School of Environmental and Biological Sciences
BIOAEROSOL RESEARCH AND TECHNOLOGY

Evaluation of SKC PPI impactor performance

Project Report

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Date: __July 19th, 2021_

PI's Signature: Gediminas Mainelis

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Objective

The goal of this project is built upon the earlier performed testing of respirable SKC PPI impactors, namely the disposable models operating at 2 and 4 L/min and reusable models operating at 2 and 4 L/min. The goal of this particular test was to determine the collection efficiencies of disposable and reusable PPI impactor models operating at 8 L/min, referred to as 8-L/min-PPI and 8-L/min-Re-PPI, respectively. PPI impactors have been designed to follow ISO 7708/CEN criteria for respirable particles. Therefore, the following impactor performance parameters were determined or calculated:

a) Penetration efficiency as a function of aerodynamic particle diameter when challenged with polydisperse (NaCl) and monodisperse (polystyrene latex, or PSL) aerosol particles.
b) Cut-off size when challenged with polydisperse (NaCl) and monodisperse (polystyrene latex, or PSL) aerosol particles.
c) Bias map for the investigated impactors.

Methods

The performance of the SKC PPI impactors was investigated as follows:

a) Experimentally, using polydisperse NaCl particles, which were produced by aerosolizing liquid NaCl suspension. The aerodynamic diameter of the aerosolized NaCl was determined using an Aerodynamic Particle Sizer (APS) (TSI, Inc., Shoreview, MN).
b) Experimentally, using monodisperse polystyrene latex (PSL) particles of the following nominal sizes: 2.9 and 4.8 μm.
c) Theoretically, by calculating bias maps for all PPI models, when aerosol distributions with different mass median diameters and geometric standard deviations are used as challenge particles. Finally, the projected collected mass concentration is calculated based on the experimental data obtained through earlier steps.

For each step above, two disposable PPI impactors designed to operate at 8 L/min and one reusable PPI impactor designed to operate at 8 L/min were investigated. Thus, a total of three PPI impactors were tested.

In addition, one 8-L/min-PPI impactor was investigated when facing the airstream at a 180-degree angle (facing away from the airstream with test particles) and when facing the test particles at a 90-degree angle (facing sideways).

Experimental setup

The impactors were evaluated using the experimental setup shown in Picture 1. The investigators have used this setup in the previous testing of the SKC PPI impactors. Here, test particles are aerosolized using a Collison nebulizer operated at 2.0 L/min and 5 psi pressure. The produced aerosol is diluted with HEPA-filtered air at a flow rate of 10 L/min. This resulting aerosol passed through a charge neutralizer Po-210, and the neutralized aerosol stream was diluted further with a HEPA-filtered airflow of 202 L/min. The airflow was adjusted to achieve isokinetic sampling conditions for the reference probe in the test section. The final aerosol stream entered the mixing box, from where it was directed downward. First, the stream passed through two static blenders and a honeycomb section to mix and laminarize the flow and achieve even flow velocities in the test section. The laminar flow (Reynolds number = 1396) then entered the test section of 7.75 inches in diameter. In the test section, we positioned a PPI impactor to be tested and a reference probe. From the PPI impactor and the probe, vertical sampling lines extended downward and were connected to the Aerodynamic Particle Sizer (TSI, Inc.) (APS). Using the APS, we alternately measured the size distribution of aerosol that penetrated the PPI and the size distribution of aerosol sampled by the reference probe, i.e., reference aerosol. The uncollected particles exited the test system through an open-ended tube into an operating biosafety cabinet, where they were removed from the air system by filtration.

Sampling adapter and reference probe

The PPI impactors were tested with the filtration section removed, and, therefore, adapters were needed to secure the impaction section of the PPIs to the sampling line. Therefore, we designed and 3D printed a unique structure that served as the adapter for the PPI (Picture 2). The adapter for the Re-PPI has a “lip” to accommodate the Re-PPI structure, but its inner diameter is the same as that of the adapter for disposable PPI. The adapters were coated with copper-based conductive spray to minimize any static effects during sampling. In addition, since the goal was to determine each impactor’s collection efficiency, we used the actual impactor head as a reference. Here, the impaction plate of the PPI impactor was carefully removed, and the impactor head was combined with a 3D printed sharp-edged guide. The air velocity at the entrance of the guide was isokinetic relative to the chamber. Thus, the reference heads and adapters (Picture 2) were prepared for disposable and reusable PPI impactors. Also, since identical adapters downstream of the impactor are used for the impactor and for reference sampling, any transmission losses between the two are the same, and that allows for accurate determination of the PPI’s collection efficiency.

Measurement procedure

The air velocity in the test section was set to 0.12 m/s when testing 8-L/min-PPIs and 8-L/min-Re-PPI. The air velocity within the test chamber varied within 5%. Once the particle aerosolization started, the aerosol was allowed to equilibrate for 5-10 minutes to achieve a stable aerosol concentration in the test section as measured by the APS. Once the concentration was stable, we alternatively measured particle concentration leaving the impactor (C_{PPI}) and particle concentration sampled by the reference probe (C_{ISO}). Seven such interspersed measurements were performed (4 with the reference and 3 with the impactor), and they constitute one set of measurements. For each test impactor and each test particle type, three sets were performed with the PPI impactor situated to the left of the probe and three sets with the impactor situated to the right of the probe. We alternated their positions to account for any particle distribution variation inside the test section.

The penetration efficiency of each test was determined by comparing C_{ISO} and C_{PPI}:

$$Penetration = C_{PPI}/C_{ISO} \qquad (1)$$

The data presented below show the penetration efficiency of individual sets (6) and the average penetration efficiency for NaCl particles and PSL particles. The average data obtained with NaCl particles and PSL particles were fitted with a 3 parameter sigmoid regression function. The resulting functions and the cut-off sizes (d_{50}) are presented for each impactor.

