NANOSCAN SMPS
NANOPARTICLE SIZER
THEORY OF OPERATION

APPLICATION NOTE SMPS-005

Introduction

The NanoScan SMPS is a portable analytical instrument which measures nanoparticle size distributions and concentrations. Additionally, the NanoScan SMPS has the ability to monitor the concentration at a single diameter with second by second time resolution. This new battery operated nanoparticle sizer has been developed to provide an affordable method to measure nanoparticles for a variety of research applications and industrial hygiene investigations.

Instrument Design

The primary design goals of the NanoScan SMPS were to develop an instrument with the capability of measuring nanoparticle size distributions accurately, reliably, and repeatable; and with the usability and form factor similar to that of commonly used optical particle counters (OPCs) which measure the size distribution of larger particles.

The benchmark method for sizing airborne nanoparticles is via Scanning Mobility Particle Sizer™ (SMPS™) Spectrometer analysis. Both the SMPS™ Spectrometer and the NanoScan SMPS are electrical mobility based sizing techniques. The benefits of sizing particles less than a micron via electrical mobility have been well documented. The National Institute of Standards and Technology (NIST) has been using this method over other techniques to measure 0.1 µm (100 nm) Standard Reference Material (SRM) Particles for well over a decade[1][2].

Electrical mobility, or the ability of a particle to traverse an electric field, is a convenient method to measure particle size, because it can be directly measured and is a first principle function of size. Electrical mobility is typically measured by using a Differential Mobility Analyzer (DMA).

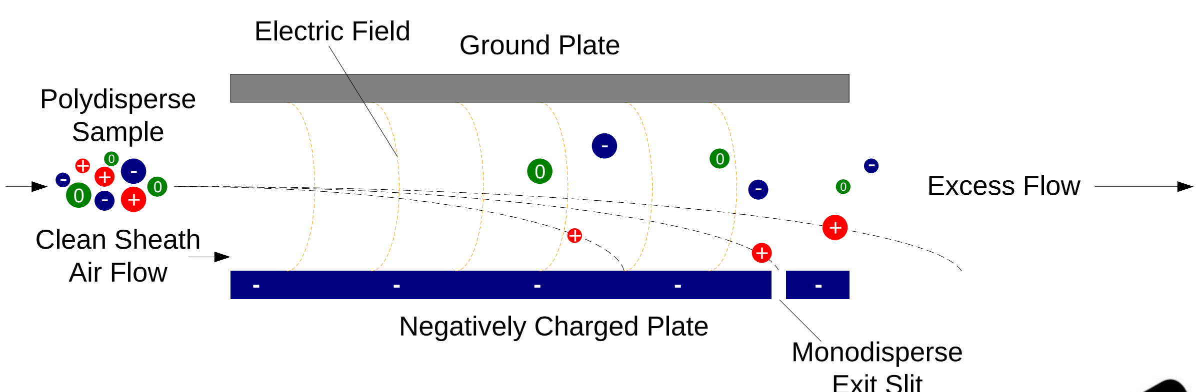

Figure 1: Schematic of Differential Mobility Analyzer

Inside a DMA, a charged aerosol particle experiences an electric field, causing it to move through the gas in which it is suspended. The particle also experiences an opposing drag force from the gas flow which can be calculated using Stokes law. These forces can be equated and the electrical mobility of the particle can be calculated.

(1) $$F_{electric} = n_p eE$$

(2) $$F_{viscous\ drag} = \frac{3\pi\mu D_p v}{C}$$

(3) $$F_{electric} = F_{viscous\ drag}$$

(4) $$Z_p = \frac{v}{E} = \frac{n_p eC}{3\pi\mu D_p}$$

Where:

n_p = number of charges per particle
e = elementary unit of charge
E = electric field strength
μ = viscosity of gas
D_p = particle diameter
C* = Cunningham slip correction
v = Velocity

**C is a lower order function of particle diameter*

It's important to note two fundamental facts regarding electrical mobility measurement using a DMA. 1) In order to calculate particle diameter from electrical mobility, the number of charges per particle must be known, and 2) only charged particles are measured.

Measurement Modes

SINGLE: At each voltage setting, a DMA outputs a slice of the aerosol that is of the specific electrical mobility determined by equation (4). The instrument works in a similar way to a bandpass filter in electronics. In SINGLE size monitoring mode, the user can monitor particle concentration at a specific electrical mobility diameter. The user selects the diameter size of interest, and the RDMA voltage is set to a fixed value calculated from equation (4) using the average number of charges per particle induced by the unipolar charger. Particles concentration downstream of the DMA is measured with 1 second time resolution.

