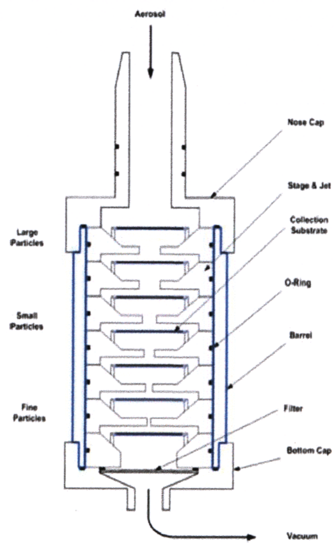
Aerosol Sample Collection with the In-Tox Products Cascade Impactor

D.A. Bowen, W.L. Bowen, and L.E. Bowen, Sr.

Abstract

In-Tox Products cascade impactors are inertial sampling devices used to determine size distributions of aerosols based on their aerodynamic properties. Their design and theoretical behavior have been well described. However, practical issues such as instrument preparation, sampling techniques, and data reduction are often left to the user. The steps necessary to properly clean, load, calibrate, and collect aerosol samples will be described. Additionally, procedures to reduce In-Tox Products cascade impactor sample data using the lognormal distribution and the cumulative mass of particles collected will be discussed.

Cascade Impactor Schematic



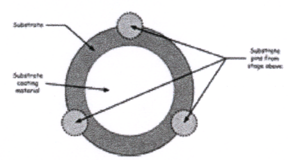
Cascade Impactor Preparation

- **Cleaning**
  - Remove all o-rings and silicone lubricating grease.
  - Clean after every use with a mild soap solution and/or water.
  - Optionally, internal surfaces may be cleaned with a 70% ethanol solution or isopropyl alcohol.
  - Do not touch internal surfaces with the ungloved hand.
  - Do not clean the impactor using an ultra-sonic device - this may damage the impactor jets through cavitation.
- **Assembly**
  - Lightly grease the o-rings with silicone grease.
  - Carefully load the impactor stages in the proper order.
    - Stages are typically numbered with 1 being the first stage.
    - Stage jets typically increase in number and decrease in diameter from top to bottom

Preparation - continued

- **Assembly**
  - Substrates may be coated with 1% apiezon grease in toluene (w:v) or 100% silicone.
    - Avoid applying coating under substrate pins. See Figure 1.

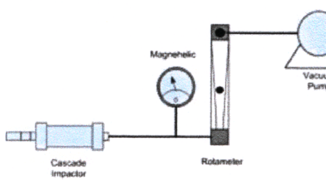
Figure 1. Substrate Coating



Calibration

- Leak test the impactor
  - Cap the impactor nose while vacuum is on.
  - Magnehelic pressure should be maximized.
  - Rotameter float should settle at zero
  - See Figure 2.

Figure 2. Impactor Leak Test Configuration



- Select a desired volumetric flow rate.
- Determine the Effective Cutoff Diameters (ECD) and Reynolds Numbers for the selected flow rate using the following equations:

$$\mathrm{ECD}_{50} = \sqrt{\frac{9\eta W}{\rho_p C_c U}}\sqrt{STK_{50}}$$

Where:

ECD_{50}	=	50% effective cut-off diameter
η	=	absolute viscosity
W	=	jet diameter
ρ_p	=	particle density
C_c	=	Cunningham slip correction factor
U	=	velocity in the jet throat
STK_{50}	=	Stokes number

$$C_c = 1 + \frac{\lambda}{d_p}\left[2.514 + 0.800\ \exp\left(-0.55\frac{d_p}{\lambda}\right)\right]$$

Where:

C_c	=	Cunningham slip correction factor
d_p	=	particle diameter
λ	=	mean free path of air (gas)

$$\lambda = \frac{1}{\sqrt{2}\ n\ \pi\ \rho_g^2}$$

Where:

λ	=	mean free path of air (gas)
n	=	average number of collisions of a gas molecule per second
ρ_g	=	gas density

$$STK_{50} = \frac{\rho_p C_c d_p^2 U}{9\eta W}$$

Where:

STK_{50}	=	Stokes number
ρ_p	=	particle density
C_c	=	Cunningham slip correction factor
d_p	=	particle diameter
U	=	velocity in the jet throat
η	=	absolute viscosity
W	=	jet diameter

Calibration

$$N_{RE} = \frac{\rho_g W U}{\eta}$$

Where:

N_{RE}	=	Reynolds number
ρ_g	=	air (gas) density
W	=	jet diameter
U	=	velocity in the jet throat
η	=	absolute viscosity

- The largest ECD should be less than 20 μm.
- The smallest ECD should be greater than 0.3 μm.
- The Reynolds Number should be greater than 500 and less than 3000 for all stages.
- Contact In-Tox Products for computer software to solve these equations.

