DIFFUSION CORRECTION USING TSI'S 1nm SMPS™ SYSTEM MODEL 3938

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APPLICATION NOTE SMPS-010 (A4)

How Influential is Diffusion for the 1nm SMPS System?

Importance of Diffusion for Sub-2 nm Particles

Working with aerosols almost always involves concerning yourself with losses. Diffusion losses are of particular importance for the smallest of particles. While minimizing losses is optimal, some losses cannot be avoided and must be corrected for. Diffusional losses can occur anywhere from the point of sampling up until the point of detection within an instrument. This includes the sampling probe, tubing connecting the sampling probe to the instrument, and losses within the instrument itself.

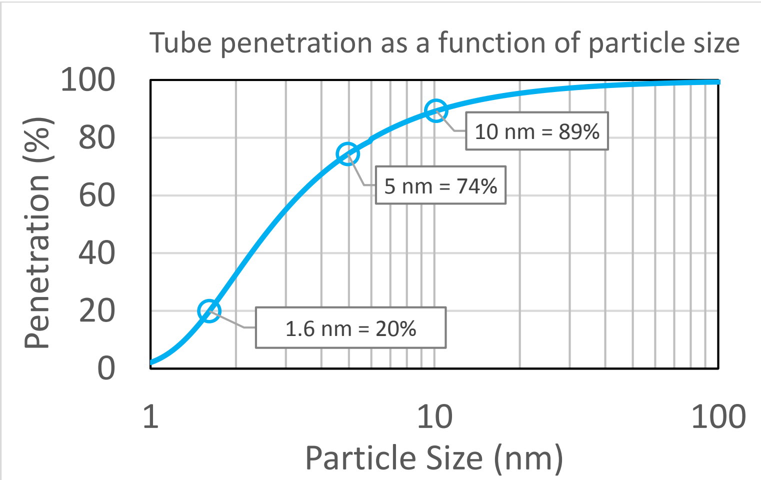

Figure 1: Penetration through a tube as a function of particle size. The curve shown is for a 1 m tube with a volumetric flow rate of 1 L/min at 293 K and 101 kPa.

Tubing and Sampling Probe

A common location for diffusional losses is tubing that connects an instrument to a sampling probe. For example, figure 1 shows that the penetration of particles through a 1 m long tube (with a flow rate of 1 L/min) decreases significantly for particles as they shrink towards 1 nm. Minimizing tubing length is a valuable way to reduce losses. Similarly, sampling probes can be a source of diffusional losses; researchers must consider this possibility during experimental design.

Instrument

While researchers can take steps to reduce diffusional losses to tubing and sampling probes, losses within instruments is not something researchers can change. Diffusional losses within the TSI 1nm SMPS instrument are corrected for using the Diffusion Correction described here.

Impact of SMPS System Configuration

In order to minimize diffusion losses within the instrument itself, the components of a 1nm SMPS system are configured differently from a standard SMPS system. This "Compact" configuration is shown in Figure 2. There are two key differences between Compact configuration and Standard configuration:

1. Both the 3086 1nm Differential Mobility Analyzer (DMA) and the 3088 Aerosol Neutralizer are placed horizontally on the bench top. This minimizes tubing used from the 3088 to the DMA, and from the DMA to the Condensation Particle Counter (CPC).
2. The aerosol inlet to the system is now the 3088's inlet, and not the inlet impactor in the front of the 3082. This removes the 3082 from the aerosol path, further reducing losses.

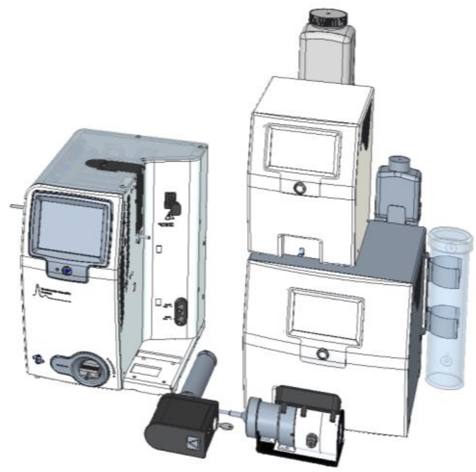

Figure 2: TSI's 1nm SMPS system in "Compact" configuration.

The diffusion correction developed for the 1nm SMPS system has been developed for this configuration.

How was the New Diffusion Correction Developed and Verified?

In order to develop a diffusion correction suited specifically to the 1nm SMPS system when used in compact configuration, it was necessary to investigate diffusion losses in some of the system components individually.

