained intact until sampling. Between sampling runs all surfaces of the sampling heads were wiped with ethanol (70% in water) to minimize microbial contamination during sampling plate loading and unloading procedures and carry-over from prior sampling procedures. After sampling approximately 180 L of air or a maximum of 300 sec (in 20-sec increments), whichever was less, each plate was removed and handled as described below.

The 6-STG was used as a reference sampler for measuring particle size distribution during each sampling period. It is a cascade impactor with 400 holes per stage, designed to be operated at a flow rate of 28.3 L/min. The d_{50} cut-points for stages 1–6 of the 6-STG sampler have been reported to be 7.0, 4.7, 3.3, 2.1, 1.1, and 0.65 μm, respectively.[6] Disposable 100-mm × 15-mm sterile plastic petri plates (08–757–13, Fisher Scientific, Pittsburgh, Pa.) were filled with 45 mL of agar such that the gap between the nozzles and agar surface met the manufacturer's specification.[7–8] The 6-STG sampler was autoclaved and handled aseptically as were the SAS samplers. After sampling approximately 170 L of air (360 sec), the plates were removed and handled as described below. The colony forming unit (CFU) counts on all six plates were combined for analysis. The volumetric flow rate of air through the 6-STG sampler was calibrated to within the manufacturer's specifications using a primary standard (spirometer).[9] During the field studies, the flow rate through the 6-STG was verified to be within the manufacturer's specification using a dry gas meter (Parkinson Cowan Industrial Products, London, England) before sampling. The dry gas meter had been previously calibrated against the same primary standard.

Malt extract agar (DIFCO Laboratories, Detroit, MI) was used to collect and culture fungi, and tryptic soy agar (DIFCO) was used to collect and culture bacteria. The sampling plates containing agar were removed from the samplers after each use, covered, inverted, incubated at either room temperature (22°C) for fungi or 30°C for bacteria, and counted after 24–72 hours. Because some microorganisms may inhibit the growth of others and identification of more than one fungal or bacterial colony at an impaction point is difficult, a positive hole statistical adjustment was made to all data. Detailed discussions of the positive hole statistical adjustment for the 6-STG are found in the literature.[6,10–12] Tables for the 219- and 487-hole impactors are available from the manufacturer (included in the newer operating manuals), or tables may be generated as described in references 11 and 12.

In the Site A study, a SAS-HF sampler, two SAS-C samplers, and a 6-STG sampler were used. The SAS samplers were oriented with the sampling heads perpendicular to the table top, while the 6-STG sampler impactor stages were parallel to the table top. The four samplers were started simultaneously. Each of the three SAS samplers was evaluated with each of the four different SAS sampling heads, with five replicates. The order in which the sampling heads were evaluated was random by use of a pseudo-random number generator.

One SAS-C sampler (NIOSH) and a 6-STG sampler were used in the Site B study. The samplers were oriented and operated as described for the previous study. Each of the four different SAS sampling heads was evaluated with 20 replications, in the hope that sufficient power would be obtained to determine differences between the samplers and among the sampling heads. The order in which the sampling heads were evaluated was randomized as previously mentioned.

