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A fast differential mobility analyzer for ultrafine particles combustion aerosols

A Fast Differential Mobility Sizer for Ultrafine Particles

Nick Collings, (U. of Cambridge and Cambustion Ltd), and Brian Graskow, (Chevron Oronite Global Technology.)

A fast particle sizer for ultrafine particles of diameter up to 100nm is described. The principle of operation is that particles are charged very quickly by means of a photoelectric charger operating at 222nm (excimer lamp), and then classified according to their electrical mobility. The classification column is similar to an ordinary DMA, except that measurement of the particle spectrum is achieved for all sizes simultaneously, via collection of the charged particles on a linear series of rings, detected by electrometer amplifiers. (An instrument operating on similar principles, but using diffusion and field charging has been developed at Tartu University by H. Tammet and his co-workers.)

Classification by this technique is shown to be viable, and a time constant of the order of 0.05 seconds was achieved. Experiments were performed using a combustion aerosol generator (a quenched propane flame), a spark ignition engine and a Diesel engine. The main issue that became evident was that the proportion of the particles becoming charged was a very strong function of the engine operating condition. This implies that the surface properties of the particles, in particular the surface work function, was significantly affected by the engine operating point. It was impossible with the equipment available to determine what the particles' surface composition was, though the developers of the Nanomet instrument (Matter Engineering), which also uses photoelectric charging, suggest that the charging efficiency is largely determined by the quantity of elemental carbon in the particle. It is concluded that photoelectric charging may not be suitable for systems where particle sizing is required. It is worth mentioning, however, that photoelectric charging is ideal for a fast response particle sizer in another respect – the charging process is very fast indeed.

Extension of the this fDMS technique to larger particles is in principle not difficult, but interpretation of the data will be more difficult because of the increasing prevalence of multiple particle charging, which has a relatively small effect for the sizes classified in the current work. Finally it should be noted that using current measurement techniques for particle detection are always up against a serious sensitivity limit.

A Fast Differential Mobility Sizer (*f*DMS) for Ultrafine Particles

Nick Collings, (U. of Cambridge and Cambustion Ltd)

(Based on the research work of Dr. Brian Graskow, now with Chevron Oronite Global Technology.)

Reasons for Developing the *f*DMS

- Particulate emissions from diesel, gasoline engines under increased scrutiny, especially ultrafine particles (d < 100 nm)
- Particle emissions dramatically increase under transient conditions
- Conventional particle sizing instruments are inadequate for transient (τ = 100 ms) measurements

Main Current Particle Number Measurement Techniques

- SMPS
- ELPI
- Nanomet

SMPS

- Main standard at present
- Measures to c. 5nm
- Measures electrical mobility
- Slow - c. 100 sec's for complete size scan

ELPI

- Fast - full spectrum with c. 1 sec time constant
- Minimum size resolvable c. 10nm
- Channel broadening artefacts
- Apparent particle density vs. size issues
- Low pressure effects
- Sensitivity

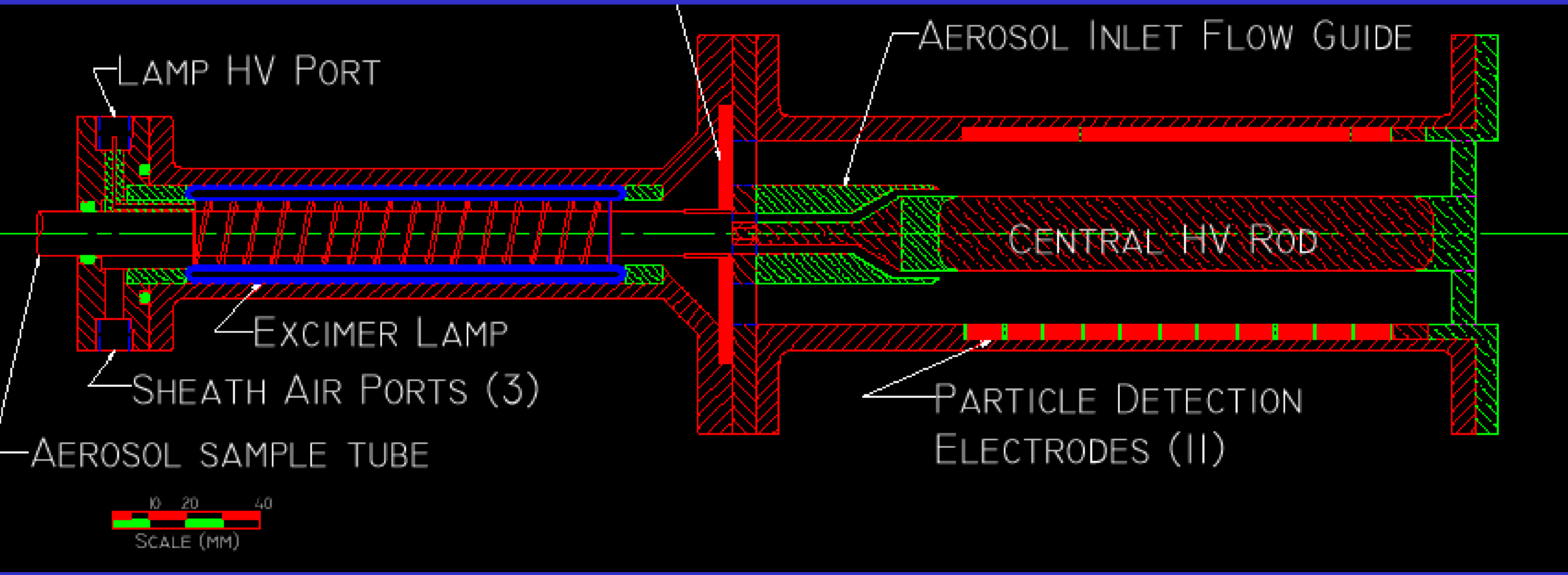
Nanomet

- Fast (c. 1sec), portable instrument
- Includes a (hot) dilution system
- Particle composition information from diffusion charging (DC) vs. photoelectric charging (PAS) data
- Active surface area concept is argued to mitigate need for size discrimination

*f*DMS (Fast Differential Mobility Sizer)

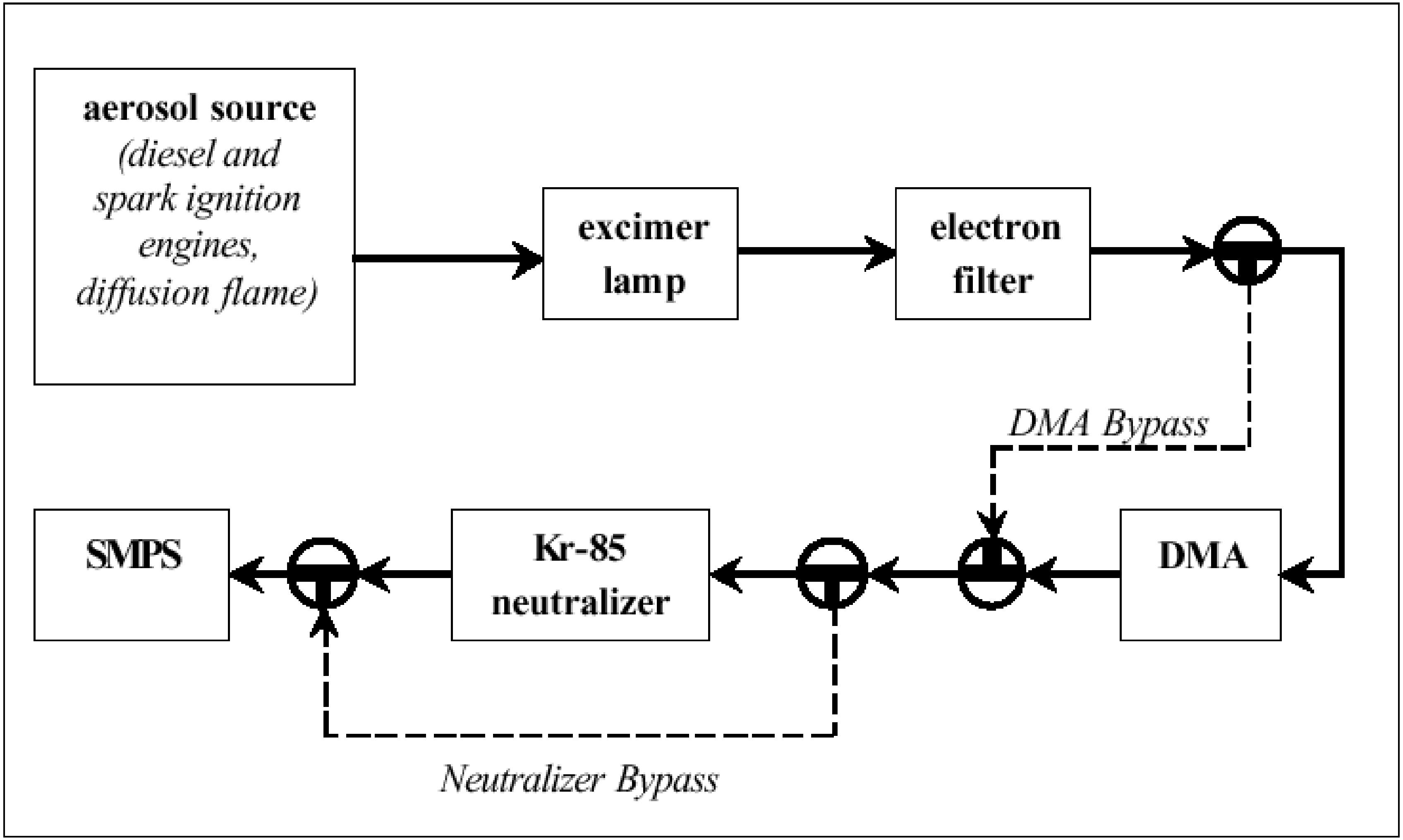
- Developed for IC engine exhaust aerosol measurements
  - compact, portable, robust
  - fast <= 50ms
  - nuclei mode size range (up to 100nm)