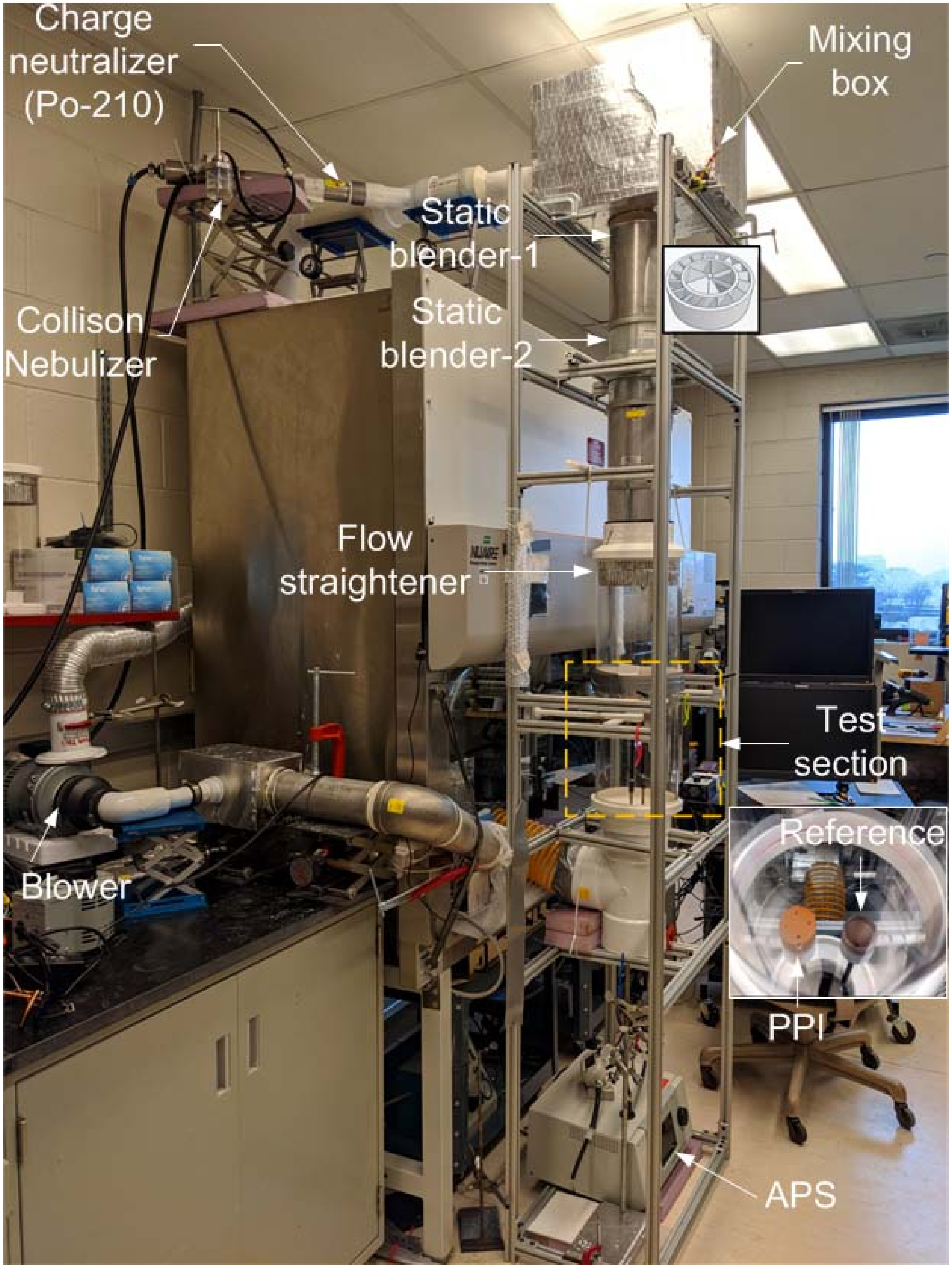
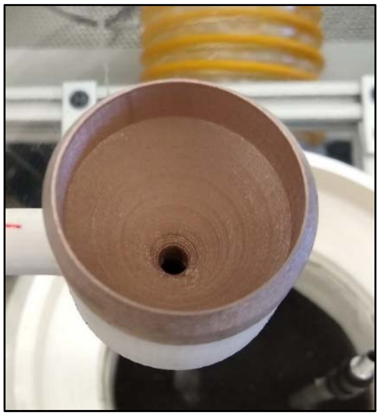
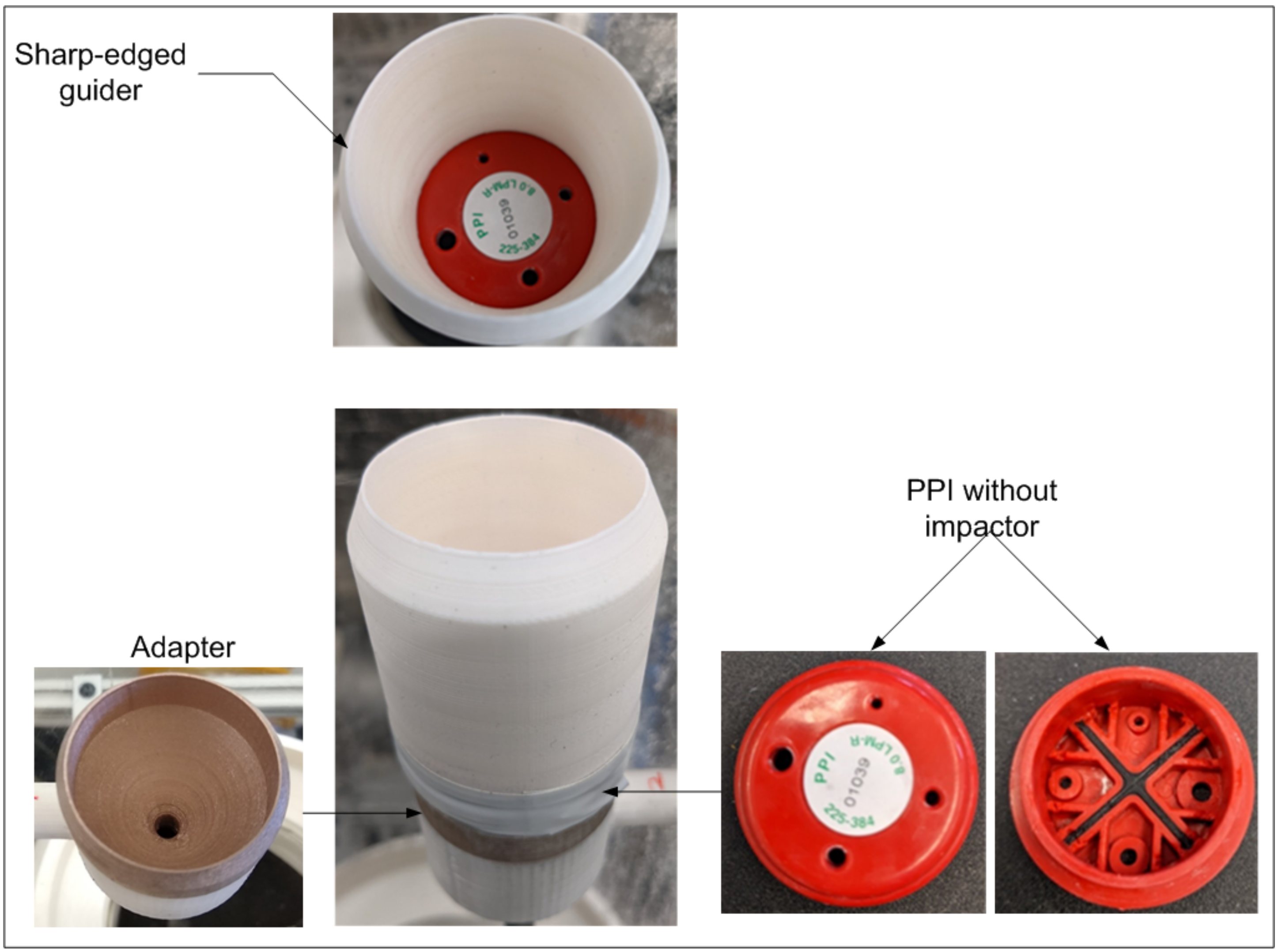