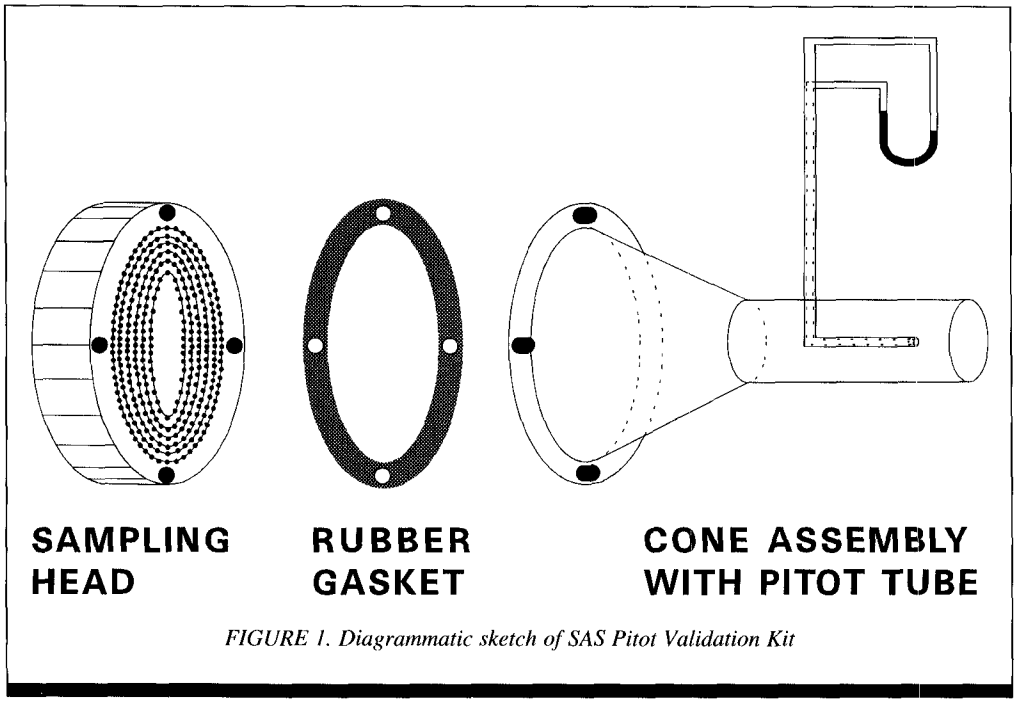

FIGURE 1. Diagrammatic sketch of SAS Pitot Validation Kit

Evaluation of Pitot Validation Kit

Prior to the purchase of the PVK, the author calibrated the flow rate of the SAS samplers by exhausting a measured volume (90 L) of air from a plastic bag through each SAS sampler and recording the sample time. Once the PVK was received, the time necessary to pull 90 L of air from a

