Cambustion Application Note DMS10

Urban ambient aerosol measurements with the DMS500

Introduction

Urban aerosols are of growing concern to the air quality management community and regulatory authorities because of their effect on health, global climate and urban visibility. Progress to characterise urban aerosols (including their size distribution) has been hampered by the lack of standard methods and instrumentation. The scientific community is looking for trustworthy and scientifically proven instruments which can measure aerosols (on a number basis) in the urban environment.

Instrumentation such as the Scanning Mobility Particle Sizer (SMPS) has been used for many years to study ambient particle size distributions. In an urban environment the time response (~1 minute) of this and similar techniques may represent a limitation. The existence of temporally and spatially localised sources of high concentrations of particles (e.g. motor vehicles, boilers and other fuel burning appliances) coupled with imperfect mixing may result in local concentrations that vary greatly over timescales of a few seconds. To accurately measure a varying concentration such as this an instrument with faster time response is required to avoid artefacts in the data.

The DMS500 [1–3] provides one option to measure particle number concentrations (PNCs) and distributions (PNDs) in the 5–1000 and 5–2500 nm size ranges with a sampling frequency of up to 10 Hz and a fast fluidic time response.

This application note describes the use of the DMS500 for measuring PNDs and PNCs in controlled (i.e. laboratory) and in operational (at various heights and above rooftop measurements in urban street canyons) conditions. It also points out how the fast response nature of this instrument helps to address the particle *number* related major regulatory concerns in urban areas. The author has successfully deployed the DMS500 in his recent studies [4–10] where several issues related to ambient measurements and modelling of urban nanoparticles were addressed.

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The DMS500 was deployed for measurements in controlled and operational conditions during recent studies. Controlled conditions included the measurements of aerosols in the laboratory (i.e. emissions from a candle and salt nebuliser [7]). The operational conditions include measurements in vehicle wakes [10], fixed height [6,9] and pseudo-simultaneous measurements at various heights [4,5] within street canyons and at roof–top level [8]. Some of the results from these studies are presented in this section.

Although in ambient studies it is common to analyse data on an hourly or a half–hourly basis, in this study it was found crucial to make measurements at a relatively fast sampling rate (~ 1 Hz) such that the collected data accurately represents the real–time emissions of each moving vehicle going past the sampling location.

When using the DMS500 for ambient measurements, two points must be considered. Data must be validated by relating it to the noise base of the instrument (The noise base is automatically displayed on the interface after zeroing for convenience). Selection of an appropriate sampling frequency for measurements is also important. Measurements made with a varying sampling rate (between 1 and 10 Hz) at the roadside in a Cambridge (UK) street canyon showed that both the roadside and the site background PNDs (respectively representing both the largest and the smallest concentrations in typical urban street canyons) were well above the noise level of the DMS500 [10]. However, it is suggested that a sampling frequency of 1 Hz or lower (below the maximum 10 Hz) would be appropriate if experiments does not critically rely upon fast response data. This will increase the sensitivity and reduce the size of data files [10].

The following fast response measurements (10 Hz) in the wake of moving vehicles investigated the competing influences of particle transformation processes (coagulation, deposition, nucleation and condensation) in the near and the far wake regions [10]. The results showed that these processes were generally complete within ~ 1s after emission, as seen in Figure 1 for both particle number and mass concentrations; this is not possible to investigate with a slower response instrument.