Figure 1. Schematic of the test set-up.



(a)

(b)



(c)

Picture 2. Adapters that were used to test PPI impactors: a) Adapter for disposable PPI. b) Adapter for Re-PPI. c) Adapters for the reference sampler (PPI inlet without impaction surface) and a sharp-edged inlet.

Bias Map

Once the particle penetration data for each PPI model was determined, a bias map for each PPI model and each additional test were calculated. The bias map shows the difference, or bias, Δ, between a mass concentration captured by the tested device, *C*, relative to the mass concentration C_R that would be captured by a reference device when both a challenged with the same aerosol (1):

$$\Delta \equiv \frac{C - C_R}{C_R} \qquad (2)$$

The reference device, in our case, was the ideal respirable sampling convention. Therefore, the bias map was generated for different hypothetical aerosols ranging in MMAD (mass median aerodynamic diameter) from 1 to 25 µm and having different size dispersions in terms of GSD (geometric standard deviation) that range from 1.75 to 3.5. However, biases for distributions beyond the line of MMAD= 10 µm and GSD = 1.5 and MMSD = 25 µm and GSD = 2.75 are not shown as they rarely occur (1). For the same reason, biases for MMAD = 1 µm and with GSD ranging from 2.25 to 3.5 are also not included.

Using bias data from all data points, we also calculated an average bias for each sampler of the test condition. The presented bias maps and color codes within the maps indicate how much a PPI oversamples or undersamples the aerosol mass compared to an ideal respirable sampler when challenged with different aerosols.

Results

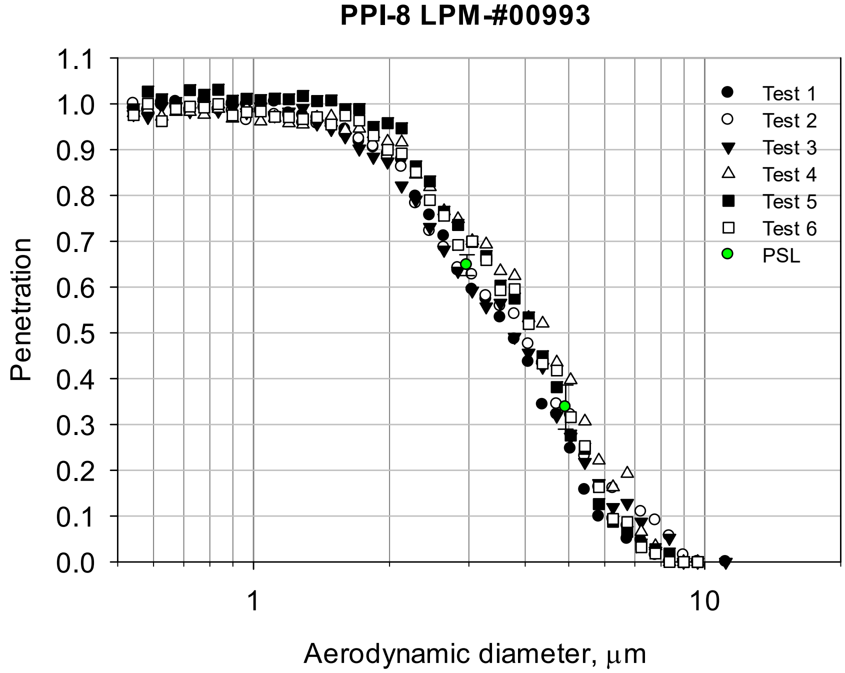
Three different PPI units were tested: SKC PPI 8 L/min (#00993 and #01252) and SKC Reusable PPI (Re-PPI) when operated at 8 L/min. In addition, the disposable PPI #01252 was also tested when facing away from the air stream and when facing sideways from the air stream. The summary of the data and plots for each individual unit and orientation are presented below.