*f*DMS design



Lamp HV Port
Aerosol Inlet Flow Guide
Central HV Rod
Excimer Lamp
Sheath Air Ports (3)
Aerosol sample tube
Particle Detection
Electrodes (11)
10 20 40
Scale (mm)

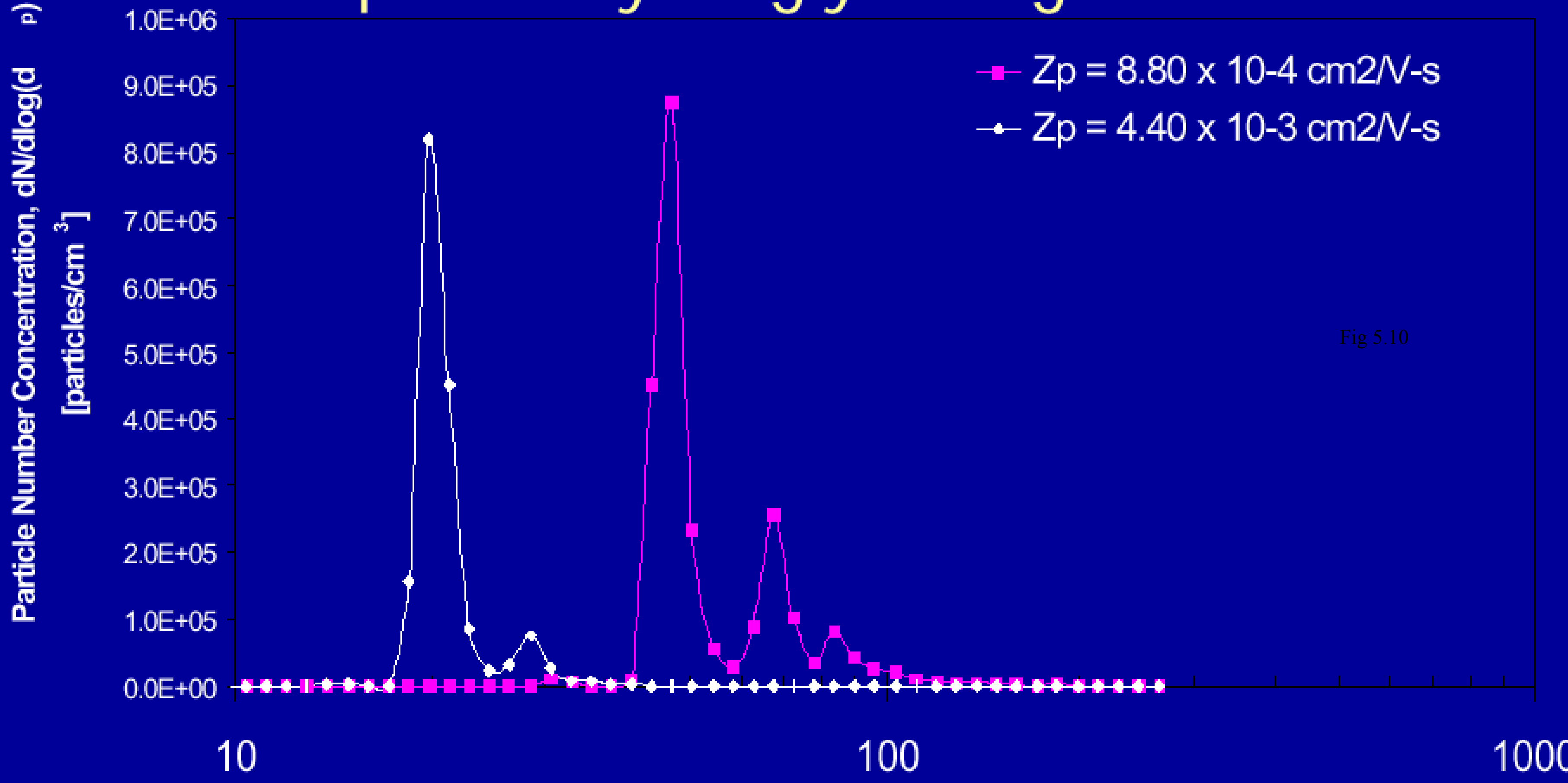
Schematic of the experimental apparatus for measuring aerosol charge distribution.



Particle Charge Distribution

Rich propane diffusion flame aerosol used

Particles are primarily singly charged



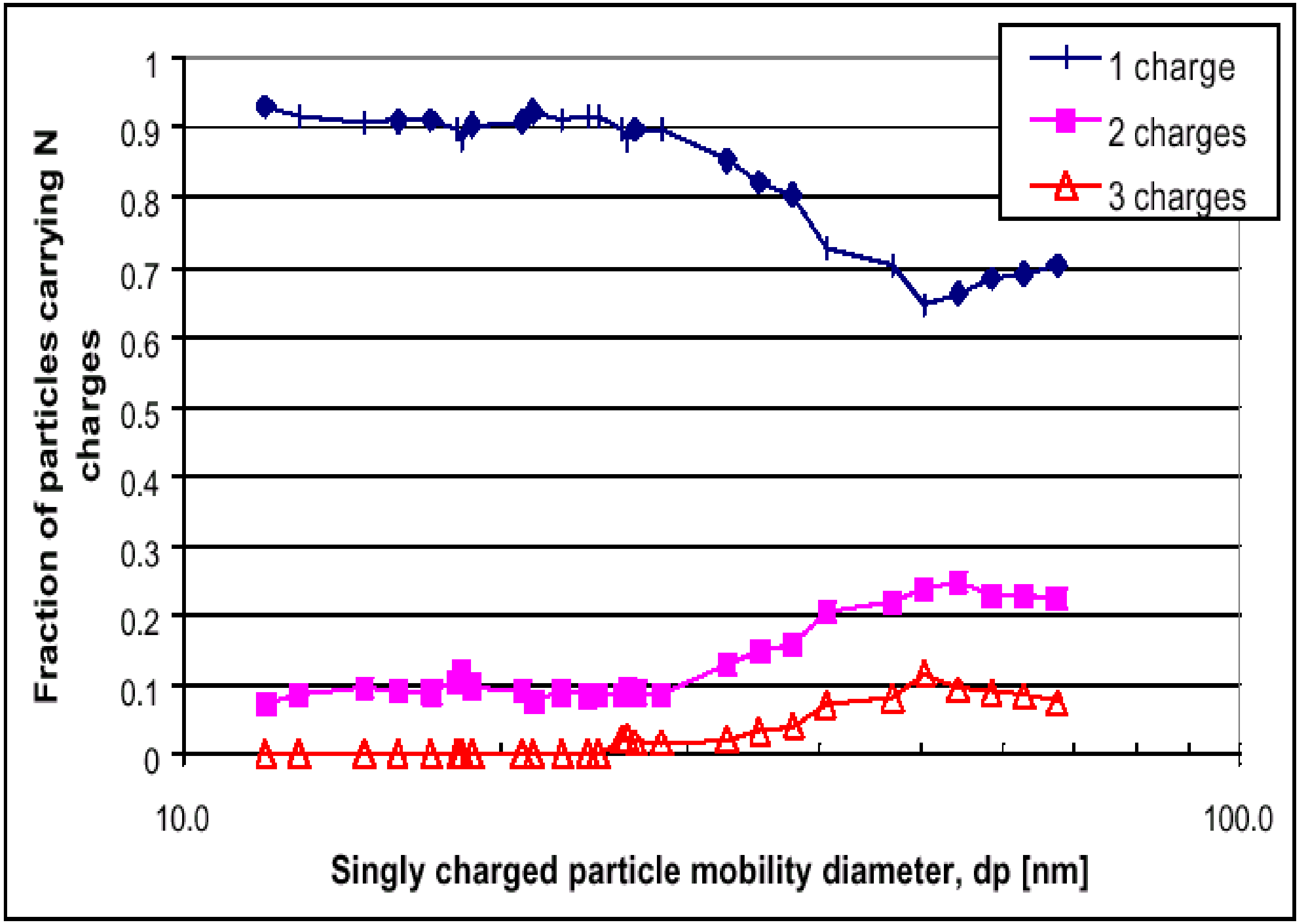


Figure 5.11. Charge number distribution for the diffusion flame aerosol .