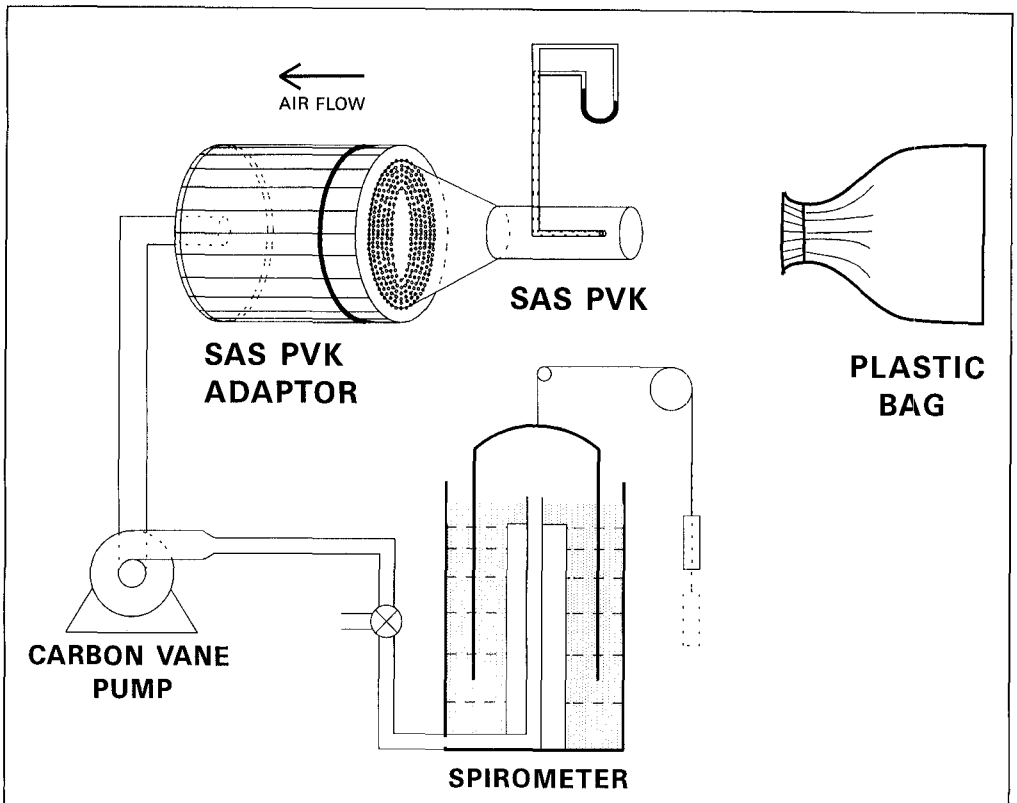

FIGURE 2. Equipment setup for calibration of the SAS PVK by spirometer and plastic bag methods

plastic bag through the PVK and each SAS sampler was recorded. A discrepancy in the calculated flow rates was observed and the PVK was further evaluated.

The PVK, shown in Figure 1, consists of a sampling head (STD-CAL 1.00-mm or LRG-CAL 1.00-mm), rubber gasket, cone assembly, Pitot tube, inlet pipe, and a manometer. The Pitot tube is located along the center line of the 100-mm inlet pipe of the cone assembly, approximately 1.2 inlet pipe diameters (d = 24 mm) from the opening.

The PVK cone assembly, which had been securely fastened with machine screws to a sampling head, was modified as follows. The PVK cone assembly from the LRG-CAL 1.00-mm sampling head was used. (The PVK cone assembly from the STD-CAL 1.00-mm sampling head was not used because it blocked some of the holes on the LRG 1.00-mm sampling head.) After separating the cone assembly from the LRG-CAL 1.00-mm sampling head, a washer-shaped gasket was glued to the end of the PVK cone assembly with silicone caulking. The PVK cone assembly and gasket were placed firmly against the sampling head attached to a SAS sampler. This modification allowed for rapid flow rate measurements of all sampling heads being evaluated. The molded plastic manometer included in the PVK (Mark II, Model MM-80, Dwyer Instruments Inc., Michigan City, Mich.) was scaled such that only the lower 0.5–5.5% of the 0–80 mm range was used. This led to an insensitive and possibly inaccurate estimate of the velocity pressure.

To enhance the confidence in the measurement of the centerline velocity pressure (VP_{CL}), an electronic digital micromanometer (Model EDM-I, Neotronics, Bishop's Stratford, Hertfordshire, England) was used in place of the plastic manometer. The center line velocity (V_{CL}) in the inlet pipe of the PVK cone assembly was calculated from the center line velocity pressure. The average velocity (V_{AVG}) through the inlet pipe of the cone assembly was estimated by multiplying the center line velocity by 0.9.[13] The average flow rate (Q_{AVG}) through the PVK cone assembly inlet pipe was calculated from the average velocity in the inlet pipe of the cone assembly and the cross-sectional area (A_{PIPE}) of that inlet pipe. The following equations were used to calculate the flow rate:

$$V_{CL} = 242{,}600 \cdot \sqrt{VP_{CL}} \quad (1)$$

$$V_{AVG} = 0.9 \cdot V_{CL} \quad (2)$$

$$Q_{AVG} = \frac{A_{PIPE} \cdot V_{AVG}}{10^6\ mm^3/L}. \quad (3)$$

V_{CL} is in mm/min, VP_{CL} is in mm H_2O, V_{AVG} is in mm/min, Q_{AVG} is in L/min, and A_{PIPE} is 438 mm^2. The manufacturer's literature, however, incorrectly indicated that V_{CL} equals V_{AVG}.[14]

During the surveys at Sites A and B, the flow rate through the SAS-C and SAS-HF samplers, for each of the evaluated sampling heads, was measured using the PVK (n = 10). The air flow rates were adjusted as described above and are shown in Tables I and II.