Table 1. The summary of d_{50} cut sizes when the impactors were tested with polydisperse NaCl particles.

Impactor	***d_{50}*, µm**
PPI 8 L/min, #00993	3.81
PPI 8 L/min, #01252	3.87
PPI 8 L/min, average	*3.84 ± 0.04*
Re-PPI, 8 L/min	4.27
PPI 8 L/min (#01252), facing down	4.13

With sharp-edged guide (**impactor head as a reference**)

(a)



(b)

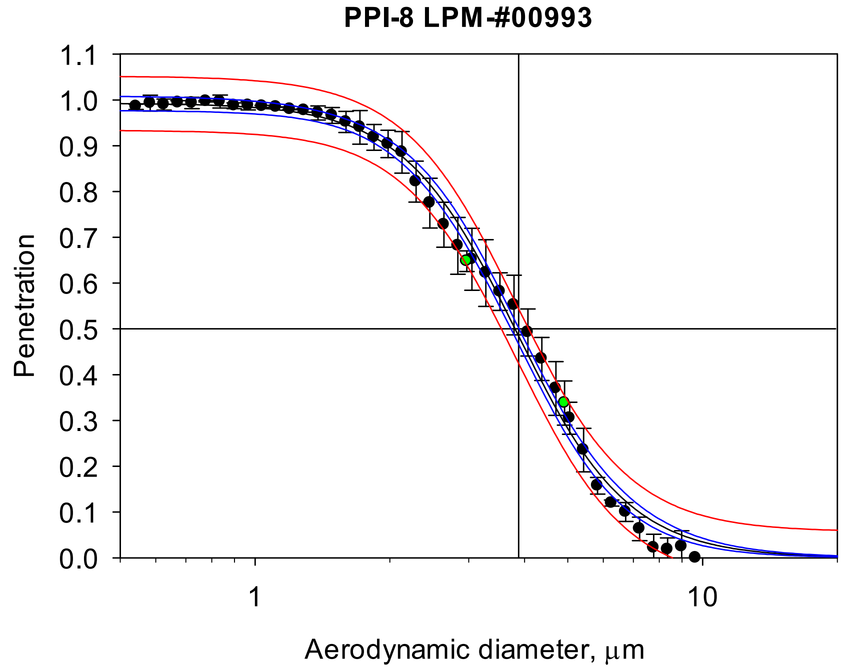


Figure 1. SKC PPI-8 L/min impactor's penetration curve as a function of particle size: a) individual data points of the six tests and b) average values and standard deviations for each particle size based on six tests.

The data were fitted with a 3 parameter sigmoid regression equation resulting in the following equation:

with NaCl: $$\eta = \frac{0.9928}{1+\left(\frac{dp}{3.824}\right)^{3.447}} \quad R^2=0.9944 \qquad (1)$$

Based on the fit, the d_{50} cut size (aerodynamic particle size at which 50% penetration occurs) of the impactor for each particle type was 3.81 μm (with NaCl) for the operating flow rate of 8 L/min.

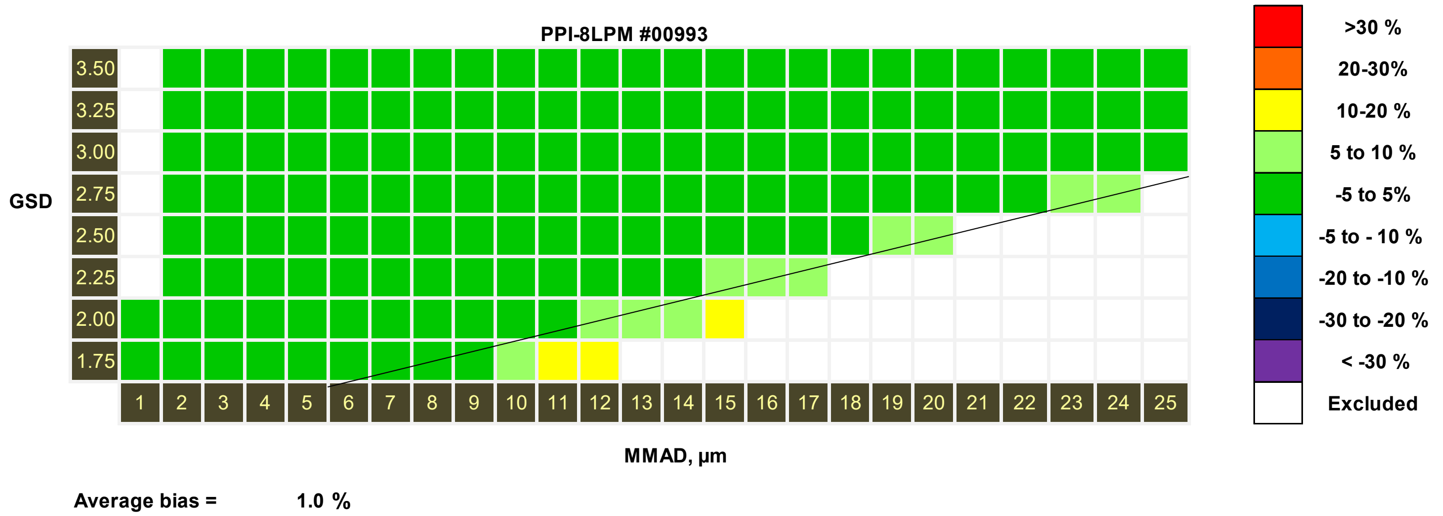
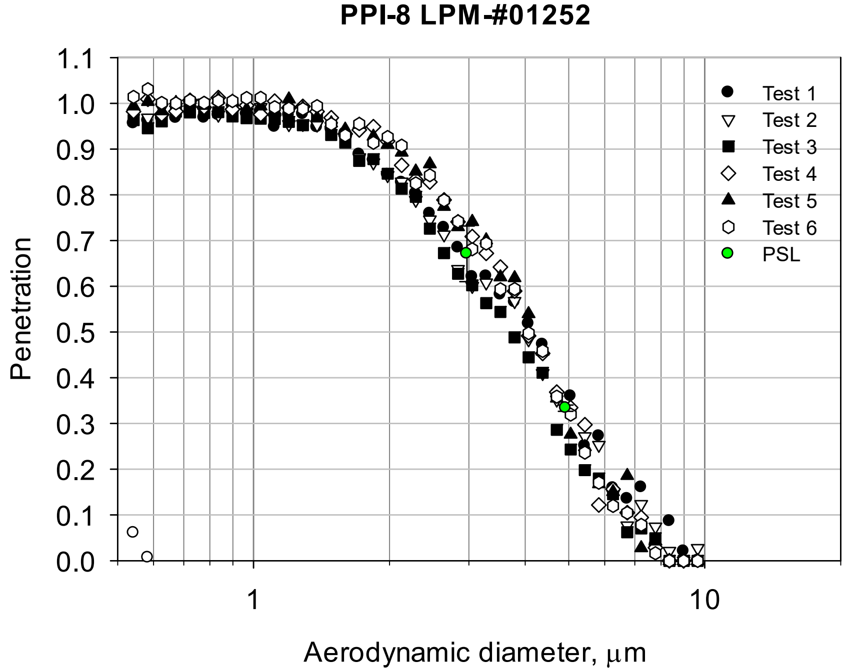


