Analyses of ambient aerosol size distribution using optical particle counter



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- 1.What is OPC?
 2.What is coincidence loss?
 3.Objective of present work
 4.Comparison of 2 OPC responses to high concentration aerosols
 5.Calibration of OPC with SMPS
- 6.Conclusion

Optical Particle Counter (OPC)

OPC can measure the size distribution and number concentration of $0.3 \sim 10 \ \mu m$ particles in situ and in real time. \Rightarrow Essential data for particle behavior so as to devise effective removal devices

Problem OPC cannot measure high concentration aerosols because it detects scattered light form single particles



In Delhi, air pollution

Doi Suthep and the world air-quality index at midnight on March 13, 2019





Cleanroom Particle Counter

Application of OPC to high concentration aerosol

PP8306 Measurable size range: 0.3 – 25 μ m Meets ISO 21501-4 and JIS B9921



Can we use OPC?



Clarify the influence of coincidence on OPC measurement results under condition of high concentration aerosols

Proper usage of OPC for high concentration aerosols

Coincidence loss for high concentration aerosol

Poisson Distribution

 P_n = Probability of n particles present in a view volume

$$P_n = e^{-\lambda} \frac{\lambda^n}{n!}$$



 λ = The expected number of particles in the view volume = $\sum nP_n = N_tQ_st_d$

For
$$n = 0$$
 $P_0 = e^{-\lambda}$
 $\frac{N_i = \text{Number concentration measured by OPC}}{N_t = \text{True number concentration}}$
 $\frac{N_i}{N_t} = \frac{P_1 + P_2 + P_3 + \dots + P_n}{\sum nP_n} = \frac{1 - P_0}{\lambda} = \frac{1 - e^{-\lambda}}{\lambda} = \frac{1 - e^{-N_t Q_s t_d}}{N_t Q_s t_d}$

Coincidence loss for high concentration aerosol

Erlang Distribution

 $P(t_k)$ = Arrival time distribution of k-th particle to view volume

$$P(t_k) = \frac{\alpha^k}{(k-1)!} t_k^{k-1} e^{-\alpha t_k}$$



OPC can count particles with t_1 longer than dead time t_d

$$\frac{N_i}{N_t} = \int_{t_d}^{\infty} P(t_1) dt_1 = e^{-\alpha t_d} = e^{-\lambda} = e^{-N_t Q_s t_d}$$

 λ = Expected number of particles in the view volume = $N_t Q_s t_d$

Calibration of OPC with SMPS

Incense smoke

OPC 117 setting

- Sample flowrate 2.83 LPM
- Sampling time 2 min
- Detected particle size
 0.3-25 μm



SMPS setting

- Aerosol flowrate (DMA) 0.3 LPM
- Sheath air flowrate (DMA) 3 LPM
- CPC flowrate 0.3 LPM
- Scanning time 2 min
- Detected particle size 0.014-0.662 μm

Humidifier



Aqueous NaCl in water solution (0, 0.01, 0.5wt% NaCl)

SMPS setting

- Aerosol flowrate (DMA) 0.3 LPM
- Sheath air flowrate (DMA) 3 LPM
- CPC flowrate 0.3 LPM
- Scanning time 2 min
- Detected particle size 0.014-0.662 μm

OPC 117 setting

- Sample flowrate 2.83 LPM
- Sampling time 2 min
- Detected particle size
 0.3-25 μm



Test aerosol – Incense smoke



The geometric mean particle diameter and the geometric standard deviation of incense smoke measured by SMPS

Total concentration (particles/cm ³)	D _{p50} (μm)	σ
5.58x10 ³	0.162	1.44
2.22x10 ⁴	0.131	1.49
5.10x10 ⁶	0.117	1.43

 $*D_{p50}$ = The geometric mean particle diameter σ = The geometric standard deviation

- The change of concentration changed PSD.
- Higher concentration provided smaller geometric mean particle diameter.
- At the highest concentration, the number concentration of small particles decreased due to the loss from diffusion.

Test aerosol – Solid NaCl particles



The geometric mean particle diameter and the geometric standard deviation of NaCl particles after dried from 0.01wt%NaCl solution measured by SMPS

Total concentration (particles/cm ³)	D _{p50} (μm)	σ
1.47x10 ⁴	0.070	2.24
4.39x10 ⁴	0.048	2.62
8.37x10 ⁴	0.045	2.51

* D_{p50} = The geometric mean particle diameter σ = The geometric standard deviation

- The change of concentration changed PSD.
- Higher concentration provided smaller geometric mean particle diameter.