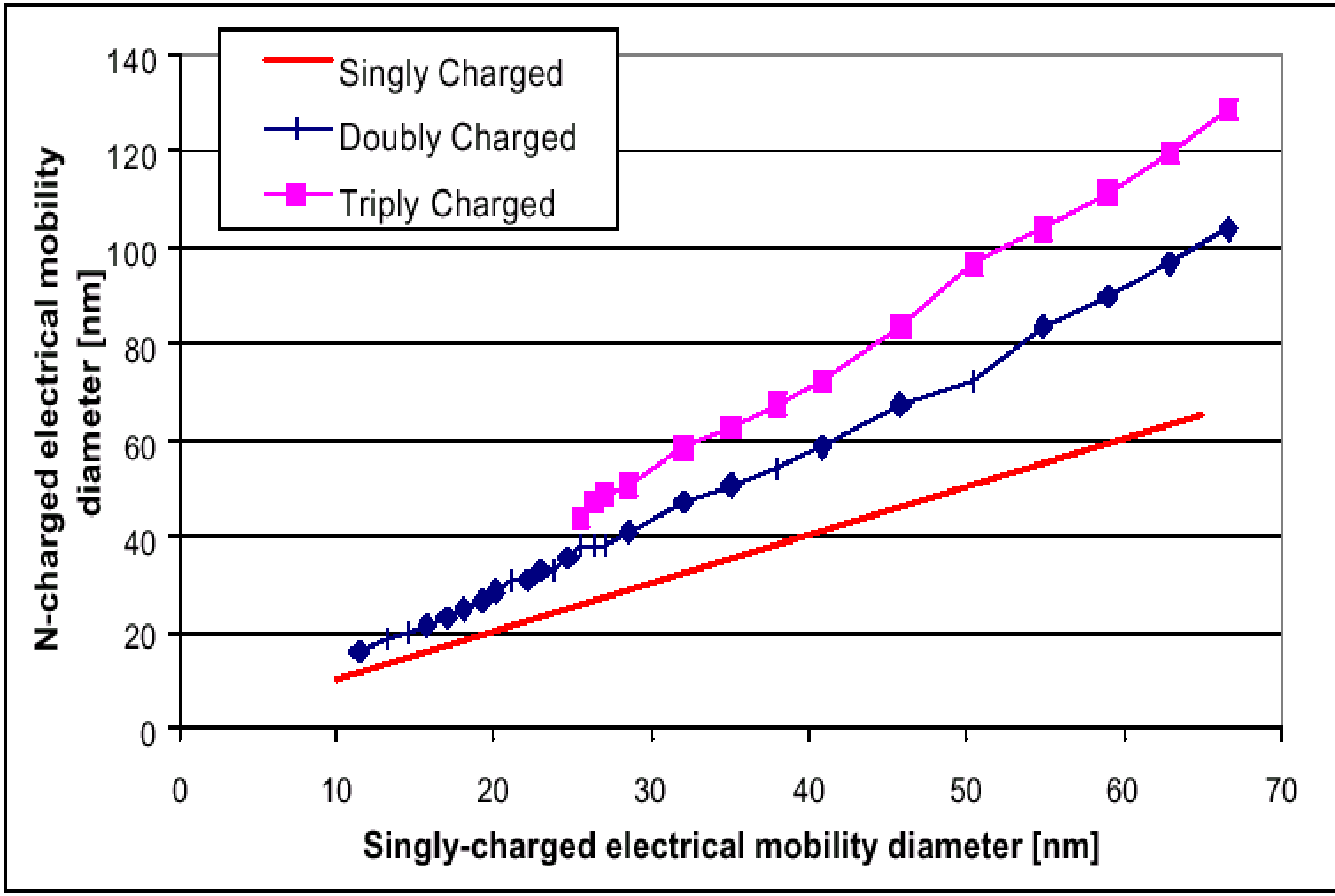
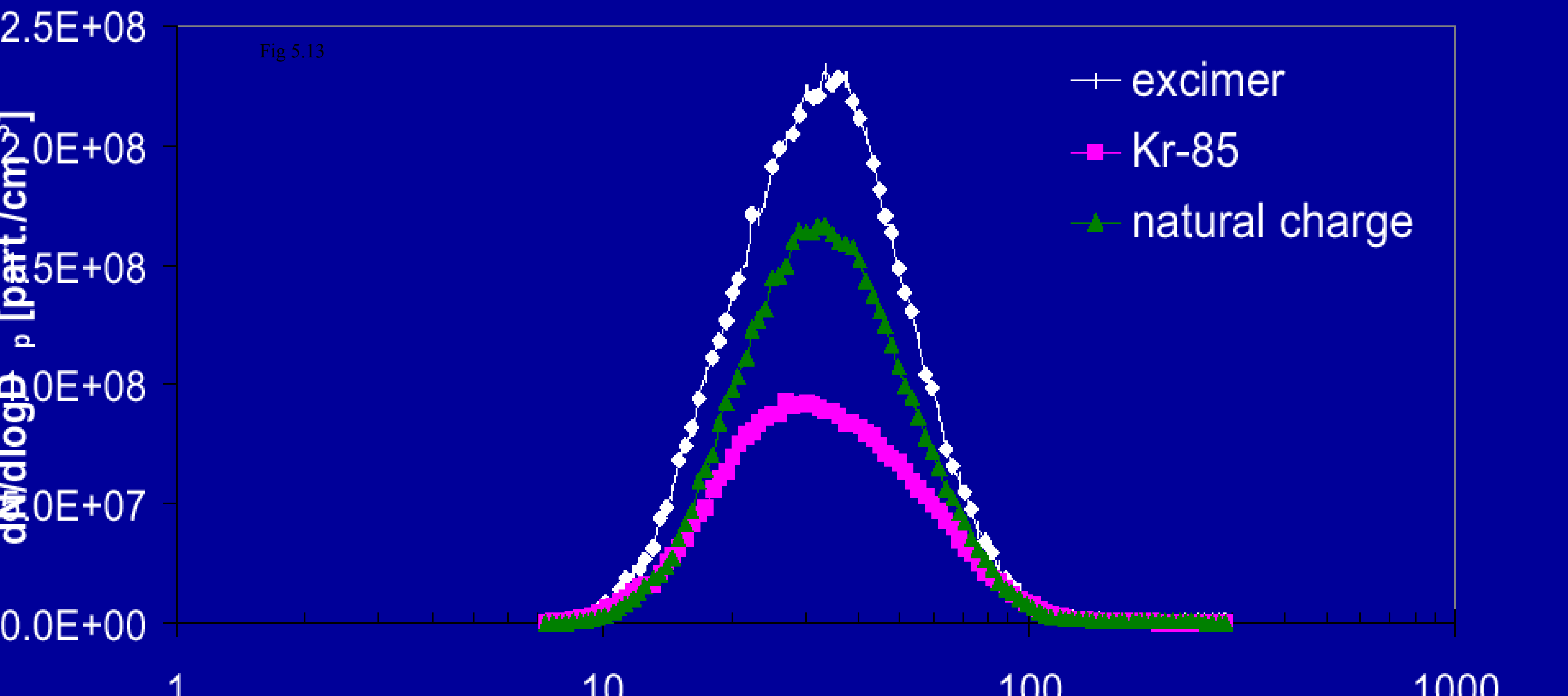


Figure 5.12. Actual diameter of multiply-charged particles as measured against their "apparent" singly charged mobility diameters.