SCAN: To measure a particle size distribution with a DMA, the voltage is quickly ramped, and the particle concentration is measured at essentially all of the mobility diameters in the sample. During each 60 second scan, the voltage exponentially ramps up for 45 seconds, during which time the internal CPC continually measures particle concentration. During the last 15 seconds the voltage is ramped down, and no additional particle concentration data is collected.

NanoScan SMPS Components

Scanning Mobility Particle Size (SMPS) analysis is the fundamental measurement technique of the NanoScan SMPS. The new nanoparticle sizer incorporates the five primary components of a Scanning Mobility Particle Sizer (SMPS™) Spectrometer into a chassis that is <1 ft^3 (<0.03 m^3).

1) **Inlet Conditioner**
   Used to remove larger particles which can potentially cause clogging and which are likely to have multiple charges. Multiple charges per particle can result in particles of two different diameters having the same electrical mobility. This degrades the instrument resolution and as such, the technique is less accurate at larger sizes. To ensure optimum resolution over the entire operating size range, a cyclone with an approximately 500 nm cutpoint is used on the inlet of the NanoScan SMPS.

2) **Aerosol Charger**
   The charge per particle must be known to calculate particle diameter from electrical mobility. In the NanoScan SMPS, a patented unipolar charger is used which increases nanoparticle

counting efficiency (by charging a higher % of nanometer sized particles), and eliminates logistical issues due to radioactive materials[3]. The induced charge distribution is well characterized and repeatable. About 10 times more 10 nm particles are charged in the unipolar charger compared to the traditional bipolar charger, which leads to better counting statistics at small sizes.

3) **Differential Mobility Analyzer (DMA)**
The DMA used in the NanoScan SMPS is a Radial DMA[4]. A radial design features shorter particle residence times, resulting in higher nanoparticle transmission efficiencies. Practically, a radial DMA is also more compact and as such more lightweight than traditional cylindrical DMA's, making it ideal for use in a portable instrument.

4) **Particle Counter/Detector**
Downstream of the DMA, the number of particles in each size bin is measured. In the NanoScan SMPS, an isopropanol-based Condensation Particle Counter (CPC) is used to provide accurate measurements at high and low concentrations using a working fluid acceptable in workplace environments. CPCs measure particle concentration by counting single particles which results in a high level of accuracy and excellent performance at low concentrations.

5) **Control Software**
The instrument control, analysis and data logging can be done completely through the instrument touch screen. NanoScan Manager software can also be used for instrument operation, data collection and expanded analysis capabilities.