Aerosol Sample Collection

- In-Tox Products cascade impactors can be used in a vertical or horizontal orientation for sample collection.
- Avoid "overloading" the impactor which can result in particle bounce and re-entrainment caused by excessive sampling times.
- Reduce the impactor flow rate if halo formations are observed around or near impacted particles and impactor jets.
- Weigh wet aerosols immediately after collection to minimize evaporation.
- Select a desired sampling time based on the expected concentration of the aerosol.
- A light coating of particles on the substrate is sufficient for gravimetric analysis.
  - ➢ A good first estimate would be 100 - 200 μg per stage.
- Use the following equation to estimate a sampling time:

$$\text{Sampling time (min)} = \frac{\text{Total particulate mass (μg)}}{\text{Aerosol concentration (μg/L)} \times \text{Flow rate (L/min)}}$$

- Pressure correct the cascade impactor sampling flow rate to adjust for particle loading.
  - ➢ Most of the pressure drop across the impactor is from the back-up filter and the stage with the smallest jets.
  - ➢ Use the average pressure between the start and finish of sampling observed on the Magnehelic pressure gage
  - ➢ Use the following equation to determine the pressure corrected flow rate:

$$Q_c = Q_n\sqrt{1 + \frac{\Delta P}{P}}$$

Where:

Q_c	=	Pressure corrected flow rate
Q_n	=	Nominal flow rate
ΔP	=	Pressure drop (usually negative)
P	=	Ambient pressure

Data Reduction

- Compile data as shown in Table 1.
- Weights may be gravimetric mass, chemical mass, or radiometric counts.
- Plot the size distributions as shown in Figures 3 and 4.
- A lognormal distribution is assumed.
- Calculate the Mass Median Aerodynamic Diameter (MMAD) and Geometric Standard Deviation (GSD)
- MMAD = particle diameter associated with 50th percentile size.
- GSD = ratio of the 84.13 percentile size divided by the 50th percentile size.
- Contact In-Tox Products for computer software to reduce cascade impactor data.

Table 1 Cascade Impactor Data

Jet Diam (cm)	Jet Num	Dar (um)	Dae (um)	Gross Wt.	Tare Wt.	Net Wt.	% Total Wt.	Cum %	100 - Cum %	Log (d_{ae})	d_{ae} Midpoint	f(Net Wt.)
			20.00									
0.5613	1	13.36	13.28	151.19	151.189	0.000	0.000	0.000	100.000	1.1232	16.2975	0
0.4978	1	11.16	11.08	151.46	151.381	0.080	2.188	2.188	97.812	1.0445	12.1298	0.1207
0.4089	1	8.31	8.23	150.86	150.685	0.178	4.867	7.055	92.945	0.9153	9.5476	0.1636
0.315	1	5.62	5.54	151.16	150.786	0.369	10.090	17.145	82.855	0.7434	6.7504	0.2549
0.1981	1	2.80	2.72	152.46	151.563	0.901	24.638	41.783	58.217	0.4351	3.8837	0.3471
0.1092	1	1.15	1.07	151.87	150.681	1.184	32.376	74.159	25.841	0.0296	1.7074	0.3467
0.061	2	0.68	0.60	150.09	149.627	0.467	12.770	86.929	13.071	-0.2201	0.8030	0.2221
			0.10	18.809	18.331	0.478	13.071	100.000	0.000		0.2454	0.0728

All curves:
Coefficients:

b[0]	-1.7534
b[1]	0.4097
r^2	0.9875

Data Reduction

Figure 3. Unimodal Distribution

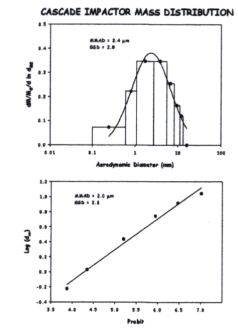
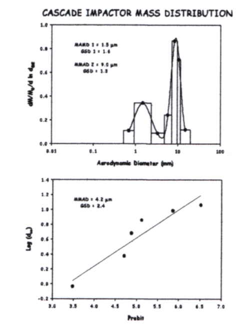


Figure 4. Bimodal Distribution



Conclusions

- Cascade impactors are considered as the primary standard for aerosol collection and particle size distribution measurements.
- In-Tox Products cascade impactors are custom designed and precision made.
- Certain impactor designs may be operated over a range of flow rates.
- In-Tox Products offers user friendly PC software to assist the aerosol scientist with describing theoretical operating conditions and reduction of cascade impactor data.