In a later laboratory evaluation the flow rate through a SAS-C and a SAS-HF sampler with STD 1.00-mm sampling heads was measured using the PVK (n = 10). In addition, a measured volume (90 L) of air was exhausted from a plastic bag through the PVK to each SAS sampler and the time recorded. Then the PVK was removed, and 90 L of air was exhausted directly into each SAS sampler (n = 10). The PVK was calibrated by pulling air through the STD 1.00-mm sampling head using a carbon vane pump and measuring the volume of air with a spirometer (n = 10). The laboratory equipment setup for calibration of the PVK by spirometer and plastic bag methods is shown in Figure 2. In addition, factors that affected the measurement of flow rate using the PVK were observed (e.g., Pitot tube alignment, room air currents, and local air flow patterns).

While using the older SAS-C sampler (ca. 1986, NIOSH) in other studies, a significant drop in air flow rate was observed within one hour of operation. Different air movers and batteries are installed in the SAS samplers currently on the market. In parallel with this study, the air flow rate through new (1993) SAS-C and SAS-HF samplers was measured, using the PVK, as

TABLE III. Geometric Mean (GM), Geometric Standard Deviation (GSD), Range of Data, and 95% Confidence Limits About the GM (CLM) Bacterial and Fungal Concentrations (CFU/m^3)

Site ID	n	Sampler ID	Sampling Head	Bacteria GM	Bacteria GSD	Bacteria Range	Bacteria CLM	Fungi GM	Fungi GSD	Fungi Range	Fungi CLM
A	5	SAS-C[A]	1	44.3	1.67	19–75	21.6–90.6	19.4	2.28	4–42	6.18–60.7
A	5	SAS-C[A]	5	47.8	1.94	20–99	19.0–120	22.5	3.51	3–102	3.94–129
A	5	SAS-C[B]	6	39.6	1.42	22–66	24.3–64.5	14.2	1.28	9–18	10.1–20.0
A	5	SAS-C[B]	8	33.6	1.32	25–56	22.8–49.3	12.9	1.45	7–21	7.73–21.7
A	5	SAS-HF[C]	1	31.4	1.67	12–55	15.4–64.0	11.6	1.77	4–18	5.22–25.7
A	5	SAS-HF[C]	5	49.5	1.47	24–75	29.1–84.4	22.7	3.14	3–92	4.63–111
A	5	SAS-HF[C]	6	59.6	1.49	38–109	34.1–104	32.7	2.65	7–85	8.43–127
A	5	SAS-HF[C]	8	36.4	1.78	19–99	16.4–80.8	17.3	3.29	3–80	5.22–25.7
A	5	6-STG		49.2	1.25	35–65	36.2–66.9	22.4	2.06	11–74	8.2–61.1
B	5	SAS-C[A]	1	47.2	1.43	26–80	28.7–77.6	102	1.18	81–121	81.1–127
B	5	SAS-C[A]	5	75.4	1.29	55–119	53.0–107	130	1.32	92–176	88.0–193
B	5	SAS-C[B]	6	43.4	1.54	19–78	22.9–81.9	93.6	1.75	31–142	42.9–204
B	5	SAS-C[B]	8	44.0	1.59	19–79	23.1–83.8	102	1.29	66–130	71.4–146
B	5	6-STG		73.7	1.30	51–116	50.9–107	143	1.56	59–189	77.2–226
B	20	SAS-C[A]	1	44.7	1.48	18–80	37.0–54.0	101	1.20	69–141	95.5–107
B	20	SAS-C[A]	5	69.5	1.32	29–199	60.8–79.5	174	1.34	92–305	158–192
B	20	SAS-C[A]	6	44.3	1.44	19–78	37.2–52.7	128	1.45	31–199	113–145
B	20	SAS-C[A]	8	43.4	1.61	12–82	34.5–54.5	115	1.23	66–197	107–122
B	20	6-STG		70.7	1.32	30–116	62.0–80.7	173	1.40	59–430	155–192

[A] Property of NIOSH, Cincinnati, OH
[B] Property of California Department of Health Services, Berkeley, CA
[C] Property of Abbott Laboratories, Mountain View, CA

the batteries were discharged. The flow rate was measured using the PVK and the appropriate equation was used to calculate the flow rate. The samplers were operated for 300 sec for a series of 14 replicates. The velocity pressure in the PVK was measured at the beginning of each sampling period using a micromanometer.