Figure 1c. Bias map for the SKC 8-L/min-PPI impactor (#00993) for different particle size distributions (MMAD and GSD).

With sharp-edged guide (**Impactor head as a reference**)

(a)



(b)

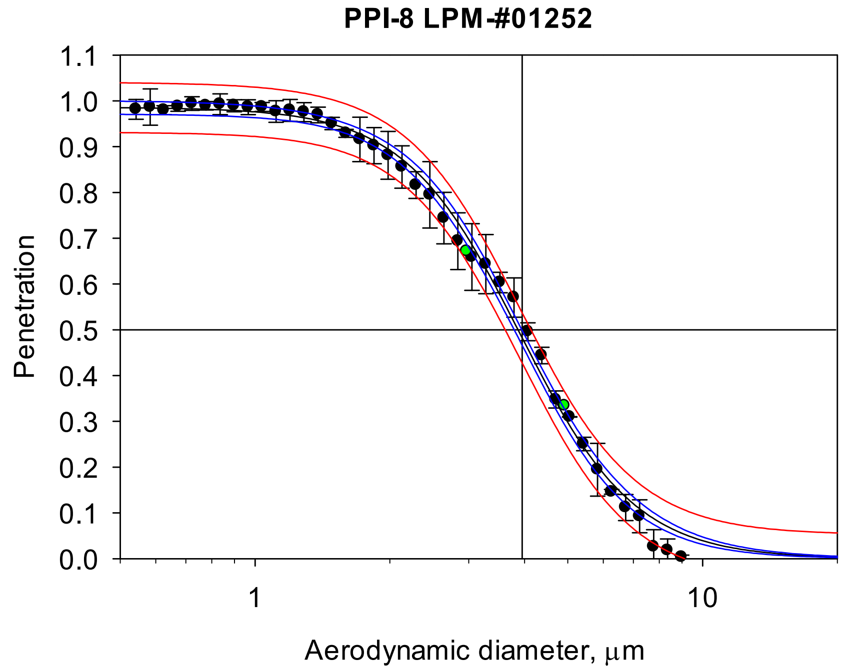


Figure 2. SKC PPI-8 L/min impactor penetration curve as a function of particle size: a) individual data points of the six tests and b) average values and standard deviations for each particle size based on six tests.

The data were fitted with a 3 parameter sigmoid regression equation resulting in the following equation:

with NaCl: $$\eta = \frac{0.9858}{1+(\frac{dp}{3.9})^{3.374}} \quad R^2=0.9948 \qquad (2)$$

Based on the fit, the d_{50} cut size (aerodynamic particle size at which 50% penetration occurs) of the impactor for each particle type was 3.87 μm (with NaCl) for the operating flow rate of 8 L/min.

