# Performance of a High Resolution Optical Particle Spectrometer

**HEE-SIEW HAN, Avula Sreenath, Nathan T. Birkeland, and George J. Chancellor**
**TSI Incorporated, Shoreview, MN, USA**

**Presented at the EAC2011, Manchester, UK, September 2011 (Paper Number 8P291)**

## INTRODUCTION

The optical particle spectrometer is one of the most widely used aerosol instruments in many areas such as aerosol research, filter testing, indoor air quality, etc. In this study, a recently developed high resolution optical particle spectrometer, TSI 3330 Optical Particle Sizer (OPS), is evaluated. The OPS is a light, portable, battery-powered unit that provides fast and accurate measurement based on single particle side scattering technology. It is capable of detecting particles from 0.3 to 10 µm in diameter in up to 16 channels at 1 lpm of sample flow rate. A concentric 1 lpm of sheath flow is used to focus the particle beam and reduce contamination inside the optics chamber for improved reliability and low maintenance. Dead time correction is also available for high concentration measurements. Since almost all optical particle spectrometers and counters are factory-calibrated with polystyrene latex (PSL) particles, size errors could be significant if the refractive indices of aerosols are very different from the PSL refractive index 1.59. To address this issue, the OPS features real-time Mie scattering calculation capability to adjust the PSL calibration curve to a curve that better fits the aerosols of interest. For non-spherical particles, an additional shape factor is available to perform further adjustment on the calibration curve.

## OPS OPERATING PARAMETERS AND FEATURES

- Sample and sheath flows are 1 lpm.
- Wide-angle spherical collecting mirror with 120° light collection to improve signal-to-noise ratio and minimize Mie oscillation effect.
- 660 nm wavelength and 30 mW laser power.
- Two-stage amplifier gain to cover size range from 0.3 to 10 µm in up to 16 channels.
- On-board Mie scattering theory-based refractive index correction to enhance sizing accuracy.
- Filter-based sample collection for later gravimetric or chemical analysis.
- User-adjustable size channel boundaries.
- Dead time correction for high concentration measurements.
- Software allows a unique density for every size channel to further improve mass concentration measurement.
- USB and Ethernet connections.

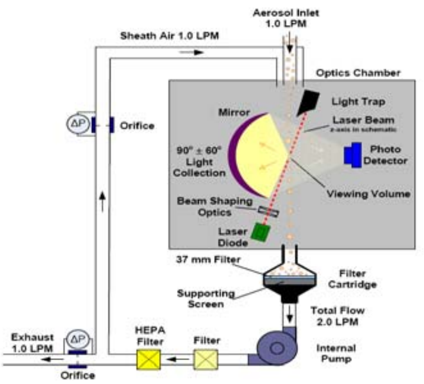



Figure 1 TSI 3330 OPS schematic diagram

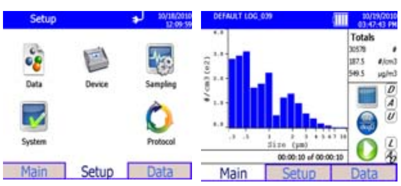



Figure 2 OPS graphic user interface

## METHODS

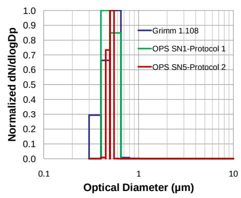
- Calibration and challenge PSL particles
  - 0.3-1.0 µm: Atomized, dried and then DMA classified NIST traceable PSL particles
  - 2-10 µm: NIST traceable PSL powders
- Test dioctyl sebacate (DOS or DEHS), sodium chloride (NaCl) and methylene blue particles were generated with an atomizer, dried with a diffusion dryer and then classified by a DMA.
- TSI 3010 CPC was used as the concentration reference for counting efficiency and linearity measurements
- Resolution measurement
  - 0.5 µm per ISO 21501-1
  - 1.0 µm per ASHRAE 52.2
- Refractive index
  - PSL: 1.59
  - DOS: 1.45
  - NaCl: 1.544 (non-spherical)
  - Methylene blue: 1.55-0.6i

## RESULTS AND DISCUSSION

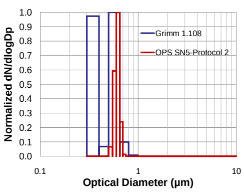
- The resolutions of 10 OPS prototypes at 0.5 µm per ISO 21501-1 method are all better than 4%, as shown in Figure 3. For comparison purpose, typical resolutions of optical particle counters designed for clean-room application are around 15%.
- Particle size distributions of 0.5 and 0.6 µm PSL particles measured by OPSs and a Grimm 1.108 Aerosol Spectrometer and Dust Monitor are also shown in Figure 3.
- Figure 4 shows the distribution of DMA classified DOS particles measured by a OPS. Besides the singly charged 0.6 µm particles, the distribution also contains +2 charge 1.089 µm and +3 charge 1.571 µm particles that also exit the DMA since they have the same electrical mobility as the +1 charge 0.6 µm particles. Being able to measure DMA multiple charged particles clearly demonstrates the OPS high resolution capability. The measurement resolution could be further improved if narrow size boundaries were used. Note that the DOS particles were sized slightly smaller because PSL calibration curve was used in this measurement.