Experimental Details

Figure 3 shows the experimental schematic for measuring diffusion losses through the 1nm DMA (Model 3086) and Model 3088 Advanced Aerosol Neutralizer. By using the High-resolution DMA (HRDMA) to emit monodisperse particles of varying sizes, electrometers upstream and downstream of the 1nm DMA were used to measure size-specific particle losses and calculate an effective length for the 1nm DMA by fitting the measured data to a curve of the form derived by Gormley and Kennedy (1949) for penetration through a circular tube. The same experiment was repeated to characterize diffusion losses within the 3088 neutralizer. Detection efficiency for the 1nm CPC (consisting of the 3757 Nano Enhancer and the 3750 CPC) had previously been characterized and include any effects of diffusion losses internal to that instrument.

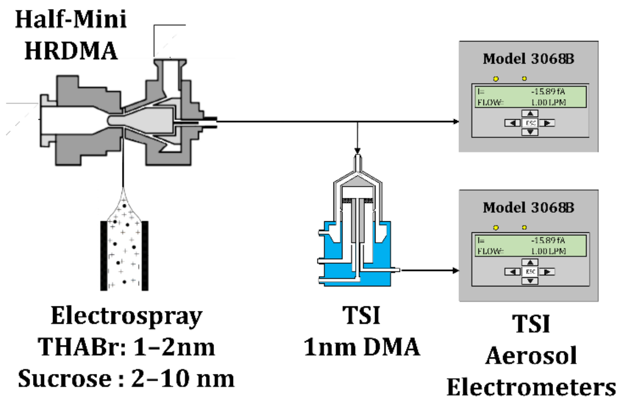

Figure 3: Experimental schematic for determining the effective length of the 1nm DMA. The experiment was repeated for the soft x-ray aerosol neutralizer.

Results

As described above, diffusion loss increases rapidly as particle size decreases. Once diffusion losses for all system components had been individually measured, the new diffusion loss correction was developed specifically for Compact configuration.

Figure 4 shows the penetration ratio (Compact/Standard) as a function of particle size. Since particles near 1 nm penetrate through the Compact configuration nearly four times more effectively than through the Standard configuration, it is clear that the Compact configuration is preferable for making sub-2 nm measurements.

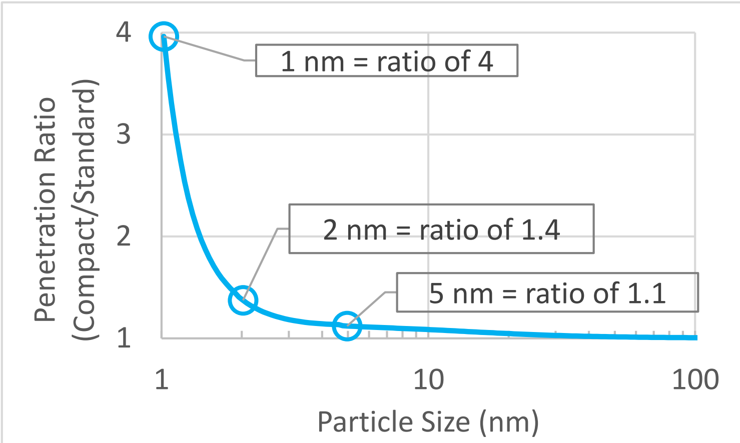

Figure 4: Ratio of aerosol penetration through different configurations of SMPS system: compact/standard.

How was the Accuracy of the New Correction Assessed?

To verify the accuracy of the correction, a 1nm SMPS system was run in parallel with a 1nm CPC.

Experimental Details

The schematic for this experiment is shown in Figure 5. Both instruments were challenged with polydisperse sodium chloride aerosol generated in a tube furnace, and total number concentrations from the two instruments were compared after the newly developed diffusion correction was applied to the SMPS system measurement. The size distribution of the aerosols exiting the furnace had a mode diameter < 1.4 nm, and > 99% of the particles were < 4 nm in size.

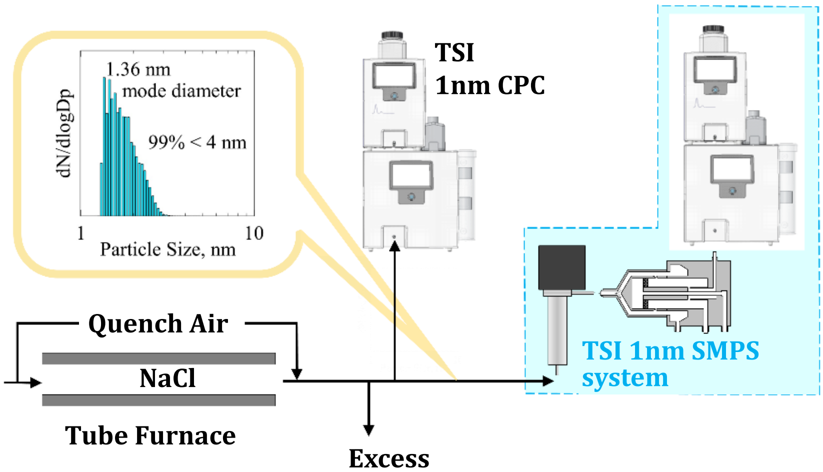

Figure 5: Experimental schematic for verifying accuracy of the 1nm SMPS system diffusion correction. The diffusion-corrected total number concentration measured by the 1nm SMPS system was compared to the total number concentration measured by the standalone 1nm CPC.

