Design Modification and Performance Analysis of The High-Flow Dual-Channel Differential Mobility Analyzer (HD-DMA)

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Introduction

A new **high-flow dual channel differential mobility analyzer (HD-DMA)** instrument design was recently introduced by our group for measurements over a broad diameter range and with a high sample flowrate. The commercially available DMAs (e.g., TSI 3081, 3085) typically have small sheath flows (~ 10 lpm) and correspondingly a small aerosol sample flowrate (~ 1 lpm), primarily because of the need to operate the instruments in a laminar flow regime. While several designs of DMAs operating with a high sheath flow have been introduced, the usage of these instruments has been limited to classification of particles smaller than ~ 20-50nm. HDDMA operates at relatively high flow rates (sheath flow ~100-300 lpm and sample flow ~ 20 lpm) while maintaining a low Reynolds number (~500) in the classification region.

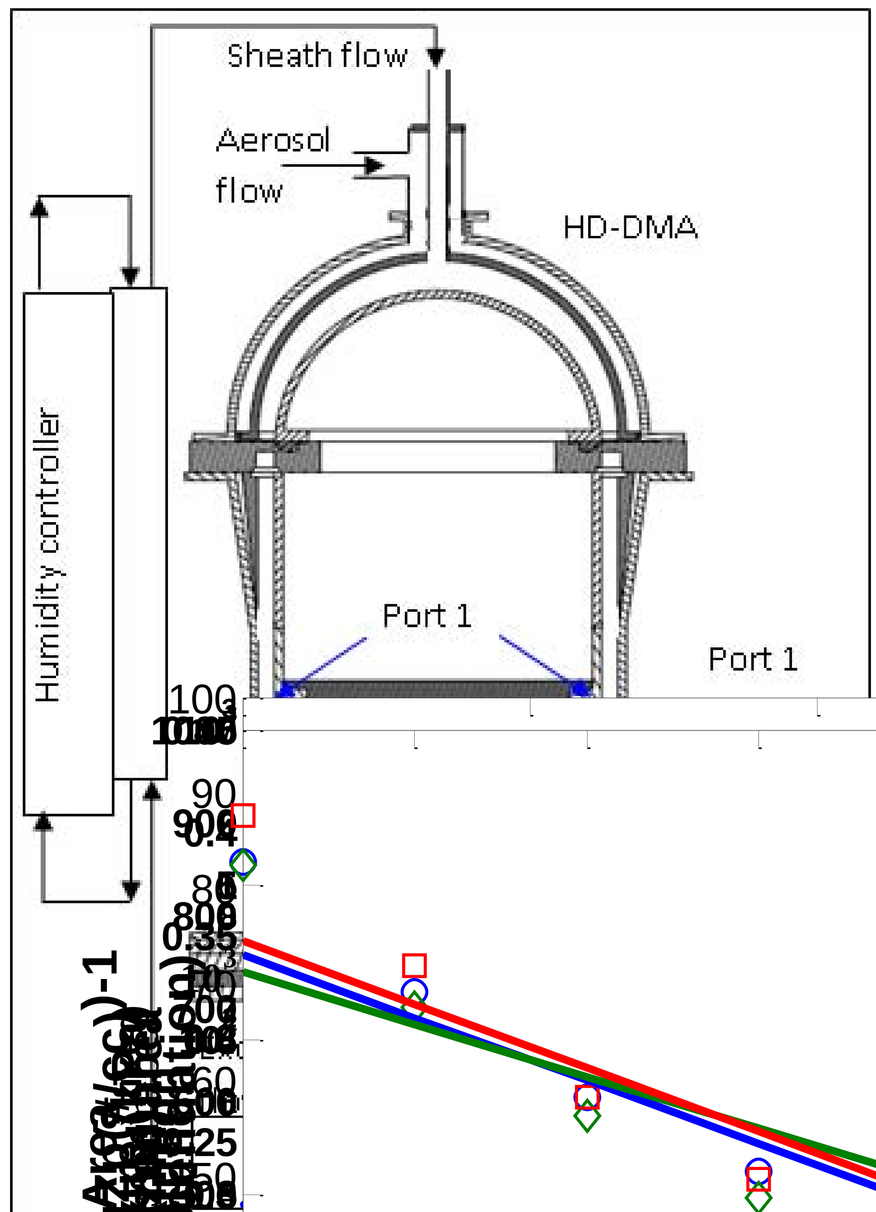
HDDMA Design

The HD-DMA has a cylindrical geometry, with the annular regions formed by inner and outer cylinders of much larger diameters than in traditional DMAs (TSI 3071). Because of the large average diameter of the classifier region, the Reynolds number in this region, for a selected flowrate, is low

The large radius of the HD-DMA permits its operation with a sheath flow ~ 7.26 times that of the long DMA for the same Reynolds number.

Also, for this large radius, the residence time of particles in the HD-DMA is decreased by 4.5 % in comparison to the long DMA, thus providing a higher resolution classification (1%-3%) in the voltage range of 10-100 V.

FIG1: The variation of the Reynolds number with the sheath flow, long DMA and HDDMA



- The first port covers a size range very similar to that of the Nano-DMA , while permitting a sheath flow and aerosol flow ~ 8 times that possible with the Nano-DMA for matched Reynolds number.
- The second port covers the same range as that of the long DMA with a flowrate 4 times greater than the long-DMA for the same Reynolds number.
- Simultaneously operating both the ports can cover a broader range of size distribution for a given range of voltage scan.