Statistical Analysis

All statistical analyses were performed using SAS Version 6.04 (SAS Institute Inc., Cary, N.C.) Test statistics were generated for testing the null hypothesis that the input data from each set of experiments were a random sample from a normal distribution.[15] If the input data were not normally distributed, the logarithmic transformations of the input data were tested for normality. The microorganism concentration data were lognormally distributed and the PVK flow rate data were normally distributed.

Linear regression models (least-squares) were performed on the sampling head evaluation data, with the logarithmic transformation of the concentration of culturable fungi or bacteria as the dependent variable and the sampler/sampling head combination as the independent variable. Test statistics also were generated and evaluated for testing the null hypothesis that the residual data (input data minus predicted data) were a random sample from a normal distribution.

Student's t-statistic was used for testing the null hypothesis that the mean difference between the indicated flow rate and the actual flow rate through the PVK was zero.[15-16] Linear regression analysis of the PVK data with the actual flow rate as the dependent variable and the indicated flow rate as the independent variable was performed.[16]

RESULTS

Evaluation of SAS Samplers and Sampling Head Combinations

Actual operating characteristics and sampling parameters of the SAS-HF and SAS-C samplers, using different sampling heads, were measured or calculated and are shown in Tables I and II. Theoretical d_{50} cut-points, calculated from measured flow rates, are listed for each sampler/sampling head combination. The results of these combination evaluations are listed in Table III and graphed in Figures 3, 4, and 5. In the Site A study (Figure 3) no significant differences were observed in the concentration of bioaerosol collected among any of the sampler/sampling head combinations or between the two SAS samplers, or the SAS and 6-STG samplers. Similar results were obtained from the Site B data when only the first five replicates were analyzed (Figure 4). However, when all 20 replicates were included in the analysis, the SAS-C with STD 1.00-mm, STD-MOD 0.50-mm, and LRG 1.00-mm sampling heads statistically undersampled the 6-STG sampler and the SAS-C sampler with the STD-MOD 0.75-mm sampling head (Figure 5). The geometric mean (GM), GSD, range of data, and 95% confidence limits about the GM (CLM) bacterial and fungal concentrations for both Sites A and B are shown in Table III.

A decrease in air flow rate through each of the new SAS samplers was observed as each battery was discharged (20% and