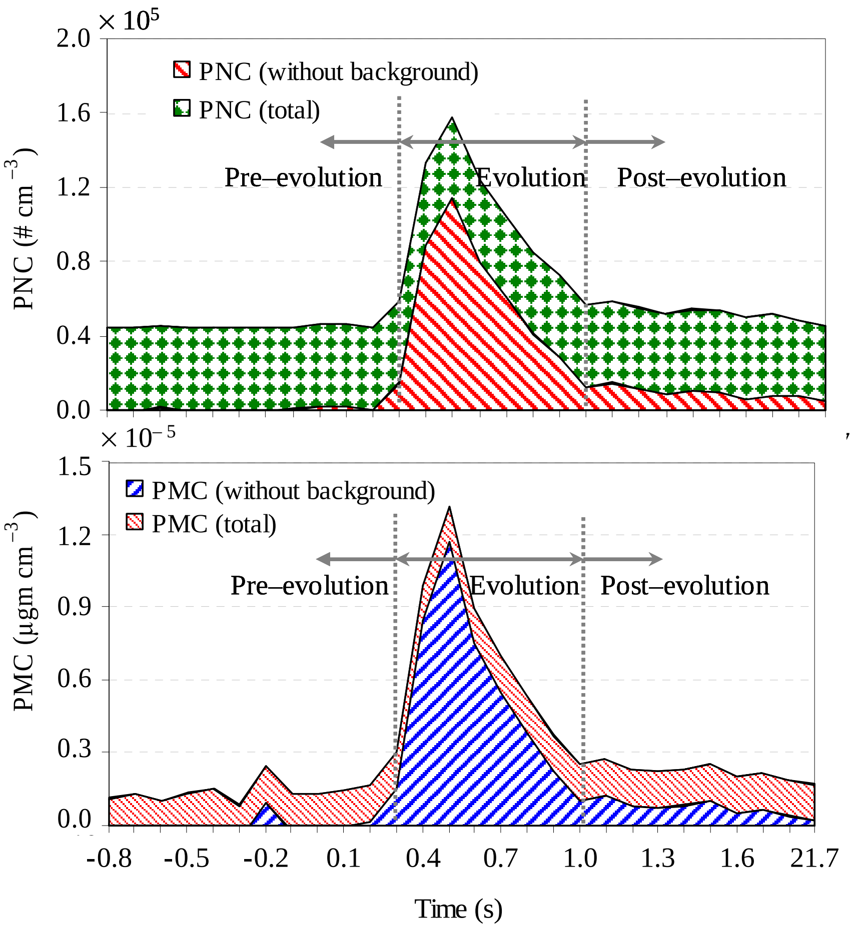

Figure 1: Temporal changes in particle number and mass concentrations (total and without site–background) at a fixed point the wake of a moving diesel car. Figure is taken from Kumar *et al.* [10].

To satisfy various objectives, measurements were made in operational conditions at several locations (various fixed heights and at roof–top level in street canyons); some examples of these measurements are described below. Pseudo–simultaneous measurements were made in a Cambridge street canyon by using a DMS500 with a 4–way solenoid switching system. The sampling frequency was 1 Hz. This study revealed the vertical variation of PNCs and PMCs close to road level [4] and in the entire street canyon [5], as seen in Figure 2 and Figure 3, respectively. These figures show hourly averaged particle number and mass distributions at 1, 2.25, 4.62 and 7.37 m heights of an 11.6 m deep street canyon.

In another study, the effect of mixing, physical and chemical conversion processes, and the competing influences of traffic volume and rooftop wind speed on the PNDs and PNCs over various size ranges at both street (~1.5 m) and roof top levels (~15 m) were investigated [8]. These measurements were also made pseudo-simultaneously at a sampling rate of 10 Hz, as seen in Figure 4.

The effect of wind speed and direction on the dispersion of nucleation (those below 30 nm) and accumulation particles (between 30 and 300 nm) modes was investigated [6]. As shown in Figure 5, the distributions of PNDs are plotted against D_p for different meteorological conditions in a Cambridge street canyon having an aspect ratio (height to width) of about unity.