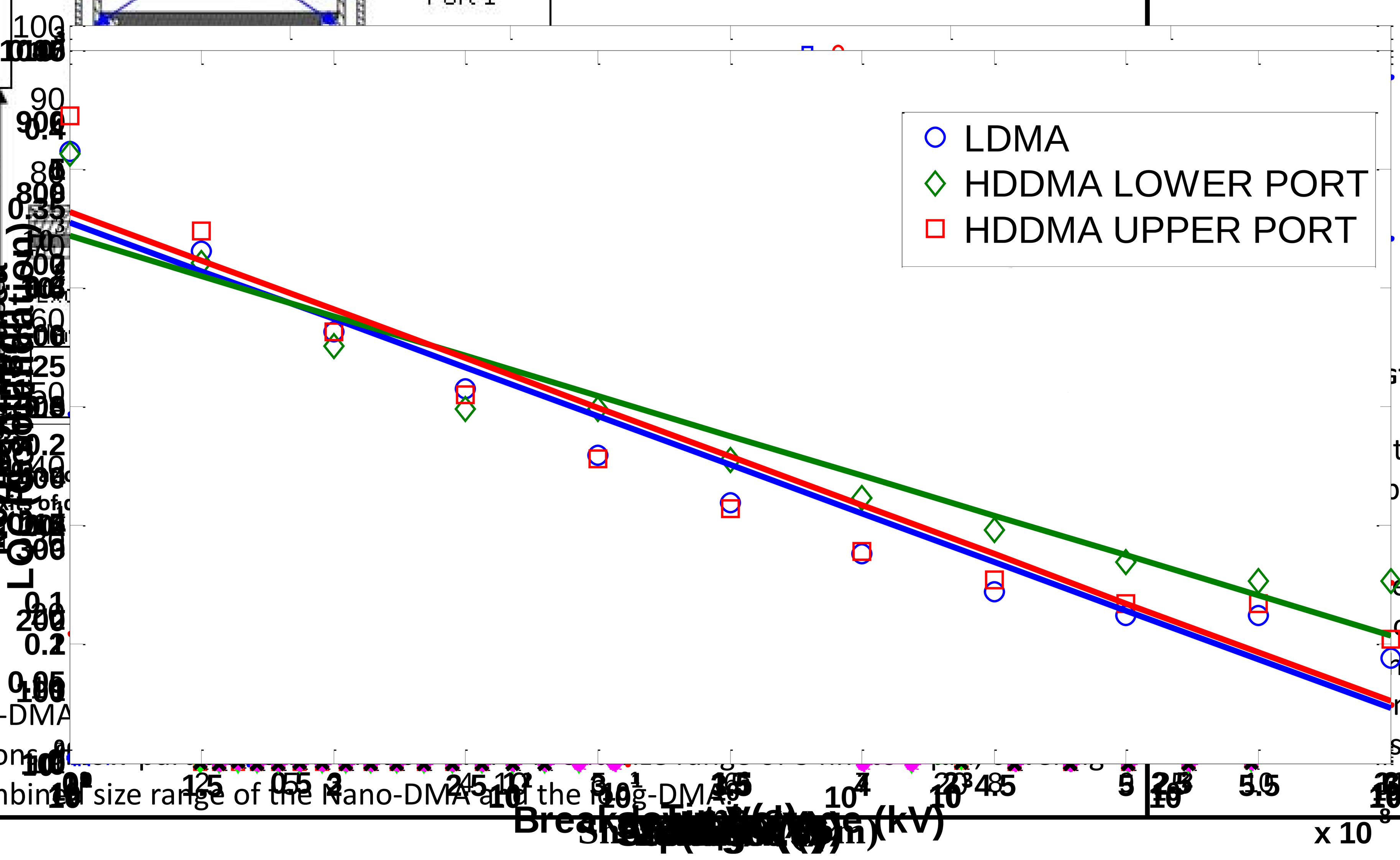


FIG2

The HD-DMA ...
conditions ...
the combin... size range of the Nano-DMA and the Long-DMA.

HDDMA Calibration

The characteristics of the HD-DMA were established with several TDMA experiments using a TSI long DMA column as one of the DMAs in the setup

Resolution

FIG4:Measured resolution of classified monodisperse particles for different ports and flow ratios (10:1 left; 5:1 Right)

Penetration Efficiency

FIG5:Area under measured monodisperse mobility normalized to upstream CPC total count. Results are shown for different voltage condition of operation and from both ports.

Transfer Function & Residence Time

FIG6:Variation in increased area under transfer function with ratio of residence time to scan rate.

The measured penetration efficiency was between 0.8 to 1 (Figure 5) representing acceptable transmission efficiency of particles. Also for a selected mobility and operating voltage, the residence time decreases with increasing classifier section radii; and thus, as the radii of the DMA is increased, the reduction in size range with scantime is minimized.

Scantime Operation

...7:Measured mobility distribution with different scantime operation of HDDMA

... that the particle size distribution obtained from fast scanning with the HD-DMA ...btained from slow scanning.

...ecrease the measurement time with a HD-DMA during each scanning ...ces the TDMA measurement time.

... sample flow that permits the sampling of monodisperse particles to more ...ment downstream of the HDDMA. Thus several properties of size classified ...simultaneously obtained.

Design Modification

The first version of the instrument had acceptable resolution characteristics (~ 75% of theoretical expectations), but its upper operating voltage limit was seen to be a ~ 13kV under dry air conditions, suggesting problems with surface non-uniformities. Using a higher precision-level of surface finish quality, the HD-DMA's voltage range is extended (to 16kV), and its measurement range is significantly improved. Changes to the downstream sample ports were made to improve response time.

FIG8: The comparison of the HDDMA voltage characteristics with TSI Long DMA with & without screen

FIG9: The comparison of the down stream smearing constant of the HDDMA and TSI- LDMA. Solid line shows the linear fitting .

In figure 8, theoretical curves were obtained according to the Pedersen's theory. Also figure 9 shows that the response time of the lower and upper port are 2.98 and 2.42 seconds respectively, which is closer to 2.45 seconds response time in LDMA.