Fraction of Particles Charged

- Measurement performed with SMPS using Kr85 bypass



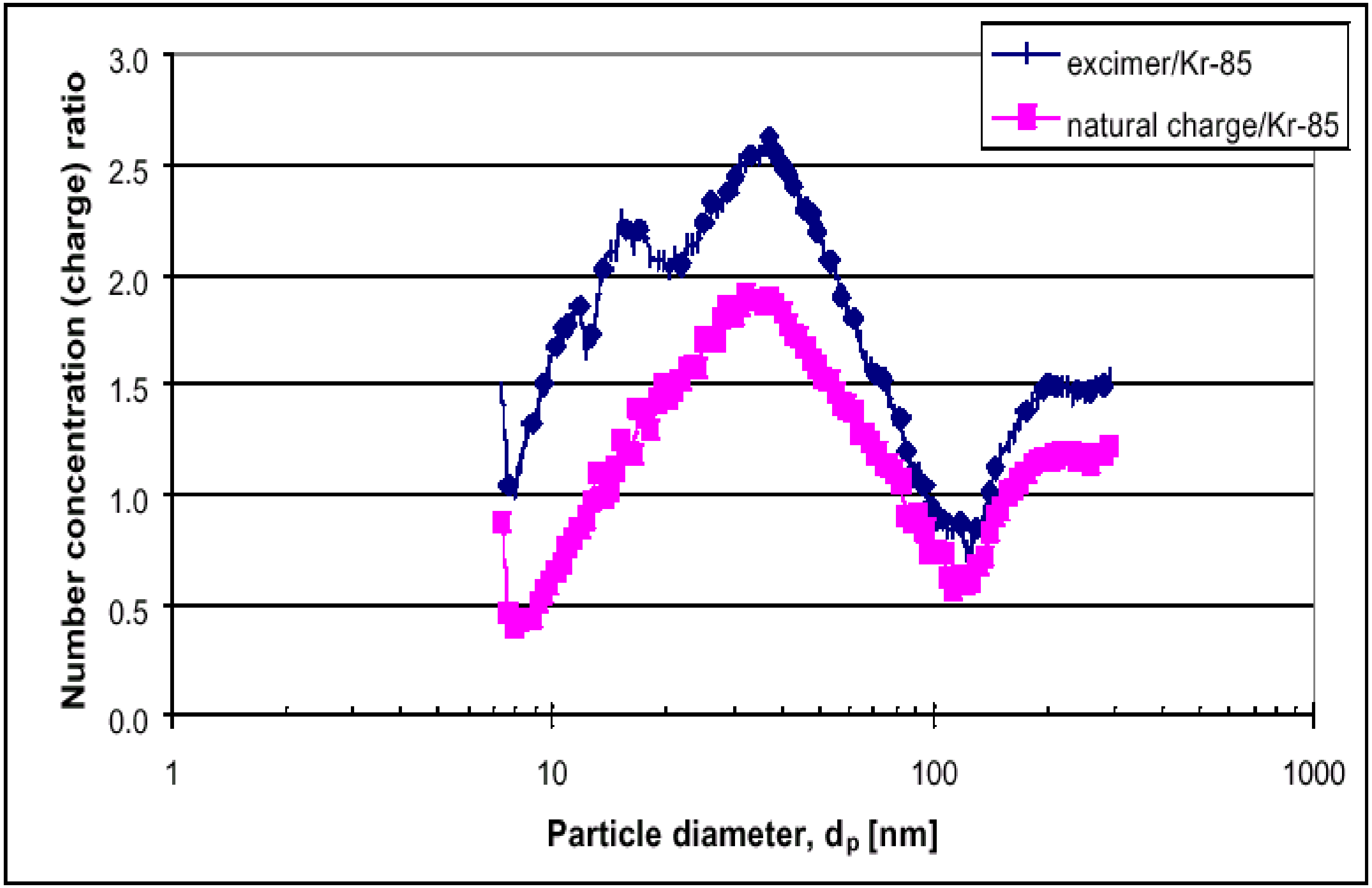


Figure 5.14. Particle charge ratios (with respect to ^{85}Kr charging) for the diffusion flame aerosol.

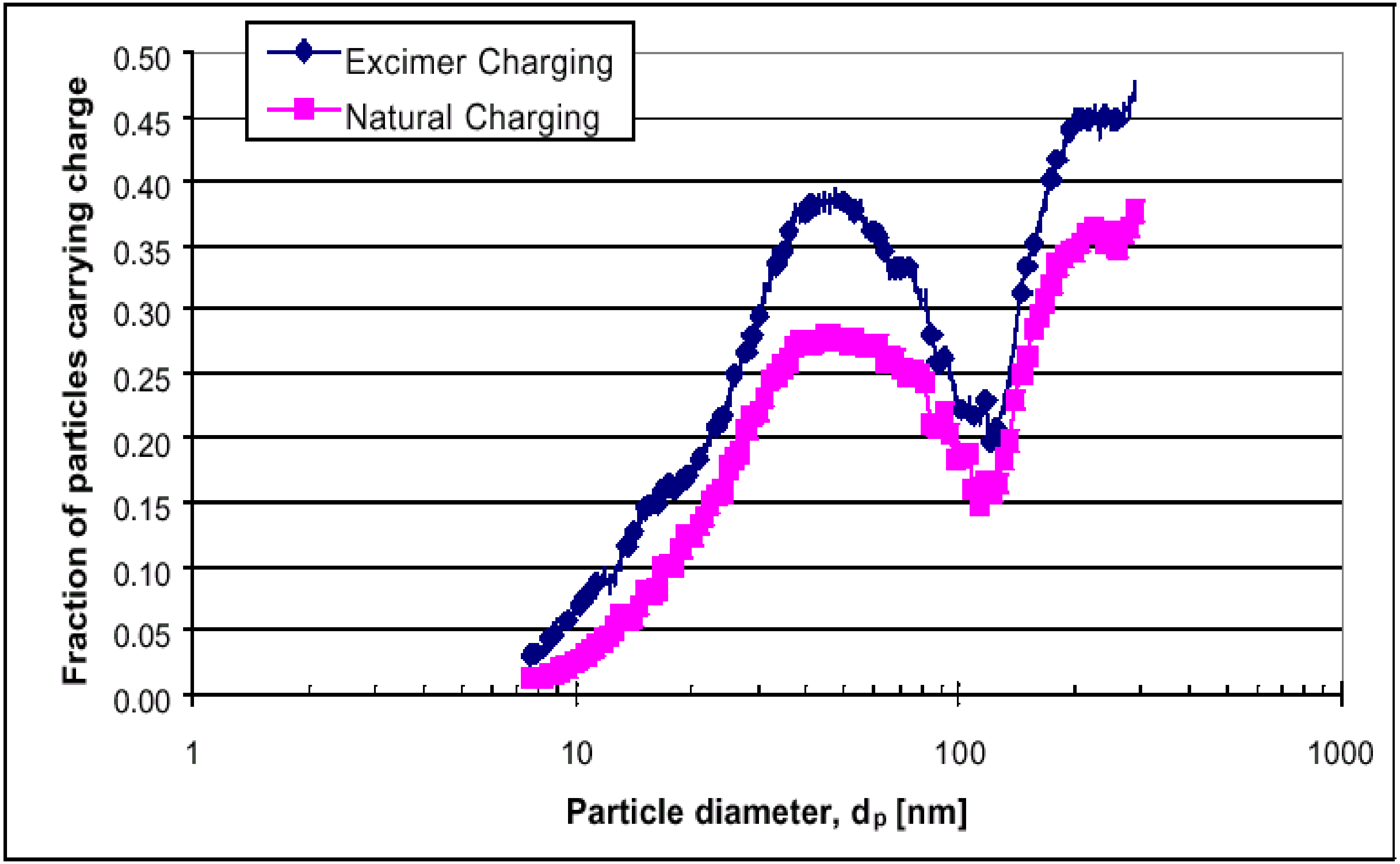


Figure 5.15. Fraction of particles carrying net charge (diffusion flame aerosol).

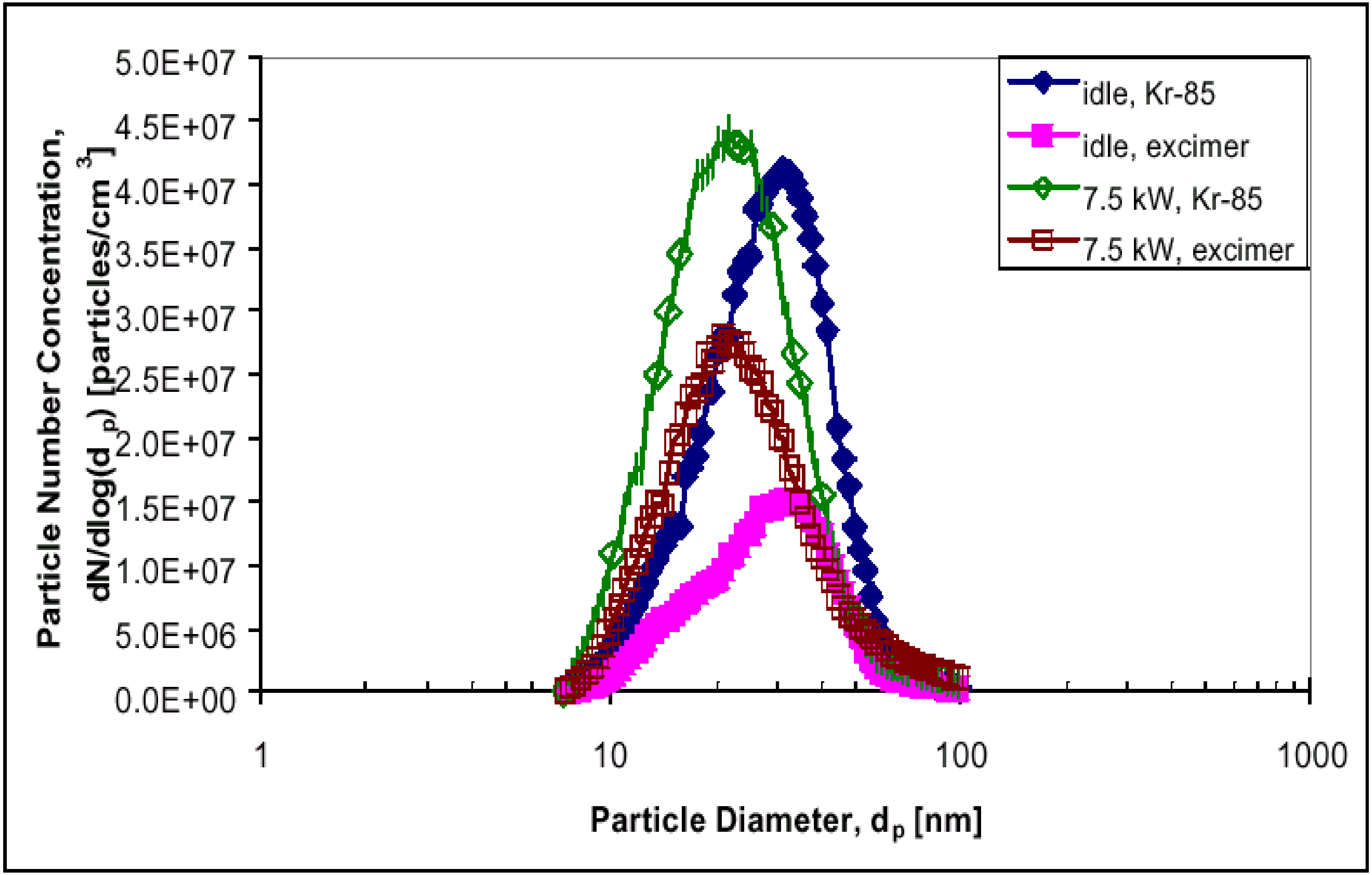


Figure 5.16. Effect of photoelectric charging on diesel engine aerosol size distribution (idle, 7.5 kW)