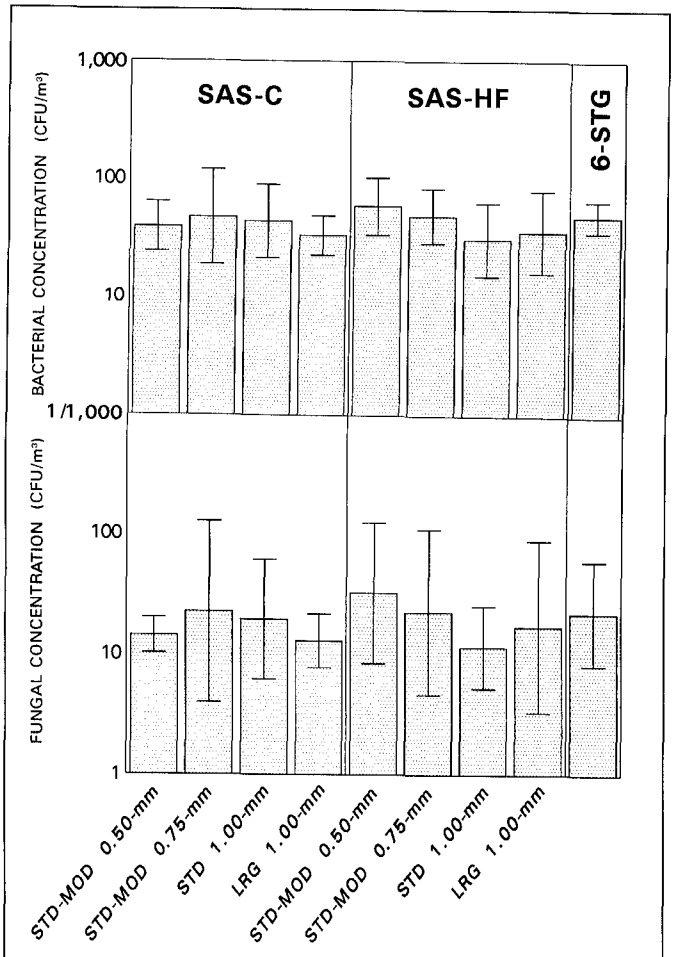

FIGURE 3. Summary of geometric mean (pattern bars) and upper and lower confidence limits (error bars) for bacterial and fungal concentrations (CFU/m³), by sampler/sampling head combination, Site A study (n = 5)

2% reductions for new SAS-C and SAS-HF samplers, respectively, after 70 minutes of operation). The lowest measured flow rate through each of the new SAS samplers was 95 and 190 L/min for the SAS-C and SAS-HF, respectively.

Particle size distribution information was obtained from the log-probability plots of the bacterial and fungal aerosols of Sites A and B.[17] The bacterial aerosols had count median aerodynamic diameters (CMAD) of 1.8 μm and 1.5 μm with GSD of 2.1 and 1.8 for Sites A and B, respectively. The fungal aerosols had CMAD of 3.9 μm and 3.3 μm with GSD of 2.5 and 2.4 for Sites A and B, respectively.

Evaluation of Pitot Validation Kit

The PVK flow rate measurements, calculated using the modified flow equations, were not significantly different from the flow rates measured using a spirometer. However, for flow rates greater than approximately 40 L/min, the PVK flow rate measurements, calculated using the manufacturer's equations, were significantly greater than the flow rates measured using a spirometer. A statistically significant increase (10%) in flow rate through the SAS-C was observed after the PVK was removed from the sampling head (Table IV). No statistically significant difference in flow rate through the SAS-HF was observed after the PVK was removed, when measured by the plastic bag method. The PVK calibration data are shown in Figure 6. The slope of the calibration line was 0.938 with a standard error (SE) of 0.0169. The intercept was 0.986 L/min with an SE of 1.36 L/min.

DISCUSSION AND CONCLUSIONS

The size distributions of the bacterial and fungal aerosols at the test sites were variable. A large proportion of bacteria-carrying and fungal spore-carrying particles, 91–98% and 60–68%, respectively, were smaller than 5 μm. This finding supports the results of Nevalainen, who also reported that most airborne culturable bacteria indoor are smaller than 5 μm.[18–19] In a study of