HDDMA Application

One of the applications of the HDDMA is for aircraft-based measurements of atmospheric particle size distributions. The concentrations of atmospheric particles above the boundary layer is low, but sampled concentrations could change dynamically because of high aircraft speed. Thus, accurate characterization of these particles requires fast measurements. (HDDMA was successfully deployed during the recent ICE-T (2011) campaign)

FIG10: HDDMA located in 19 inch rack in C-130 aircraft to measure particle size distribution in upper atmosphere

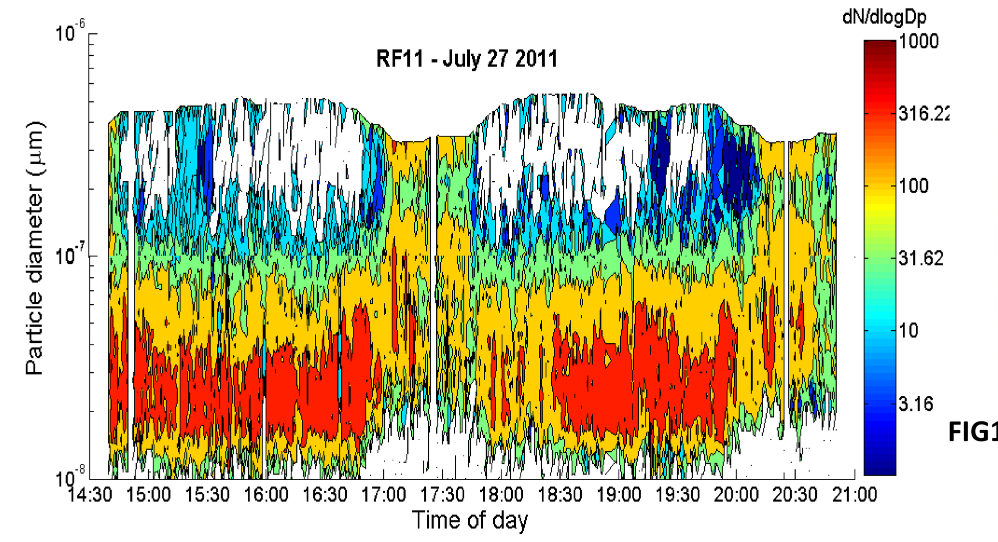


FIG11: Particle size distribution measured from HDDMA in ICE-T research flight. Scantime is 20 seconds.

Future Work

The HDDMA operated in a Tandem (TDMA) setup will be used to obtain the measurement of size-classified aerosol properties like hygroscopicity, volatility, etc.

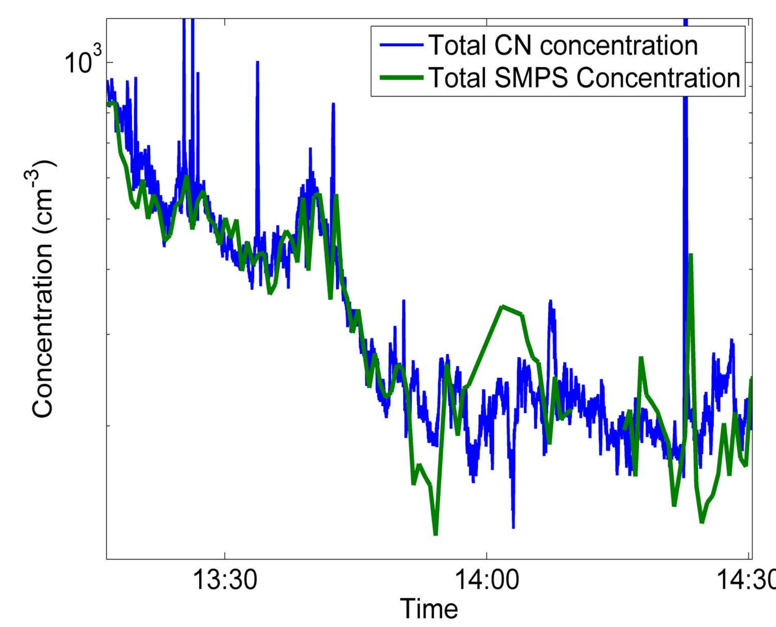


FIG12: The variation of the total CN & SMPS concentration during the measurement.

Acknowledgment

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