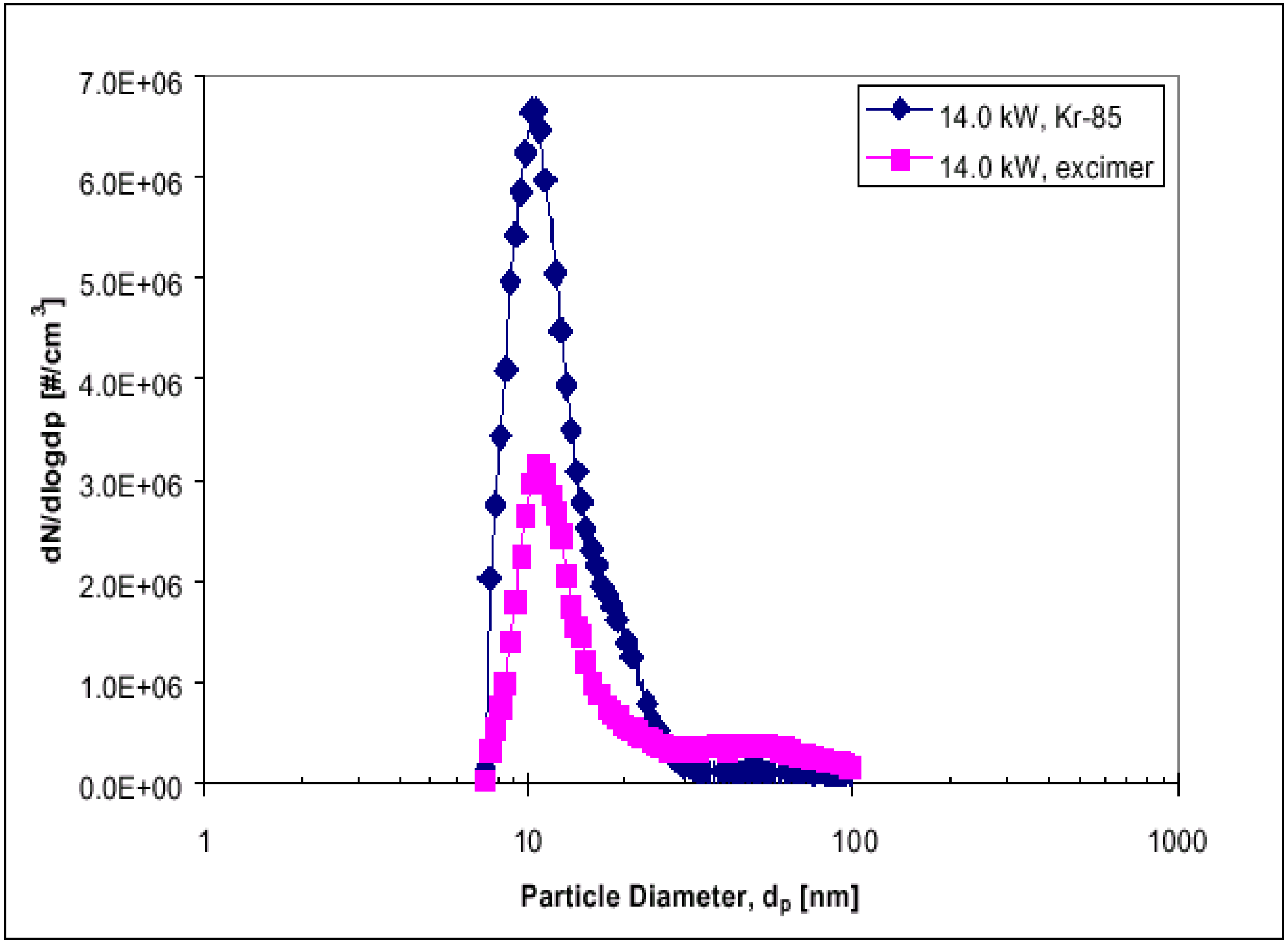


Figure 5.17. Effect of photoelectric charging on diesel engine aerosol size distribution (14.0 kW)

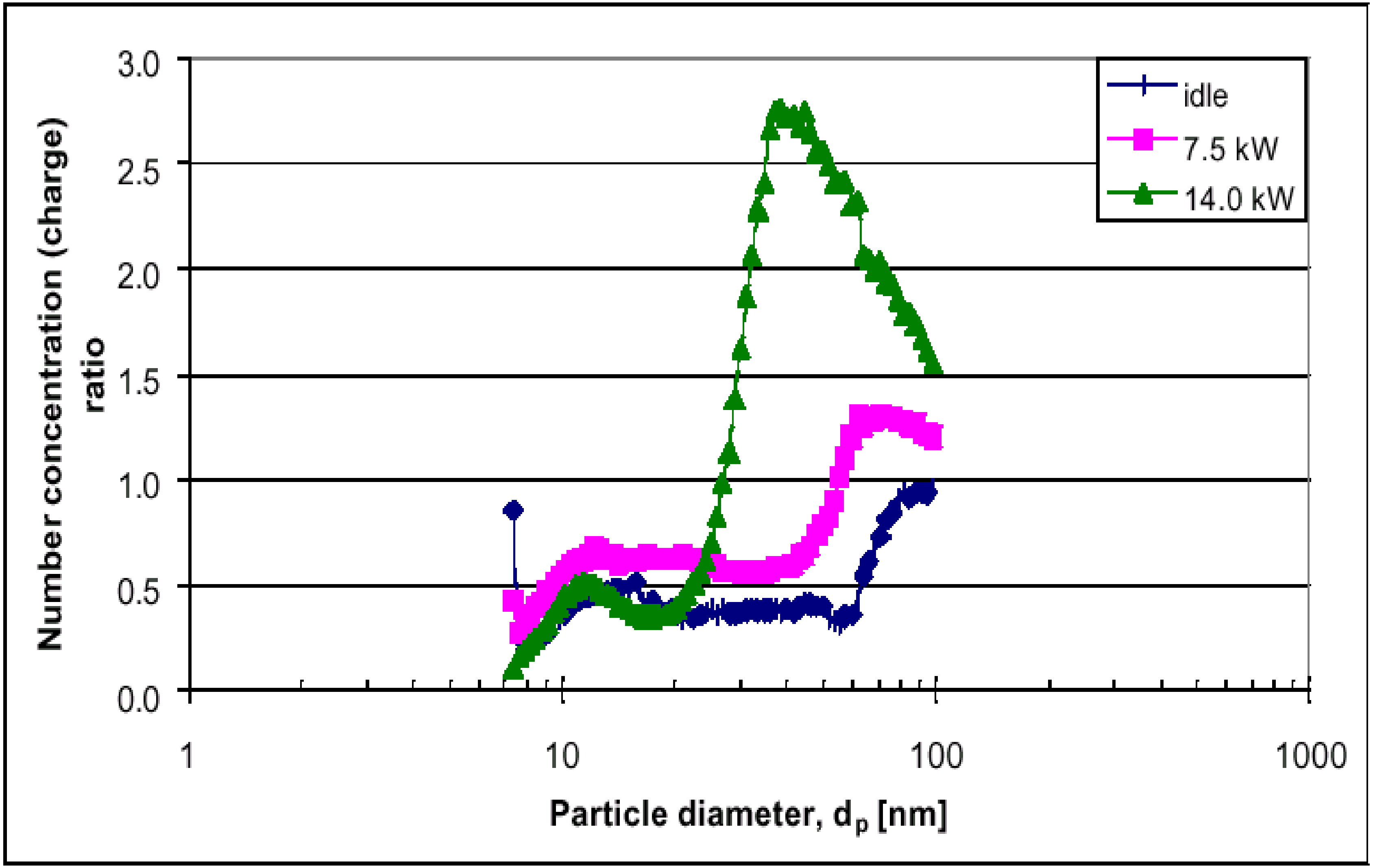
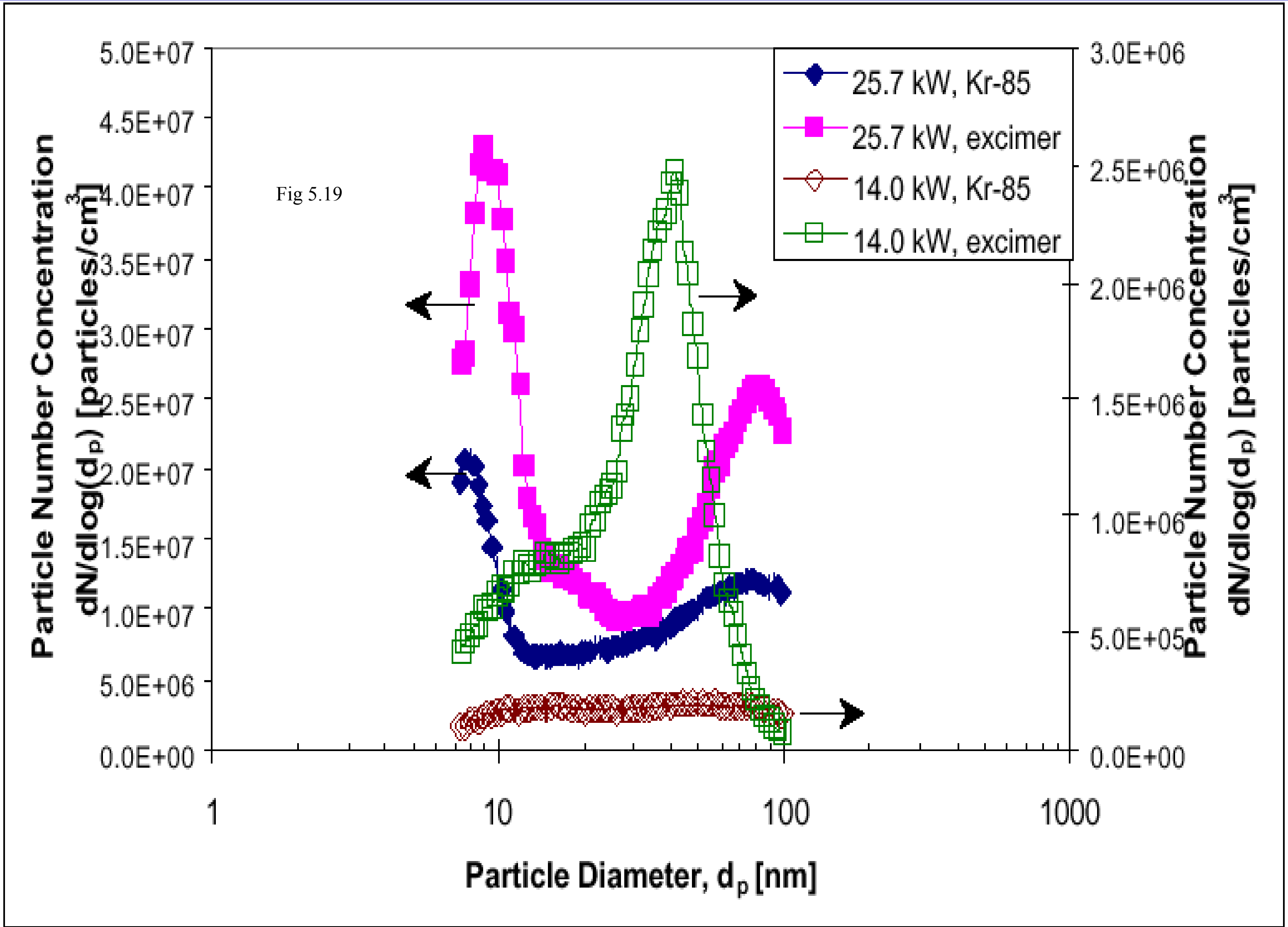