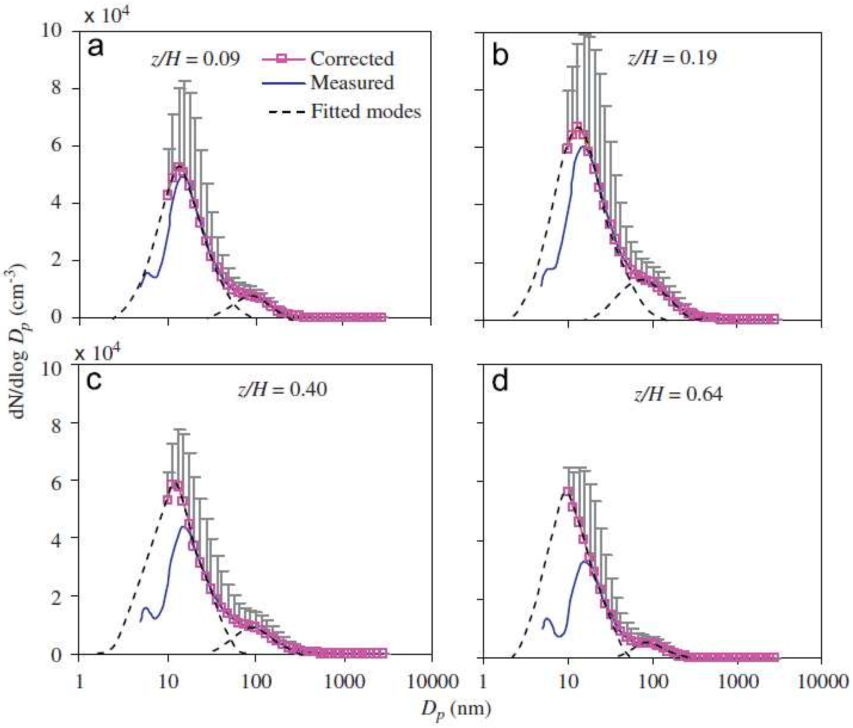

Figure 2: Hourly averaged corrected and measured particle number distributions at (a) 1 m, (b) 2.25 m, (c) 4.62 m and (d) 7.37 m. Dotted lines represent mode fitting curves to the corrected PNDs. Bars show the standard deviation of the hourly averaged PNDs at each height; only positive standard deviation values are plotted for the clarity. These figures are taken from Kumar *et al*. [5].

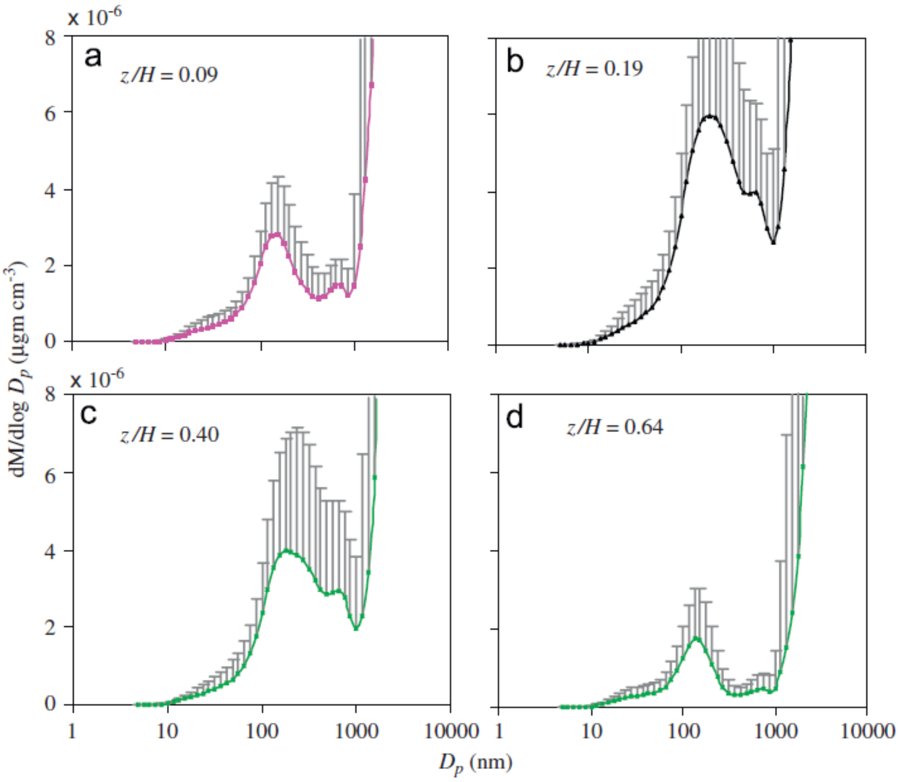

Figure 3: Hourly averaged particle mass distributions at (a) 1 m, (b) 2.25 m, (c) 4.62 m and (d) 7.37 m. Bars show the standard deviation of the hourly averaged PMDs at each height; only positive standard deviation values are plotted for clarity. These figures are taken from Kumar et al. [5]