Results

Figure 6 shows the total diffusion-corrected SMPS system concentration as a function of the 1nm CPC concentration. Excellent agreement is observed, with a best fit slope of 98.99% and average error of 5%.

This agreement demonstrates that once corrected using the new Diffusion Correction, SMPS system total concentrations agree very well with 1nm CPC concentrations. This agreement between a 1nm CPC and the diffusion-corrected SMPS system not only demonstrates the accuracy of the SMPS-measured total concentration, but also conveys confidence in the size-specific concentrations therein.

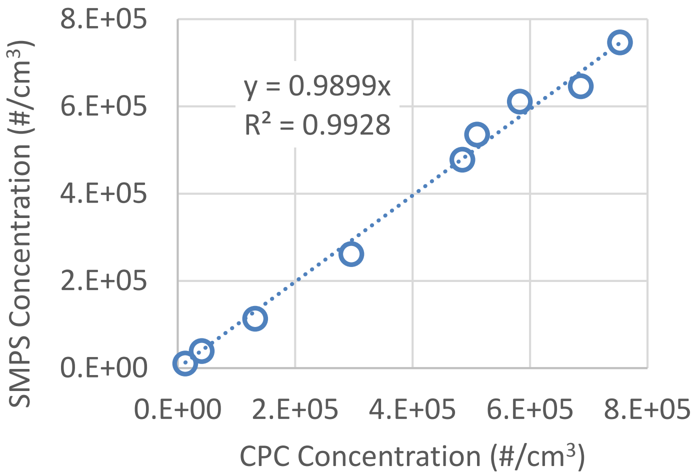

Figure 6: Total number concentrations as measured by a diffusion-corrected 1nm SMPS system and a standalone 1nm CPC. The agreement between these two measurements attests to the accuracy of the new diffusion correction.

How do I Apply this New Correction to my Data?

With the release of Aerosol Instrument Manager® (ver. 11.0) SMPS software, the diffusion correction work described above is included; no additional steps are required to apply this correction. When setting up your file in Aerosol Instrument Manager Software (ver. 11.0), be sure to enable "Compact Configuration." For data collected in Aerosol Instrument Manager Software (ver. 10.3), the section below provides guidance on how to apply the correction.

Recommended: A Post-Processing Approach

The newly developed diffusion correction may be applied to 1nm SMPS data taken using Aerosol Instrument Manager Software (ver. 10.3) in a post-processing fashion. This approach is recommended for the majority of users, since the correction cannot be automatically applied in Aerosol Instrument Manager Software (ver. 10.3). Using this post-processing approach guards against human error, and thus protects your data quality.

For detailed instructions on how to modify the data using a post-processing approach, see the updated Aerosol Instrument Manager Software (ver. 10.3) for Scanning Mobility Particle Sizer™ (SMPS™) Spectrometers manual.

Automatic Approach to the New Diffusion Correction

To automate the application of the new correction to their data, the researcher must modify a file in the Aerosol Instrument Manager Software (ver. 10.3) installation directory. This file (user_192.eff) contains comma-separated values of size and penetration. These values will be applied to all SMPS data collected on this computer. Consequently:

- **Inaccurate data will result** if using this method when viewing or collecting SMPS data from any other combination of SMPS components:
  - ✗ Long DMA with any CPC
  - ✗ Nano DMA with any CPC
  - ✗ 1nm SMPS system in Standard configuration (vertical DMA).
- **Accurate data will result if:**
  - ✓ The 1nm SMPS system is used in Compact configuration, and
  - ✓ The "Diffusion Correction" checkbox in Aerosol Instrument Manager Software is left unchecked.

For detailed instructions on how to modify the **user_192.eff** file, see the Aerosol Instrument Manager Software for Scanning Mobility Particle Sizer (SMPS) Spectrometers manual, Revision N.

References

1. Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles. 2nd ed, by William C. Hinds. John Wiley & Sons, New York, 1999.
2. Aerosol Instrument Manager Software for Scanning Mobility Particle Sizer™ (SMPS™) Spectrometers manual, P/N 1930038, Revision N, August 2018.
3. Gormley, P.G. and Kennedy, M. (1949) "Diffusion from a stream flowing through a cylindrical tube". *Proceedings of the Royal Irish Academy*, **52A**, 163-169.

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