Figure 5.18. Number concentration (relative charge fraction) ratios for photoelectrically charged diesel engine aerosol particles.

Effect of photoelectric charging on spark ignition engine aerosol size distribution (14.0, 25.7 kW)



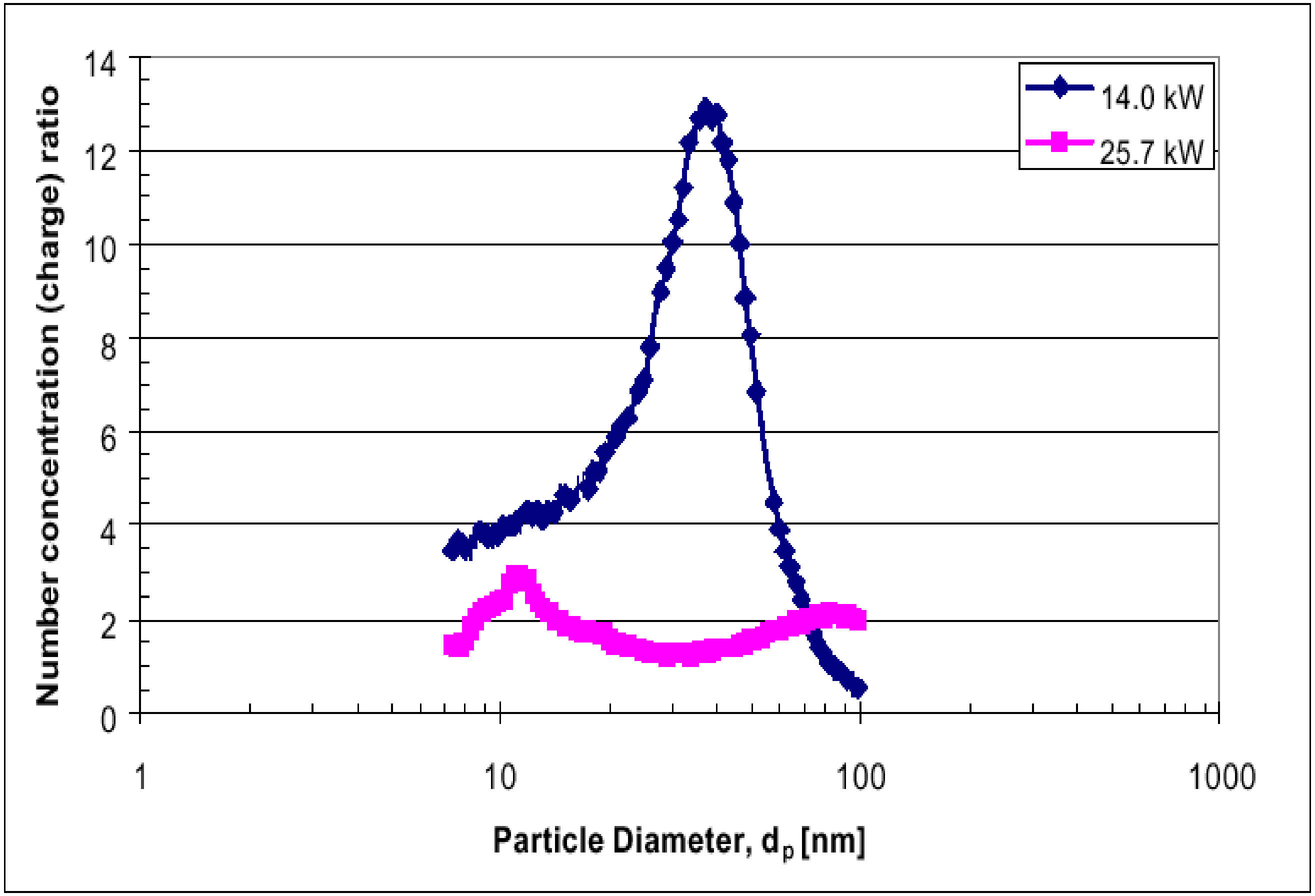


Figure 5.20. Number concentration (relative charge fraction) ratios for photoelectrically charged spark ignition engine aerosol particles.