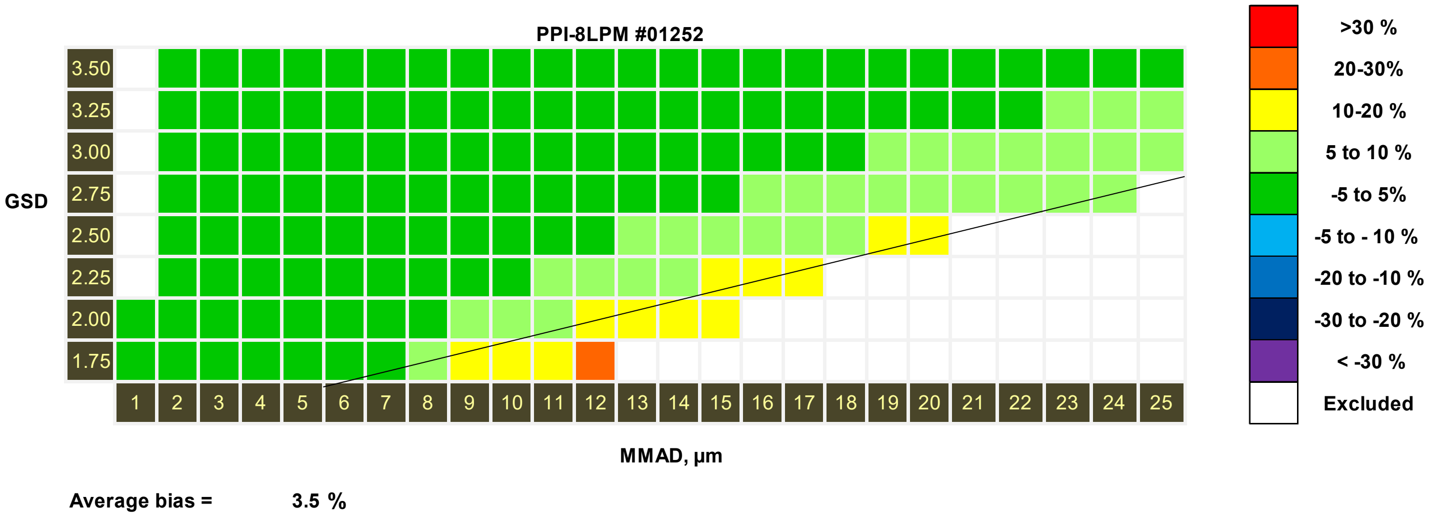
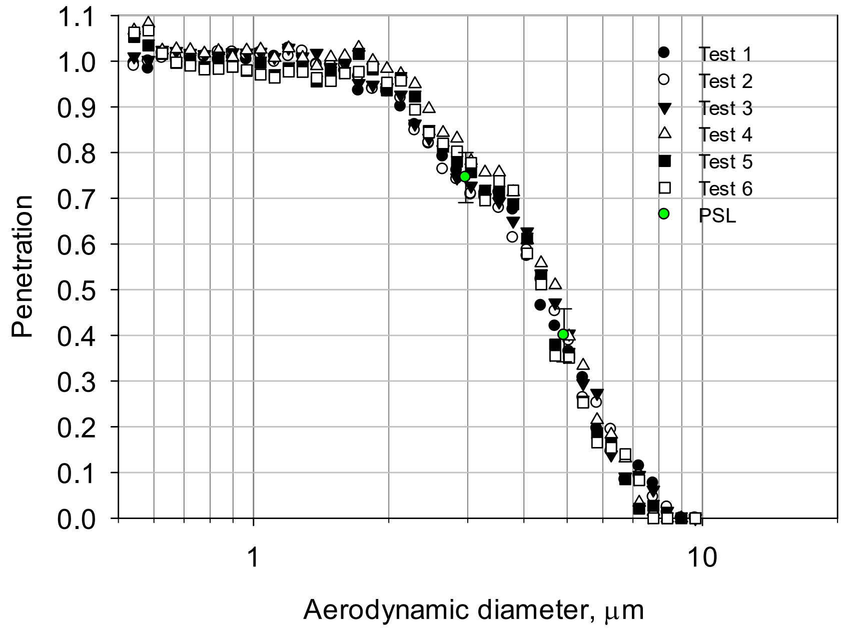


Figure 2c. Bias map for the SKC 8-L/min-PPI impactor (#01252) for different particle size distributions (MMAD and GSD).

With sharp-edged guide (**Impactor head as a reference**)

(a)

RePPI-8 LPM



(b)

RePPI-8 LPM

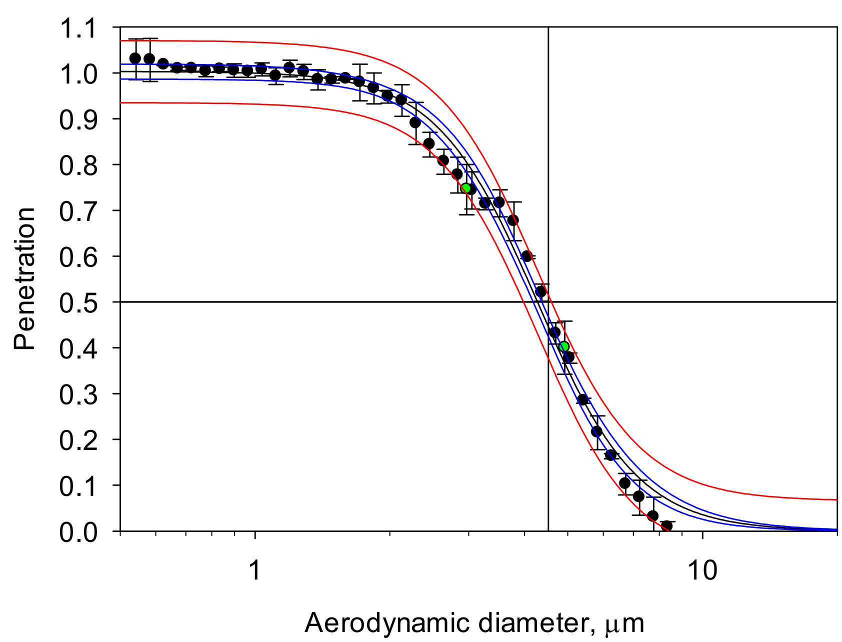


Figure 3. SKC RePPI-8 L/min impactor penetration curve as a function of particle size: a) individual data points of the six tests and b) average values and standard deviations for each particle size based on six tests.

The data were fitted with a 3 parameter sigmoid regression equation resulting in the following equation:

with NaCl: $$\eta = \frac{1.003}{1+(\frac{dp}{4.266})^{3.871}} \quad R^2=0.9913 \qquad (5)$$

Based on the fit, the d_{50} cut size (aerodynamic particle size at which 50% penetration occurs) of the impactor for each particle type was 4.27 μm (with NaCl) for the operating flow rate of 8 L/min.