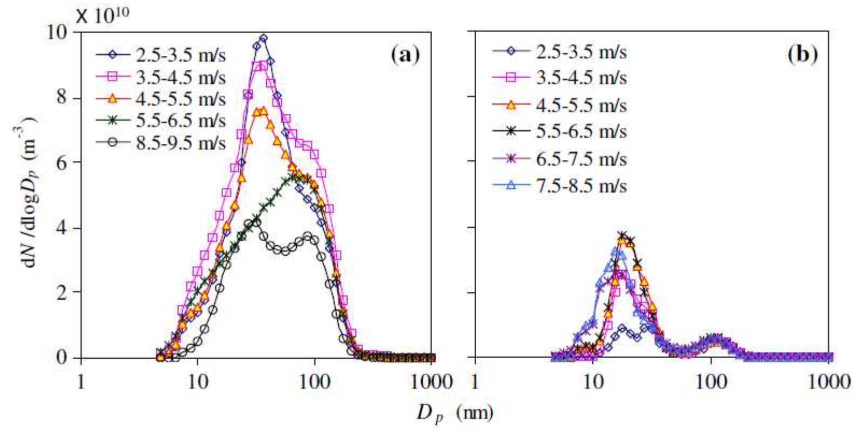

Figure 4: Effect of wind speed on particle number distributions at (a) street level (averaged over locations at 0.20, 1.00 and 2.60 m), and (b) rooftop level (20 m). Both figures show averages of half-hourly wind speeds and PND data for various ranges of wind speed. This figure is adopted from Kumar *et al.* [8].