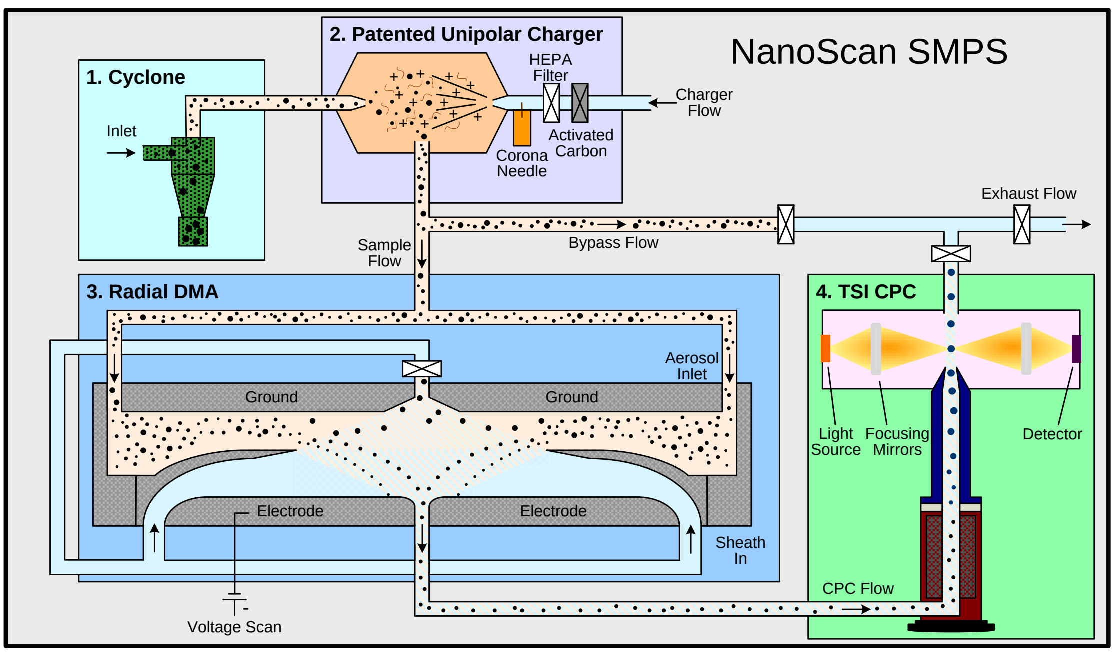

Figure 2: NanoScan SMPS Schematic

Unipolar Charger

The charging device in the NanoScan SMPS is the "Corona-Jet" charger based on work by Medved et al[5]. Positive unipolar air ions from a corona needle-tip discharge are swept by clean air through an orifice into a small, field-free mixing chamber; forming a jet which collides with an opposing jet of the incoming particle stream. The turbulence of the two colliding jets improves the mixing of the sampled particles with the unipolar ions, so that within the residence time in the mixing chamber most of the particles have reached their limiting charge state.

Radial Differential Mobility Analyzer

Many are more familiar with the classic cylindrical DMA developed by Knutson and Whitby[6]. A cross sectional view of the Radial DMA used in the NanoScan SMPS is included in Figure 2, and a top view is shown in Figure 3. Particle-free sheathe air enters a circular channel from the bottom outside edge of the RDMA and passes through a flow straightener to achieve laminar flow. The sample (polydisperse) flow is also introduced tangentially through an inlet channel at the top. The top plate of the RDMA is at ground, and the bottom plate is at a negative voltage—creating an electric field. The size classified aerosol exits out of the bottom center port of the DMA through the 'monodisperse outlet' and continues to the CPC to be counted. Excess flow exits through the top center port of the DMA. The sheath and excess flows operate in a closed, recirculating flow loop to optimize flow field laminarity.

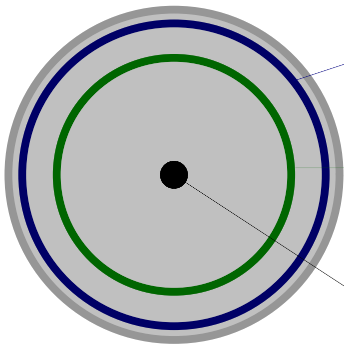

Figure 3: Top view of Radial Differential Mobility Analyzer

RDMA Transfer Function

The term "transfer function" was coined by Knutson and Whitby in 1975 to describe the probability that a particle with the mobility Z_p which enters a DMA will be selected and exit through the monodisperse outlet. In other words, if the DMA is set to a single voltage, what is the distribution of electrical mobility diameters which are size classified by the DMA? Ideally, only one mobility diameter will be selected (i.e. 17 nm). However in reality, a tight distribution will be selected (i.e. 16.8 – 17.3nm). This distribution ideally has a triangular shape, and is frequently mathematically described by its half width (½ the width of the base of the triangle). The transfer function was well defined for cylindrical DMAs by Knutson & Whitby. In 1995 Zhang et al derived the transfer function for the RDMA[7].

The half-width of the RDMA transfer function can be described as:

(5) $$\Delta Z_p = \frac{Q_a b}{\pi (R_2^2 - R_1^2) V}$$

Where:

Q_a = aerosol flow
b = the spacing between two electrodes
R_1 = radius of Monodisperse outlet
R_2 = radius of Excess flow outlet
V = DMA voltage

Conclusion

The NanoScan SMPS is easy for new users to operate and features a color touch screen with graphical data display, and onboard date storage capability. The size distribution can be weighted as number, surface area or mass. This analytical tool is useful for a variety of applications including general applied research, indoor/outdoor air quality investigations, nanotechnology/engineered nanoparticle applications, combustion/emission research, mobile studies, health effects/inhalation toxicology and industrial hygiene activities such as worker exposure, nanoparticle emission measurements, and point source tracking.

References

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[3] US Patent 6,544,484, S.L.Kaufman, F.D. Dorman, “Aerosol Charge Adjusting Apparatus Employing a Corona Discharge,” April 8, 2003.

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