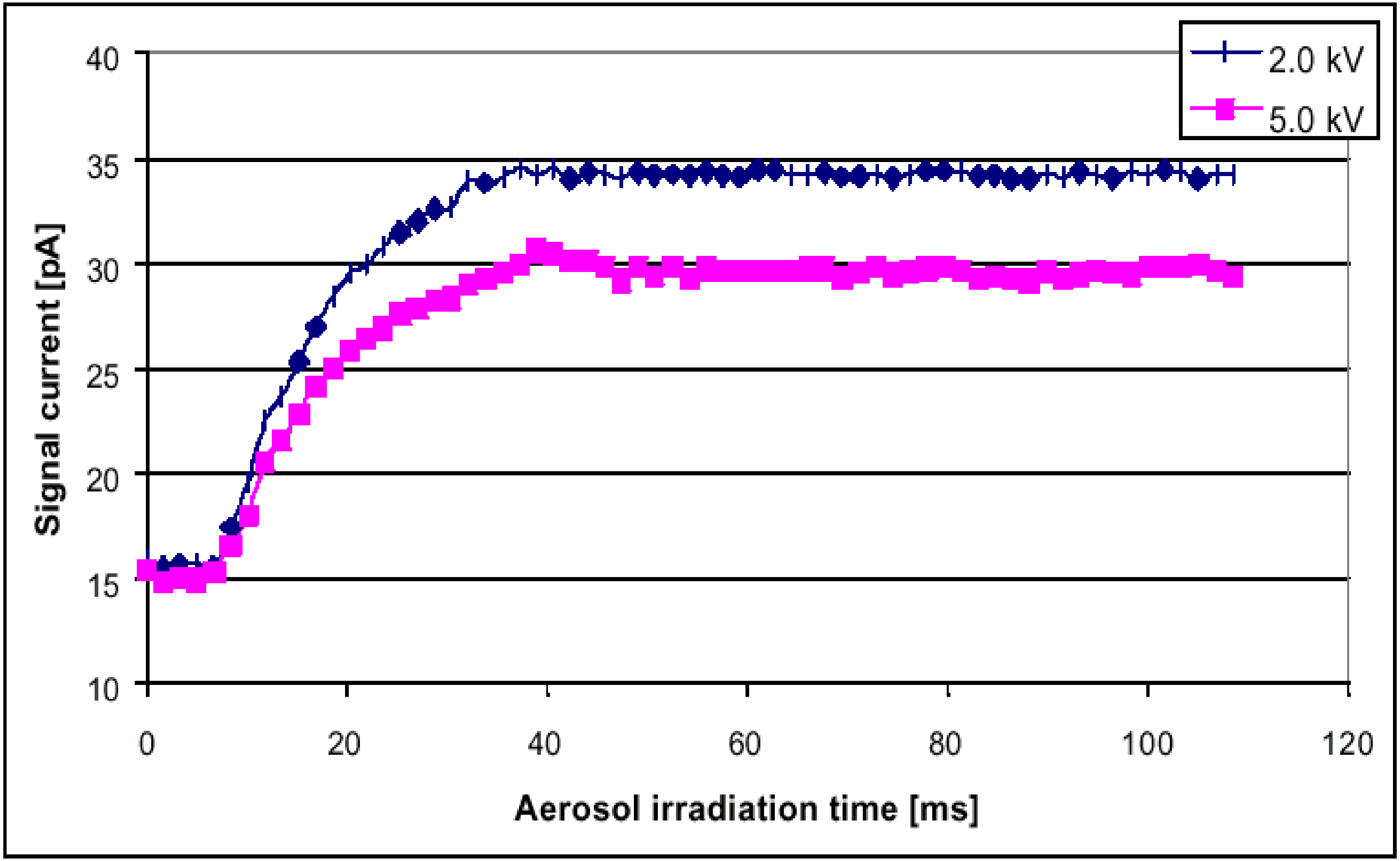


Figure 5.21. Photoelectric charging effectiveness in the FAS as a function of aerosol irradiation time (central rod voltage 2.0, 5.0 kV).

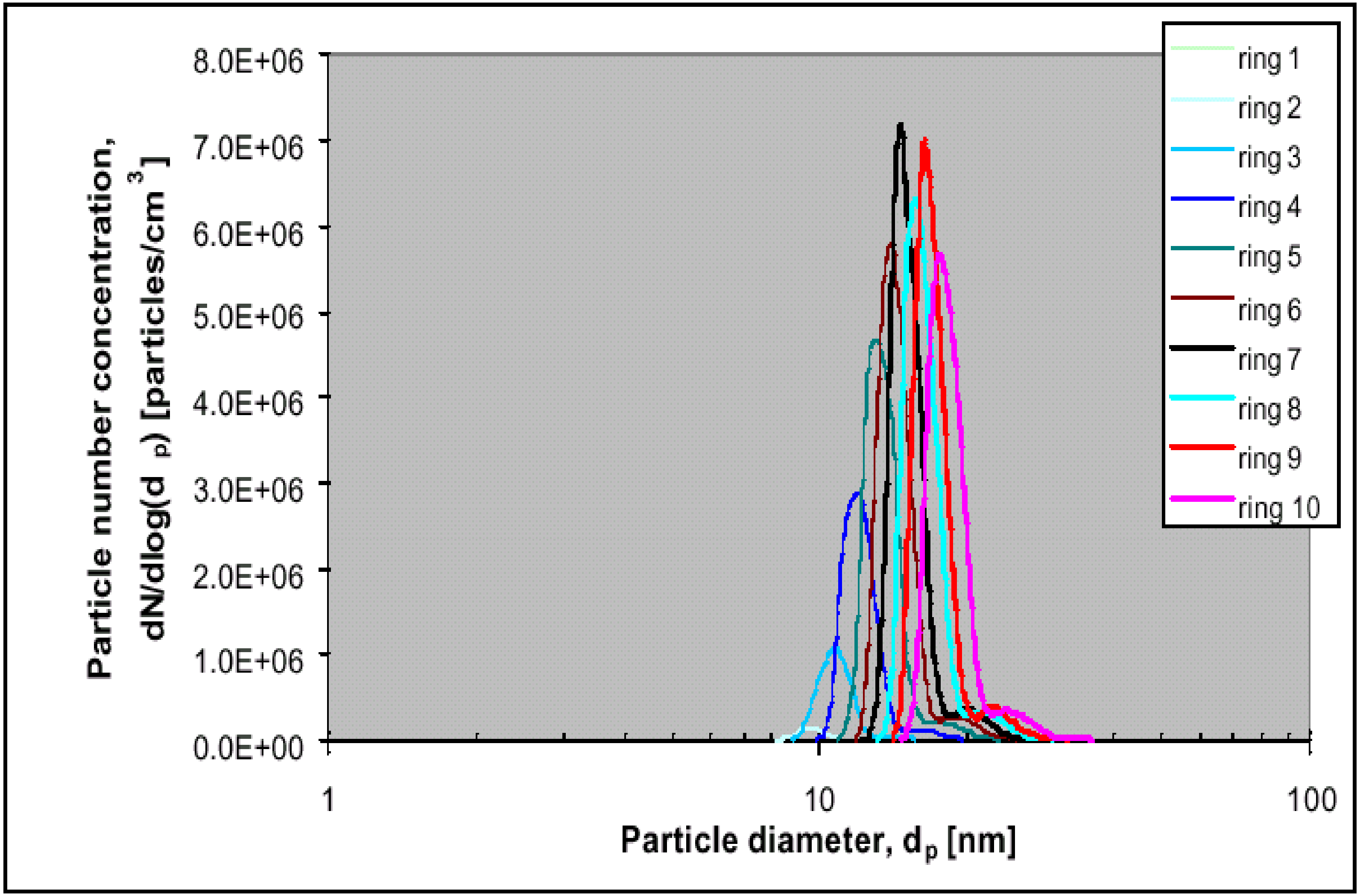


Figure 5.22. Axial particle size distribution within the FAS classifier (central rod voltage 2.0 kV, 5.0 l/min aerosol flow, 50 l/min sheath air flow).

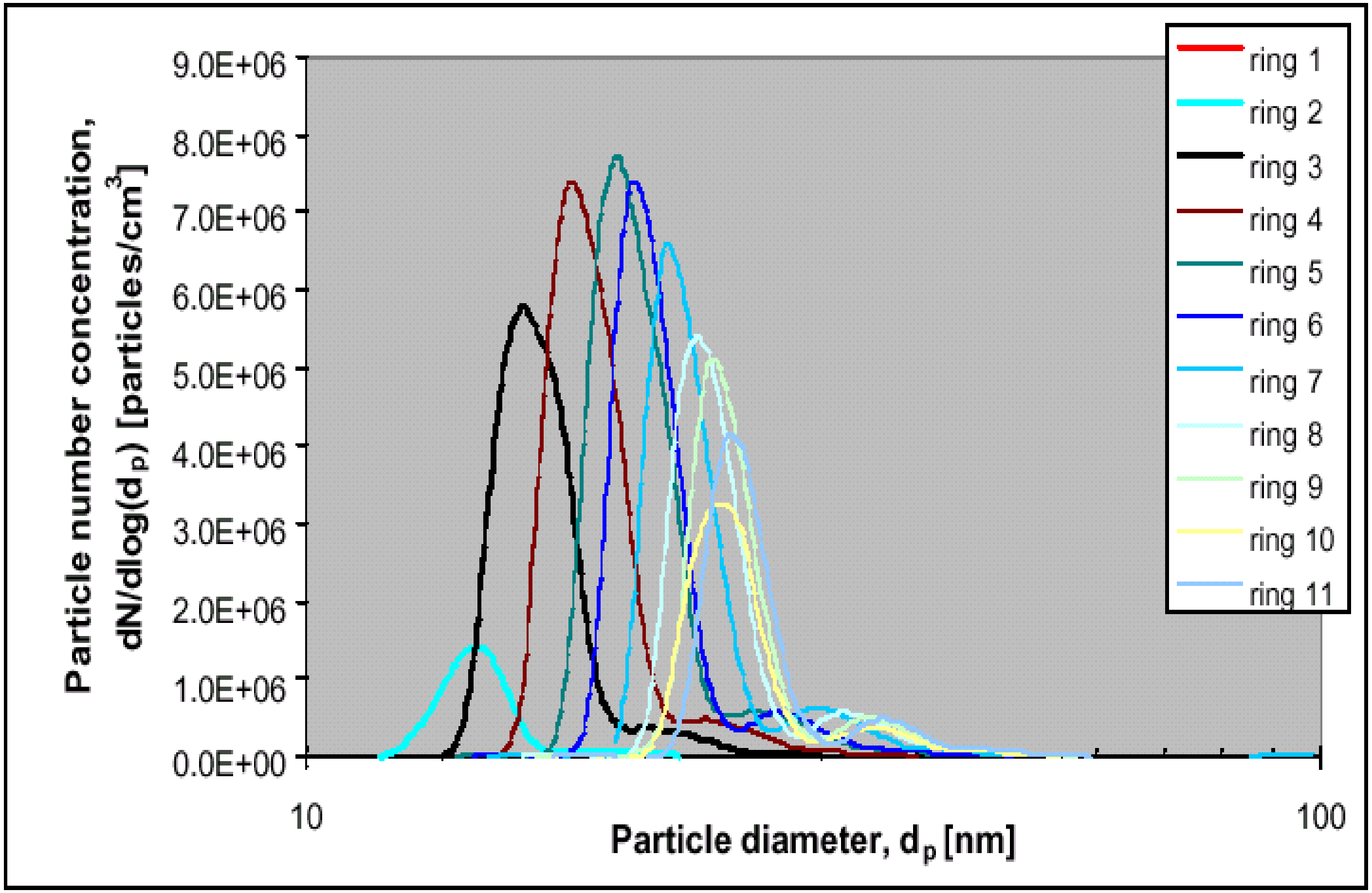


Figure 5.23. Axial particle size distribution within the FAS classifier (central rod voltage 5.0 kV, 5.0 l/min aerosol flow, 50 l/min sheath air flow).

