

Precision Measurement of Nanoparticle Slip Correction

INTRODUCTION

The drag force in various particle sizing techniques is required to modify since gas behavior at the sphere surface may not guarantee the no-slip boundary condition, used by Stokes law in viscous fluid regime and since particle-fluid interactions may not be simply predictable for a small sphere, with the size of the order of gas mean free path or smaller than that. The slip correction factor, given by Cunningham (1910) and Knudsen and Weber (1911), is defined as a function of Knudsen number:

$$C(Kn) = 1 + A \cdot Kn$$

$$A = \alpha + \beta \cdot \exp(-\gamma / Kn)$$

where Kn: Knudsen number = λ/r

and α , β , and γ are characteristic parameters that are somewhat dependent on particle surface and gas characteristics, and need to be experimentally determined. λ is gas mean free path and r is a particle radius.

Allen and Raabe (1982) re-evaluated Millikan's oil drop data for the motion of small particles in air over the Knudsen number range of 0.001 – 100. Later (1985), they measured slip correction factor for solid, spherical particles in air at Knudsen number between 0.01 and 10. The slip corrections for polystyrene and polyvinyltoluene spheres were measured by varying both size and pressure. Rader (1990) re-evaluated the experimental data of Ishida's oil drop work (1923) for the slip correction to Stokes drag law for a variety of common gases. He determined γ value for oil-drops in air, CO₂, and

He according to his fitting method. Hutchins *et al.* (1995) measured slip correction for solid spherical particles in air by modulated dynamic light scattering. They suggested that the drag force ratio varies significantly with test particle type and that drag force measurements provide a means for study of molecule-surface interactions. Recently, Schmid *et al.* (2002) used Allen and Raabe's slip correction in sizing of polystyrene latex spheres in gases other than air using a differential mobility analyzer. Previous slip correction works are summarized in Table 1.

Table 1. Parameters for Cunningham slip correction factor.

Author (Year)	Size	Material	α , β , and γ
Allen and Raabe (1982)	0.35 – 2.5 μm	Oil-drops	1.155, 0.471, and 0.596
Allen and Raabe (1985)	0.8 – 5.0 μm	PSL	1.142, 0.558, and 0.999
Rader (1990)*		Oil-drops	1.207, 0.440, and 0.780
Hutchins <i>et al.</i> (1995)	1.0 – 2.2 μm	PSL	1.231, 0.470, and 1.178

* Based on the Ishida's experimental work(1923)

Figure 1 shows the comparison of the slip correction factor (A) over wide range of Knudsen numbers between 0.01 and 1000. Four researches show different estimations in continuum regime regardless of particle materials, but two results show almost same predictions from PSL experiments for free-molecular regime. As seen in Table 1, most particles used in the slip correction measurements were micrometer scale, and nanoscale particles of size range of less than 100 nm need to be used for the slip correction measurements as the size of working particles decreases in various aerosol fields. In

addition, different particle materials are in demand for some related researches over wide range of Knudsen number conditions.

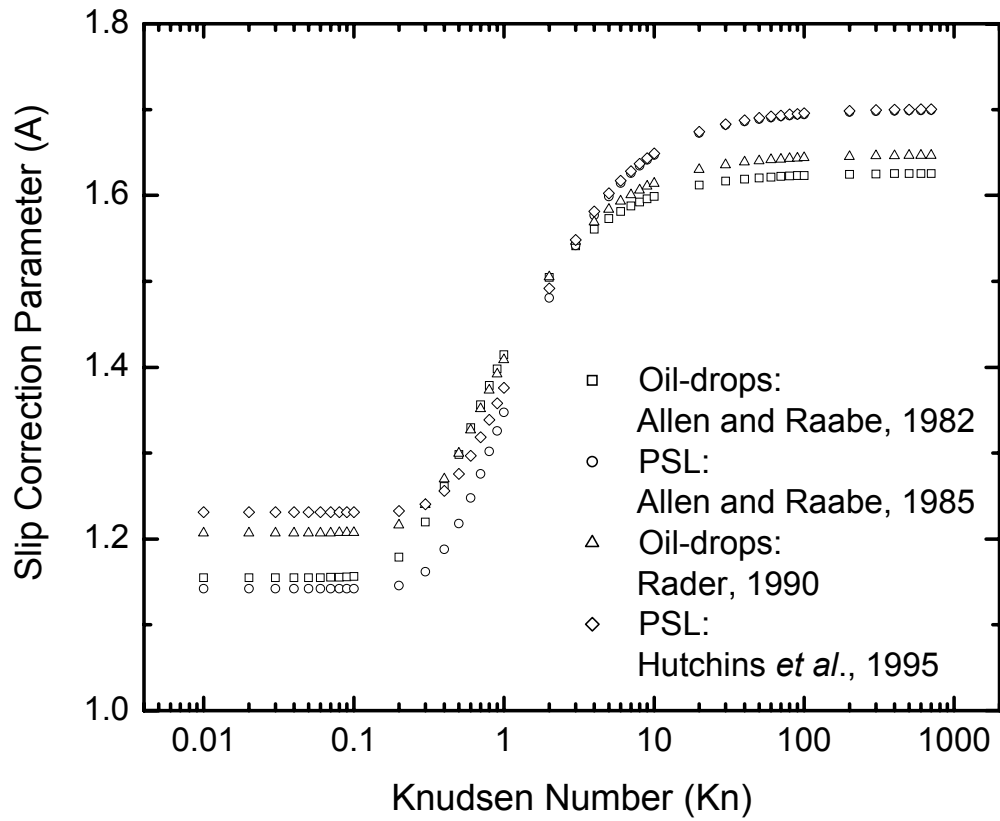


Figure 1. Comparison of the slip correction parameter (A) from the previous results.