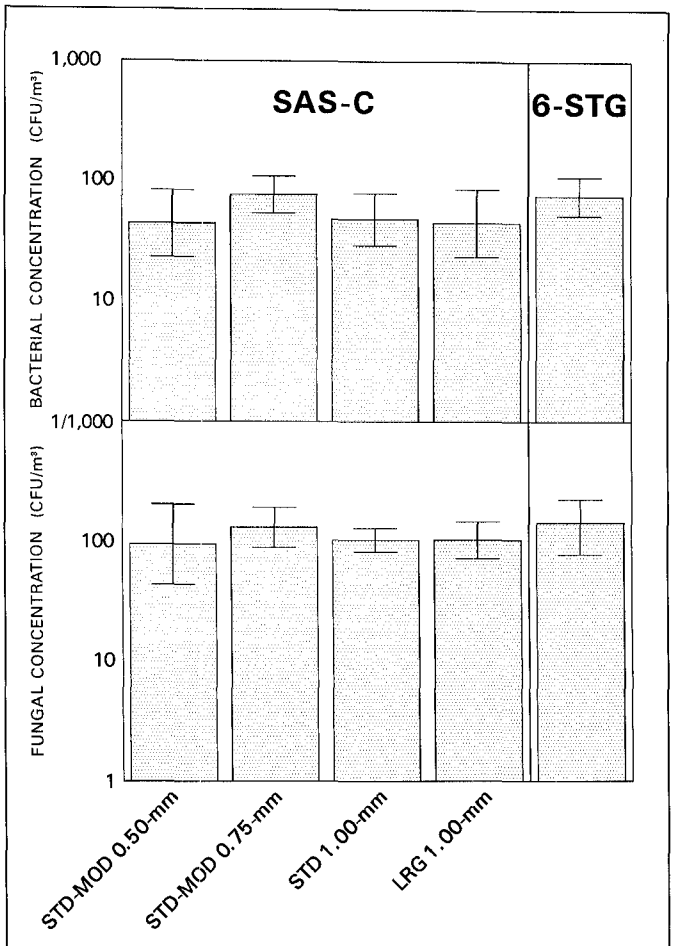

FIGURE 4. Summary of geometric mean (pattern bars) and upper and lower confidence limits (error bars) for bacterial and fungal concentrations (CFU/m³), by sampler/sampling head combination, Site B study (n = 5)

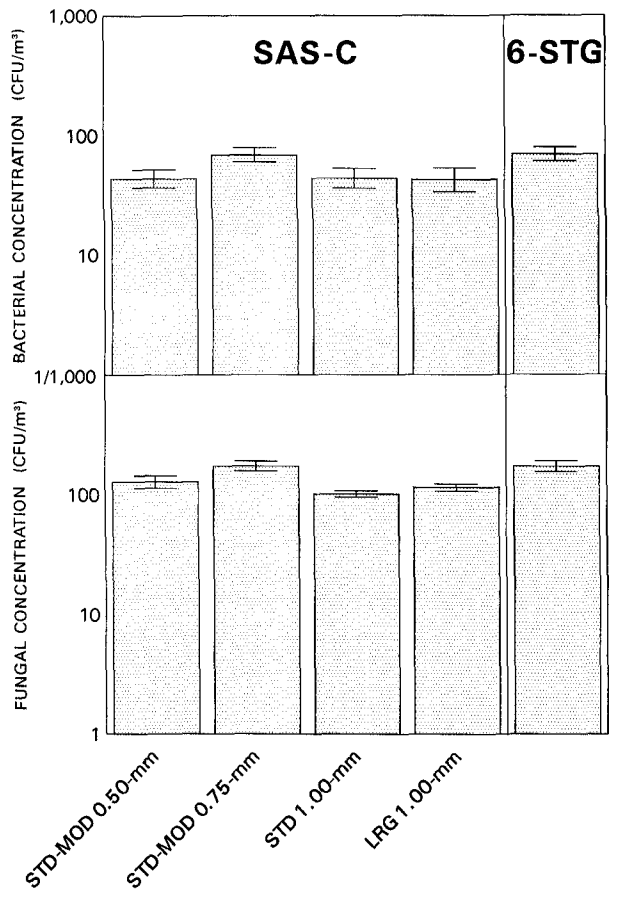

FIGURE 5. Summary of geometric mean (pattern bars) and upper and lower confidence limits (error bars) for bacterial and fungal concentrations (CFU/m³), by sampler/sampling head combination, Site B study (n = 20)

TABLE IV. Flow Rate Through the SAS-C and SAS-HF Sampler With and Without the PVK

Sampler	Mean (L/min)	95% Confidence Interval about the Mean (L/min)	n
SAS-C with PVK	69.0	±1.52	10
SAS-C without PVK	76.1	±0.96	10
SAS-HF with PVK	167	±2.88	10
SAS-HF without PVK	174	±3.51	10

Hawaiian homes Kodama and McGee found that 80% of the fungi collected were of respirable size (< 8.0 μm) while 40% of the bacteria were found to be of respirable size.[20] In a study of a Californian apartment Macher et al. found indoor CMAD of bacterial and fungal aerosols to be 3.0 and 3.4 μm, while the CMAD of outdoor bacterial and fungal aerosols were 3.4 and 3.9 μm.[21] However, this finding differs from the results of others. Noble et al. reported that organisms associated with human disease (bacteria and fungi) were usually found on particles with a CMAD range of 3–22 μm.[22] Others reported that most culturable microorganisms in outdoor air were larger than 5 μm.[23–24]