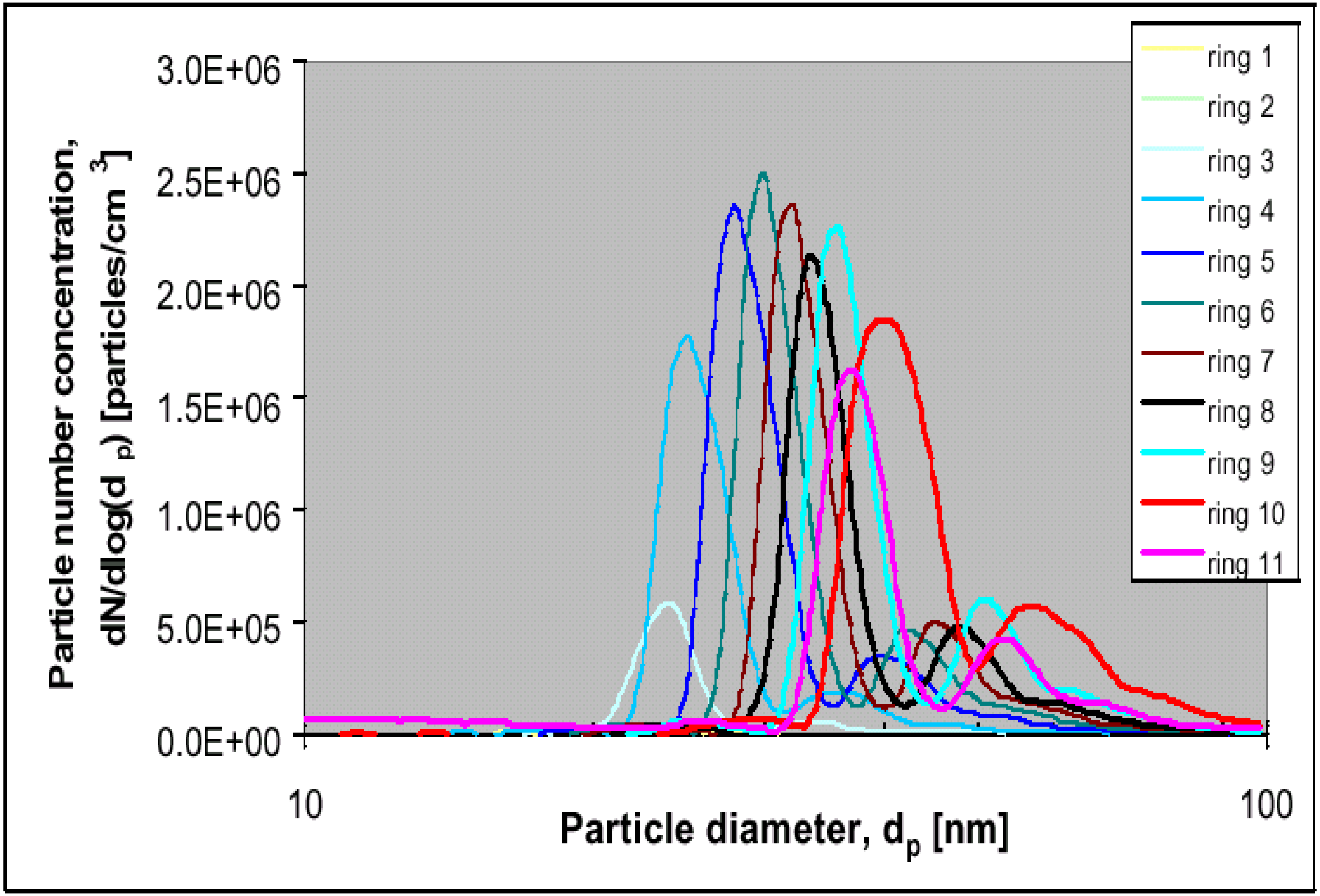
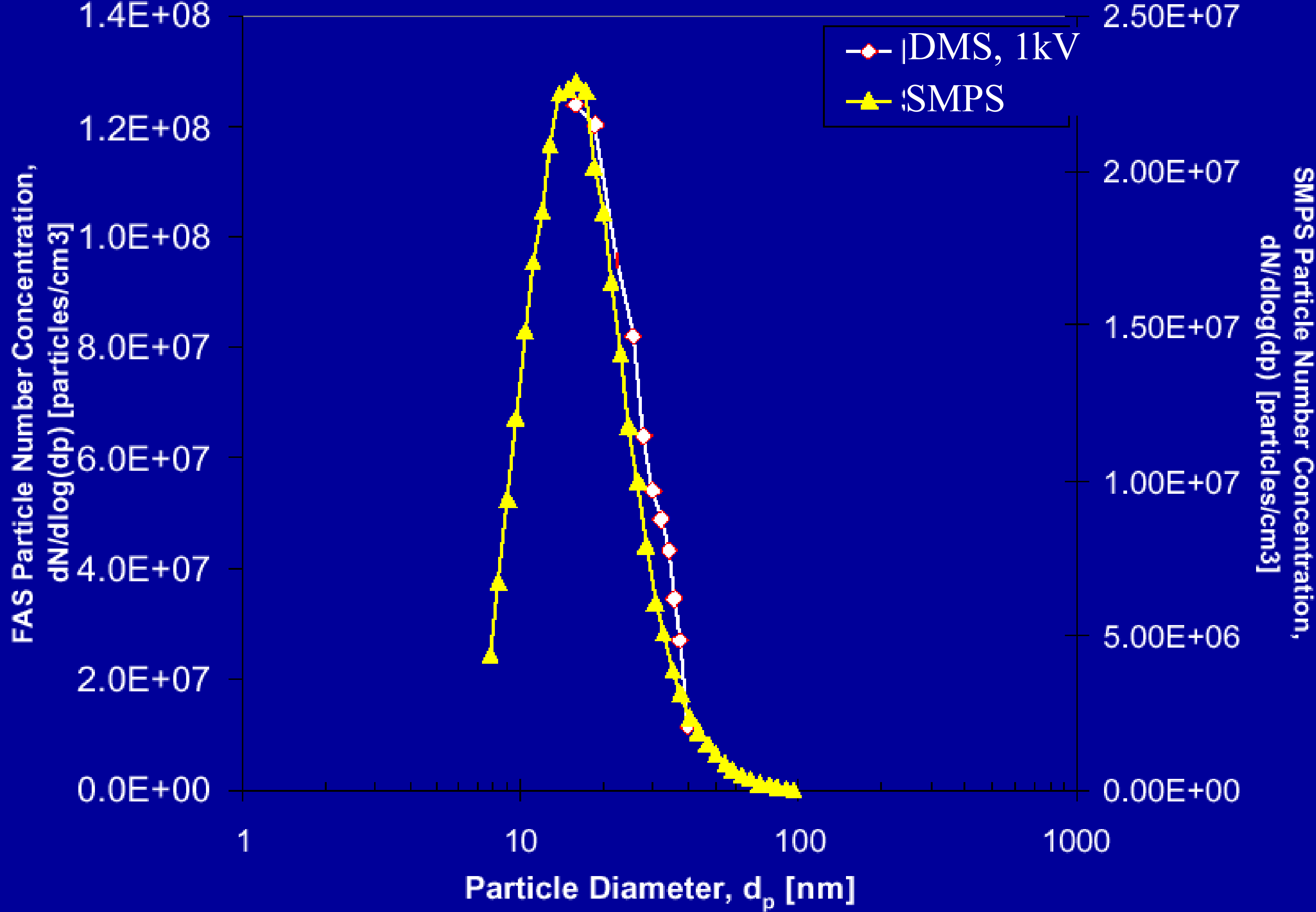


Figure 5.25. Axial particle size distribution within the FAS classifier (central rod voltage 10 kV, 5.0 l/min aerosol flow, 50 l/min sheath air flow).

*f*DMS/SMPS Comparison



Corrected for flow field, electric field, multiple charging

No "calibration" factors

Conclusions

- *f*DMS concept may be useful for engine measurements, but:
  - there may be issues associated with photoelectric charging for sizing purposes
  - multiple charging issues will become more of a problem for bigger particles
  - electrometer sensitivity always limits lower detectable limit - unlike the CNC