OBJECTIVES

1. Perform precision measurements for the estimation of slip correction factor using two differential mobility analyzers connected in series with NIST SRM 1963, 100 nm PSL sphere. The first DMA will be operated under normal conditions and the second one will be operated under low-pressure conditions in order to obtain various Knudsen numbers.
2. Measure peak voltage from DMA 1, and determine particle diameters. Measure peak voltage from DMA 2, and determine electrical mobility of the particle. Calculate slip correction factor for the experimental conditions (Knudsen number under low pressure, electrical mobility, and particle diameter).
3. Perform measurements at several different low-pressure conditions for different Knudsen number conditions. Construct a master curve, and obtain the best fitting function whether it will be Cunningham form or other new functional form.
4. Use different types of high purity gas, e.g., He, Ar, and other appropriate gaseous media with different viscosities.
5. Perform measurements with several different particle materials such as gold, dendrimer, and large protein to examine the effects on the type of materials.

TIMELINE FOR OUR GOAL

1. First manuscript for J. NIST by December 2003.
2. Second full manuscript for J. Aerosol Sci. by June 2003.

EXPERIMENTAL

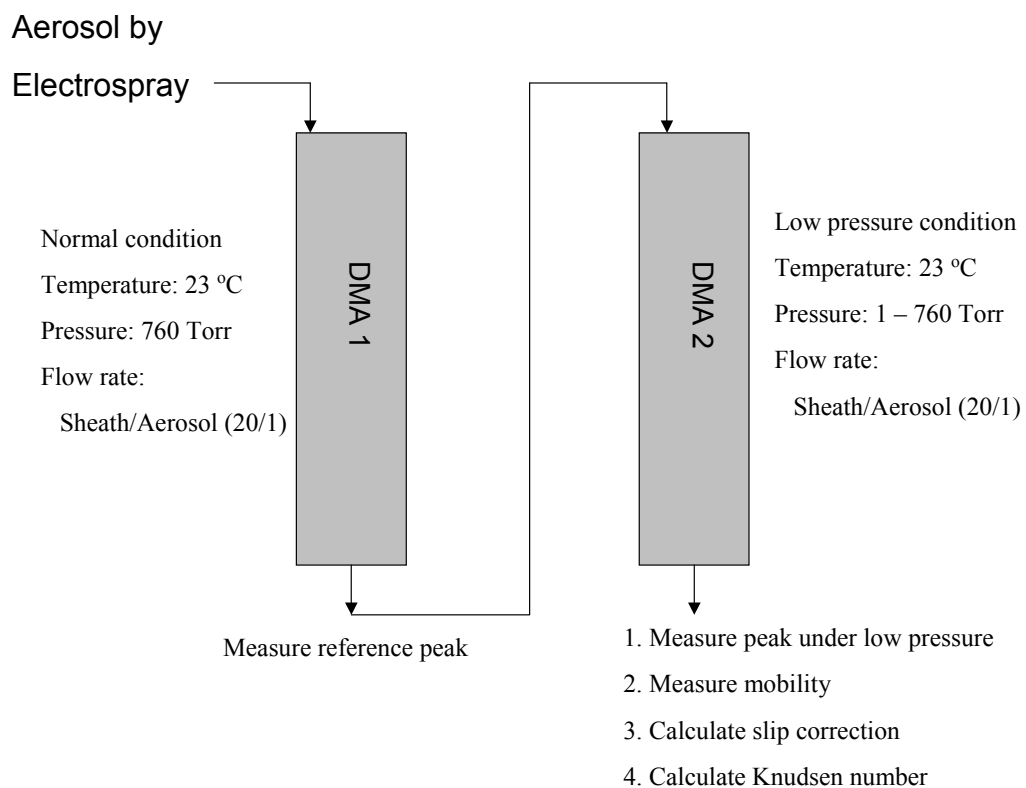


Figure 2. Schematic for slip correction measurements using two differential mobility analyzers in series.

REFERENCES

1. Allen, M. D. and Raabe, O. G. (1982) *J. Aerosol Sci.* **13**, 537.
2. Allen, M. D. and Raabe, O. G. (1985) *Aerosol Sci. Technol.* **4**, 269.
3. Rader, D. J. (1990) *J. Aerosol Sci.* **21**, 161.
4. Hutchins, D. K., Harper, M. H., and Felder, R. L. (1995) *Aerosol Sci. Technol.* **22**, 202.
5. Schmid, O., Trueblood, M. B., Gregg, N., Hagen, D. E., and Whitefield, P. D. (2002) *Aerosol Sci. Technol.* **36**, 351.
6. Mulholland, G. W., Bryner, N. P., and Croarkin, C. (1999) *Aerosol Sci. Technol.* **31**, 39.