| Unit | Resolution (%) |
|---|---|
| SN1 | 3.06 |
| SN2 | 2.98 |
| SN3 | 3.44 |
| SN4 | 2.18 |
| SN5 | 3.90 |
| SN6 | 3.15 |
| SN7 | 2.82 |
| SN8 | 3.64 |
| SN9 | 2.61 |
| SN10 | 2.59 |

(a) OPS resolutions at 0.5 µm




(b) 0.5 µm PSL




(c) 0.6 µm PSL

Figure 3 OPS resolutions. Channel boundaries of Protocol 1 are same as Grimm 1.108. Protocol 2 has finer channel boundaries.

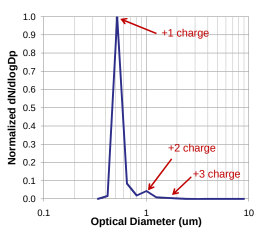



Figure 4 DMA classified DOS particles measured by a OPS. DMA size was set to 0.6 µm.

- The OPS linearity was tested with classified 0.55 µm DOS particles. The pulse heights of these particles were roughly equivalent to 0.5 µm PSL particles. A two-stage dilutor was used to obtain necessary particle concentration values.
- Without dead time correction (DTC), the concentrations start to deviate from the 1:1 line at about 1000 #/cm³. With dead time correction enabled, concentrations of the two units could go as high as 3000 #/cm³. The linearities of two OPS units are excellent, with $R^2$ values higher than 0.99.

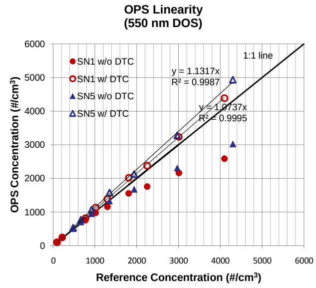



Figure 5 OPS linearity

- The refractive index algorithm performs quite well. Without refractive index adjustment, the size errors for methylene blue particles are as high as 40%. With Mie scattering correction, the sizing accuracy improves significantly for DOS and methylene blue particles, while the size errors for NaCl particles increase slightly. Since Mie scattering theory is based on spherical particles, some uncertainties could occur if particles are non-spherical such as NaCl. To mitigate this issue, an additional shape factor is available to do further adjustment. By tweaking the shape factor, the sizing accuracy of the NaCl particles improve significantly. Note that although the shape factor is designed for non-spherical particles, it appears that it also improves the sizing accuracy of supposedly spherical DOS and methylene blue particles. Therefore, the shape factor could be used to fine tune the calibration curve after Mie scattering calculation so that the measured sizes are in even better agreement with the actual particle sizes.

| Diameter (µm) | No Correction (%) | Mie Scattering (%) | Mie Scattering + Shape Factor (%) |
|---|---|---|---|
| 0.4 | -7.13 | -4.98 | -2.66 |
| 0.5 | -9.81 | -6.50 | -2.91 |
| 0.6 | -8.35 | -3.75 | 1.55 |
| 0.7 | -13.14 | -7.37 | -0.04 |
| 0.8 | -8.49 | -3.38 | 0.85 |
| 1.0 | -8.65 | -5.96 | -2.96 |

(a) DOS

| Diameter (µm) | No Correction (%) | Mie Scattering (%) | Mie Scattering + Shape Factor (%) |
|---|---|---|---|
| 0.4 | -1.89 | -2.60 | 2.90 |
| 0.5 | -0.46 | -1.57 | 3.73 |
| 0.6 | -5.42 | -6.75 | 2.71 |
| 0.7 | -12.08 | -13.69 | -2.18 |
| 1.0 | -6.54 | -7.33 | -1.94 |

(b) NaCl

| Diameter (µm) | No Correction (%) | Mie Scattering (%) | Mie Scattering + Shape Factor (%) |
|---|---|---|---|
| 0.5 | -21.14 | 9.70 | 10.88 |
| 0.6 | -30.49 | -0.78 | 0.65 |
| 0.7 | -38.18 | -9.73 | -8.22 |
| 0.8 | -42.78 | -12.19 | -10.79 |
| 0.9 | -40.43 | -4.47 | -3.79 |

(c) Methylene blue

Figure 6 Refractive index correction

## SUMMARY

- A high resolution optical particle spectrometer capable of measuring particle size from 0.3 to 10 µm was successfully developed. It was found that the resolutions of 10 prototypes evaluated were all better than 4%.
- Being able to measure multiple charged particles of DMA-classified DOS particles clearly demonstrates the high resolution capability of the OPS.
- For measurements with aerosols with different refractive indices from calibration PSL particles, the on-board Mie scattering calculation could improve the sizing accuracy significantly. For non-spherical particles, further adjustment can be made with the additional shape factor.