Lognormal probability plot of NaCl particles from 0.01wt%NaCl solution measured from SMPS at different sampling concentration

Test aerosol – Saline droplets

NaCl particle diameter converting to Saline droplet diameter

Mass balance (on an assumption 100% dry of saline droplets)

$$(wt\%NaCl)\rho_{Sol}(\frac{\pi d_d^{3}}{6}) = \rho_{NaCl}(\frac{\pi d_p^{3}}{6})$$

wt%NaCl = weight percentage of NaCl in water ρ_{Sol} = density of NaCl solution \approx density of water (kg/m³) d_d = diameter of saline droplet (m) – conversion diameter ρ_{NaCl} = density of NaCl particle (kg/m³) d_p = diameter of NaCl particle obtained from SMPS (m)

 $C_{0.3-0.5} = (\%Cum_{0.5} - \%Cum_{0.3})C_t$

 $C_{0.3-0.5}$ = the number concentration of saline droplets (particles/cm³) of particles at diameter in the range of 0.3 - 0.5 µm % $Cum_{0.3}$, % $Cum_{0.5}$ = percentage cumulative concentration of saline droplets at diameter in the range of 0.3 and 0.5 µm C_t = total number concentration of saline droplets (particles/cm³)



Lognormal probability plot of NaCl particles from 0.01wt%NaCl solution measured by SMPS

Test aerosols

- Incense smoke
- NaCl particles

Materials	D _{p50} (μm)	σ _g
Incense smoke	0.15	1.45
NaCl particles (0.01 wt%)	0.05	2.46
NaCl particles (0.5 wt%)	0.07	2.31

• Saline droplets

Materials	D _{p50} (μm)	σ _g
Saline droplets (0.01 wt%)	1.71	2.17
Saline droplets (0.5 wt%)	0.53	2.24

*D_{p50} = The geometric mean particle diameter σ = The geometric standard deviation

Comparison of 2 OPCs to incense smoke



Responses of OPCs are consistent even over the measurement range of concentration.

Saline concentration (1.0 wt% NaCl)



Particle size	Number concentration of		
	particles (particles/m ³)		
(μm)	OPC 117	OPC 120	
0.3 – 0.5	136,940,403	152,721,542	
0.5 - 1.0	315,630,086	367,397,133	
1.0 – 2.5	594,697,088	664,882,982	
2.5 - 5.0	377,058,214	368,534,496	
5.0 - 10.0	2,146,414	1,765,961	
10.0 - 25.0	31,005	39,976	
Total	1,426,503,210	1,555,342,091	

Responses of OPCs are consistent even over the measurement range of concentration.

Incense smoke



- The number concentration of incense smoke measured by OPC <u>linearly increases</u> with that measured by SMPS .
- The curve reaches a plateau at 1000 particles/cm³.
- The number concentrations measured by OPC are about a half of those measured by SMPS because incense smoke is opaque.

Saline droplets and NaCl particles



NaCl particles and saline droplets data are not much different from the incense smoke data

For incense smoke in which there are many particles smaller than the detection limit of OPC, and for saline droplets with the number median size of 2 μ m, when 0.3-0.5 μ m number concentration measured by the OPC does not exceed the 10% coincidence loss concentration specified by the manufacturer, we can measure the concentration by OPC.

10% coincidence loss concentration specified by the manufacturer is 1000 cm⁻³.

Coincidence loss based on Poisson

$$\frac{N_i}{N_t} = \frac{1 - e^{-N_t Q_s t_d}}{N_t Q_s t_d}$$

 N_i = Number concentration measured by OPC N_t = Number concentration measured by SMPS Q_s = Sampling flowrate = 2.83 LPM t_d = Dead time = 4 µs



The concentration at 10% coincidence loss is 1,137 cm⁻³.

Conclusion

- OPC can be applied to measure high concentration aerosols as long as the concentration of minimum size bin of OPC does not exceed the 10% coincidence loss concentration even when there are many particles smaller than the detection limit of OPC.
- 2. Coincidence loss curve follows Poisson distribution rather than Erlang distribution.
- 3. Responses of 2 OPCs for high concentration aerosols are consistent if the calibration is properly conducted according to ISO 21501-4, which implies that we may introduce a correction scheme to retrieve true concentration from measured concentration.



Thank you for your kind attention