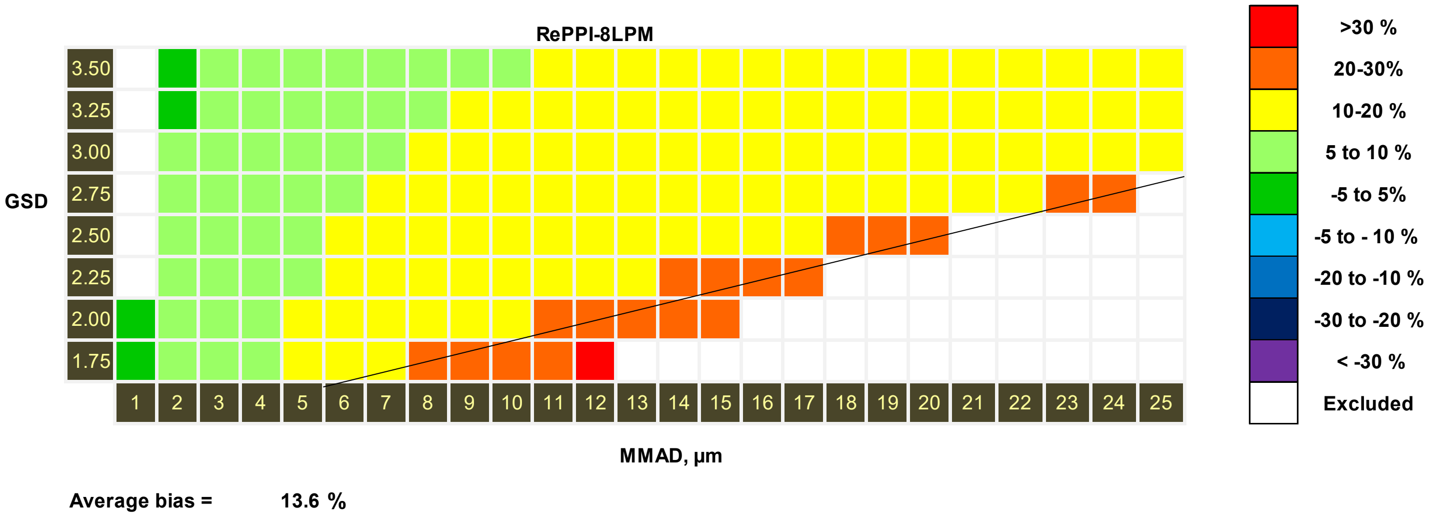


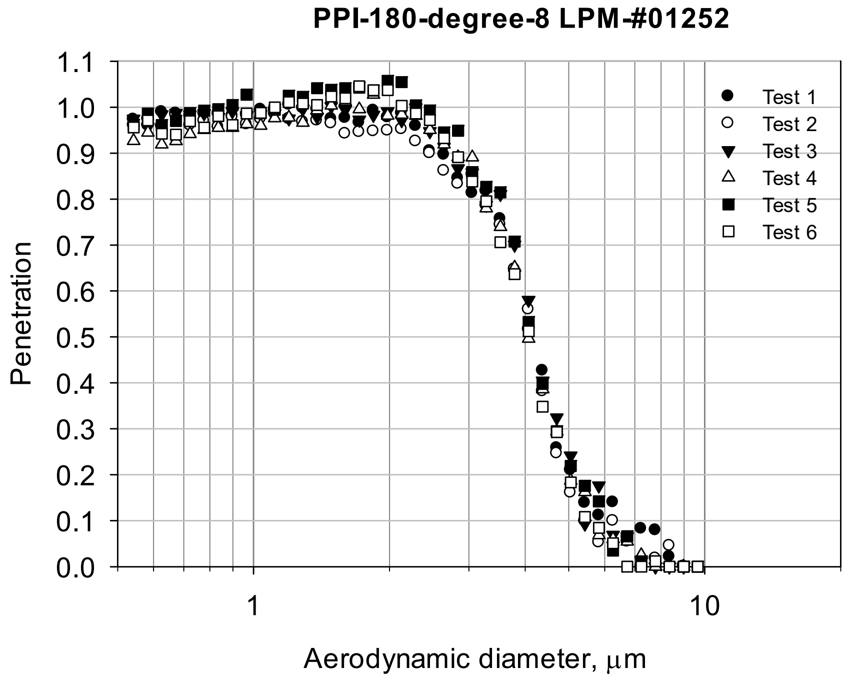
Figure 3c. Bias map for the SKC 8-L/min-RePPI Impactor for different particle size distributions (MMAD and GSD).

Test of PPI-8 L/min when facing down (180 degrees to the aerosol stream)

Picture 3. Location and orientation of PPI-8 L/min impactor in the test chamber when it was tested facing down. This test was performed with NaCl particles only.

PPI facing down

(a)



(b)

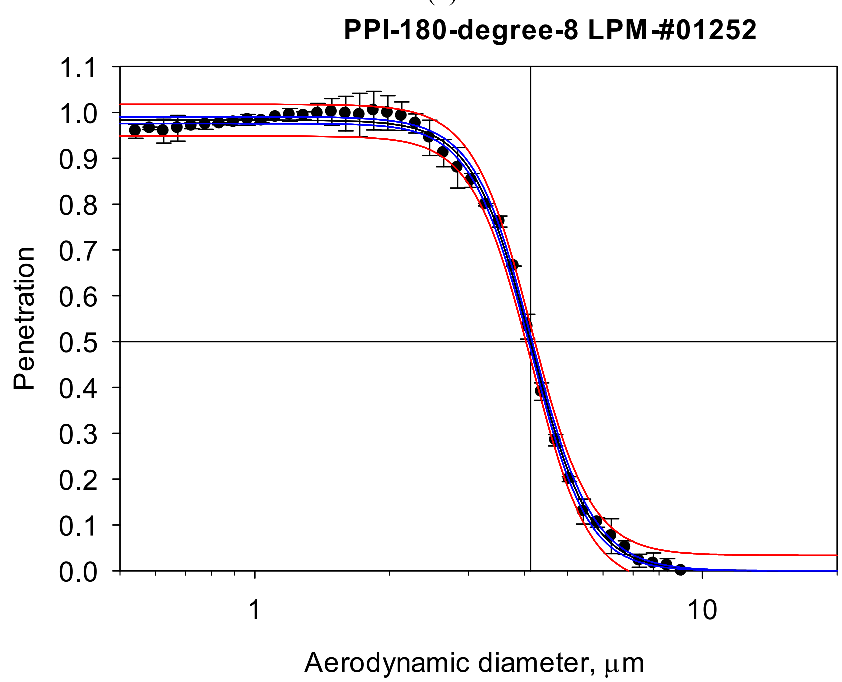


Figure 4. SKC PPI-8 L/min impactor penetration curve as a function of particle size: a) individual data points of the six tests and b) average values and standard deviations for each particle size based on six tests.