The SAS manufacturer succeeded in increasing the particle collection efficiency of samplers by decreasing hole diameter; however, a small sample size (n = 5) was not sufficient to detect differences in the concentration of collected bioaerosols between sampler/sampling head combinations at two sites. The results show that the 6-STG and SAS-C (STD-MOD 0.75-mm) samplers collected comparable amounts of bioaerosol with the larger sample size (n = 20), and all samplers collected comparable amounts of bioaerosol with the smaller sample size (n = 5). In addition, the results show the difficulty in obtaining reasonable confidence limits with a sample size of five. The combination of a small sample size and high variability made it difficult to see small but real differences between sampler/sampling head combinations. Such small differences may be significant if the concern is an infectious agent; however, they may be insignificant when sampling normal microflora. In addition, because the CMAD of the fungal aerosols (3.4 μm) was greater than the d_{50} cut-points for all SAS sampler/sampling head combinations, no difference in collection efficiency of fungi should have been observed, based on particle physics. The variability of environmental data and the decrease in flow rate through the SAS sampler with the STD-MOD sampling heads confirm the results of Pan et al.[25] An earlier study showed that the SAS-C sampler with the STD 1.00-mm sampling head significantly undersampled the 6-STG sampler when sampling free bacteria with a CMAD of 1.4 μm and a GSD of 1.3.[4]

The power of the SAS fans (SAS-C and SAS-HF) varies with the voltage applied. A fully charged battery would result in a significantly higher flow rate than one that is almost completely discharged. The air movers in the SAS samplers are not powerful enough to overcome the pressure drop across a dry gas meter,

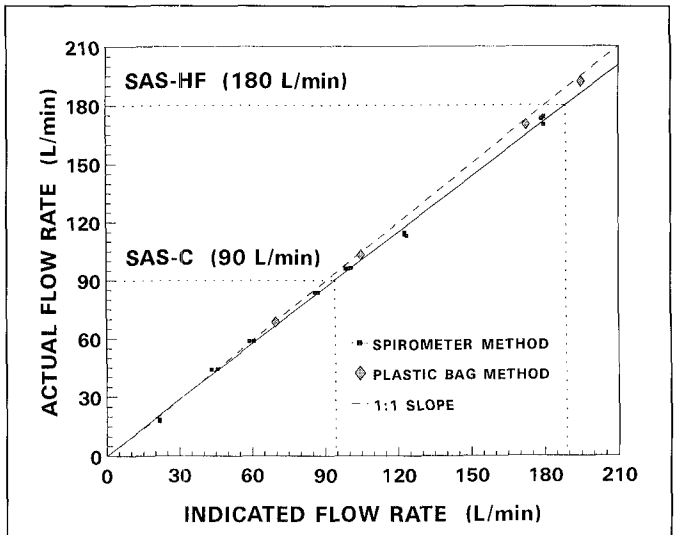

FIGURE 6. Calibration of the SAS PVK by spirometer and plastic bag methods; indicated flow rate versus actual flow rate through the SAS PVK

and a marked decrease in air flow was observed with decreasing sized holes in the sampling heads (see Tables I and II).

The PVK may be used as an accurate flow rate measurement device with the SAS-HF if Equations 1–3 are used for computation. For the SAS-C sampler, the equation in the manufacturer's literature provides an accurate estimation of V_{AVG}. This is the result of the 10% drop in the observed flow rate due to the pressure drop across the PVK. Other factors that influence the flow rate measurement include the alignment of the Pitot tube in the PVK, power of the sampler fan (fan static pressure), accurate measurement of the VP_{CL}, and room air currents near the PVK. The Pitot tube must be aligned along the center line of the PVK inlet pipe. Ideally, the center line reading should be taken 10 diameters of inlet pipe downstream from the nearest disturbance (i.e., the opening).[13] Unfortunately, the Pitot tube is located only approximately 1.2 inlet pipe diameters from the opening. Instead of the manometer supplied by the manufacturer, a Hook gage or a hand-held digital micromanometer should be used with the PVK. Use of the PVK should be limited to areas where room air currents are minimized.

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