The data were fitted with a 3 parameter sigmoid regression equation resulting in the following equation:

with NaCl: $$\eta = \frac{0.9829}{1+(\dfrac{dp}{4.148})^{6.638}} \quad R^2=0.9982 \qquad (7)$$

Based on the fit, the d_{50} cut sizes of the impactor were 4.13 µm for collection flow rates of 8 L/min.

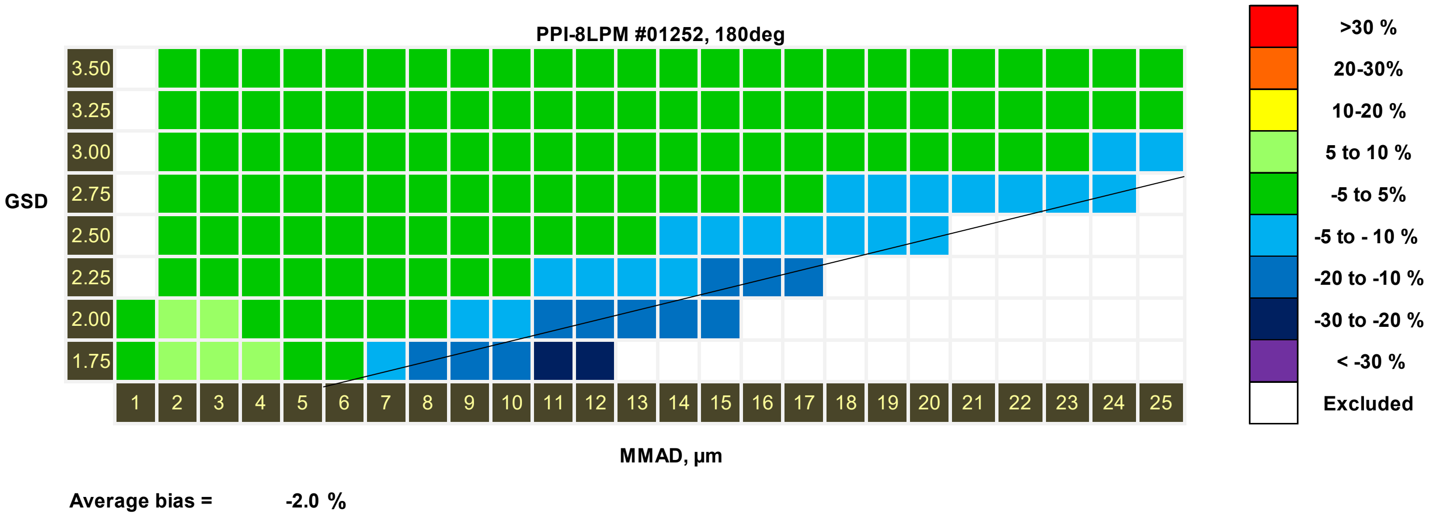


Figure 4c. Bias map for the SKC 8-L/min-PPI impactor (#01252) for different particle size distributions (MMAD and GSD) with the sampler facing down (180 degrees to the airflow).

Summary of Penetration Efficiency Results

<u>Penetration efficiency</u>

The tested SKC 8-L/min-PPI and SKC 8-L/min-RePPI showed cut-off sizes within 5-7 % of the expected and theoretically predicted value of 4.0 µm when facing the airflow or facing away from the airstream.

The performance of both the disposable impactor and the reusable impactor when facing the airflow was measured using an identical impactor's inlet (without the impaction surface) as a reference. In this case, the aspiration efficiency of the tested impactor and the reference are the same. Since the observed collection efficiency and the resulting d_{50} value are close to the theoretical value, one can infer that the impactor itself works as designed. Interestingly enough, the d_{50} of both tested disposable impactors was below the 4 µm value, while the d_{50} of the reusable 8 L/min PPI was above the 4 µm value. However, the observed d_{50} agreed with the expected d_{50} of 4 µm within 5-7 % in both cases.

The d_{50} for the SKC 8-L/min-RePPI was 4.27 µm. Interestingly enough, the same value was observed when testing the SKC 4-L/min-RePPI. An extra set of measurements (not presented in this report) showed that the d_{50} of the SKC 8-L/min-RePPI could be brought to the expected range with an increased sampling flow rate of ~ 9.15 L/min, i.e., approximately 10 % flowrate increase. The reasons for the higher d_{50} of the SKC 8-L/min-Re PPI are unknown at this point. It is suggested that the manufacturer analyzes the structure and physical dimensions of the SKC 8-L/min-Re PPI for deviations from the specifications. If such variations are found and confirmed, the impactor design should be adjusted and retested.

<u>Bias maps</u>

A similar pattern was observed for the bias maps: bias maps for the two tested SKC 8-L/min-PPI units and SKC 8-L/min-RePPI showed little deviation from the expected performance, and for the vast majority of challenge aerosol, the bias was within +/-5%. The average bias for the two SKC 8-L/min-PPI units was 1% and 3.5%. The SKC 8-L/min-RePPI shows an average bias of 13.6%. Here, the bias of +20% begins to occur only for challenge particles with MMAD of 8 µm and greater and more polydisperse particles.

When a reusable 8 L/min PPI faced away from the air stream, its average bias was -2%.

Overall, for the tested samplers and test conditions, the expected bias is less than a few percent (e.g., disposable 8 L/min PPI) or within 10-15% (e.g., reusable 8 L/min PPI).

References

1. American Society for Testing Materials. Standard Practice for Evaluating the Performance of Respirable Aerosol Samplers (D6061 - 01). 2012.