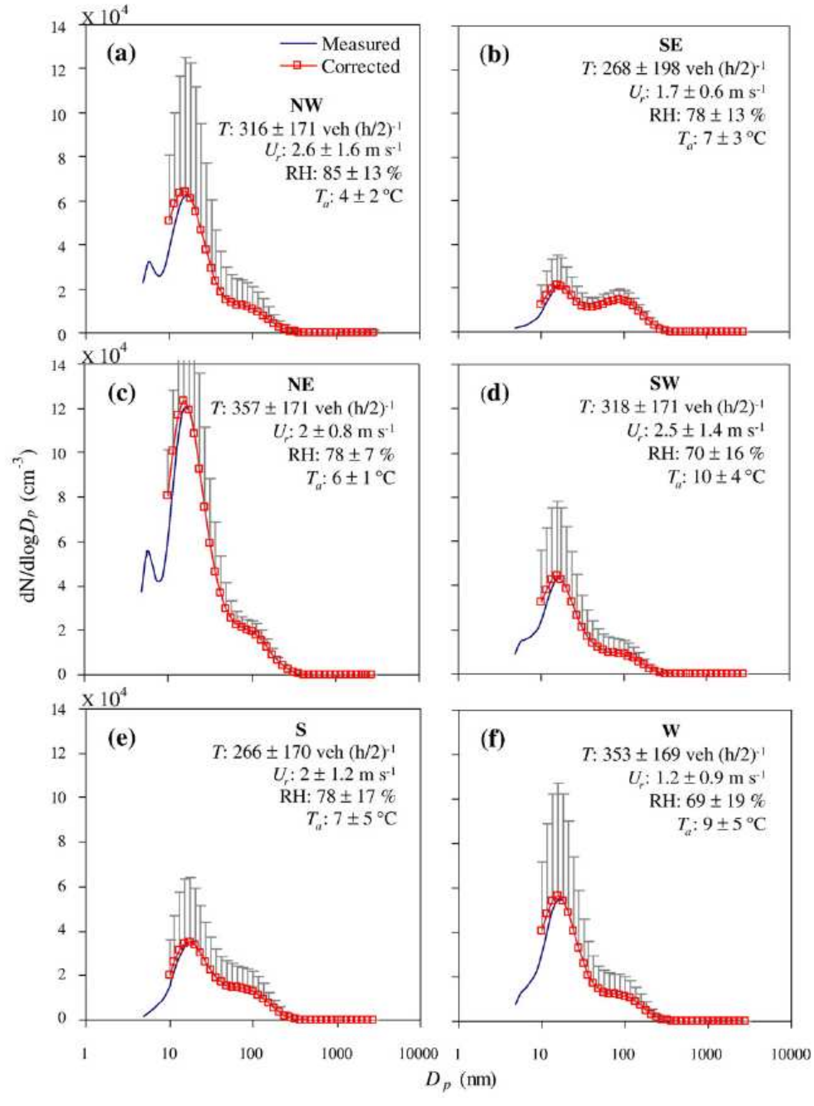

Figure 5: Half-hourly averaged measured and corrected particle number distributions during winds from the (a) NW, (b) SE, (c) NE, (d) SW, (e) S and (f) W. Symbols D_p, T, U_r, RH and T_a represent particle diameter, traffic volume, above-roof wind speed, relative humidity and ambient temperature respectively, and quantities are half-hourly averaged values together with their standard deviations over the entire

sampling duration. Bars show the standard deviation of the half-hourly averaged PNDs. This figure is taken from Kumar *et al.* [6].

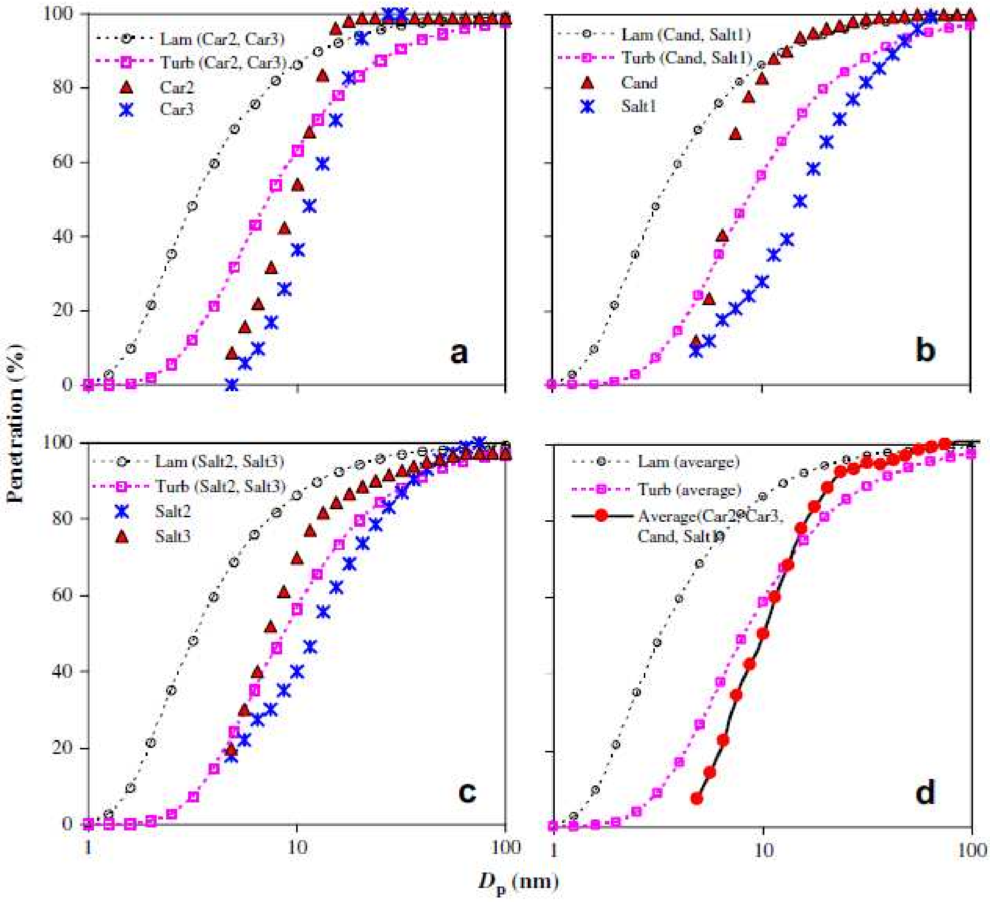

Figure 6: Size dependent measured and modelled penetration in 5.55 m long sampling tube for (a) Car$_2$ and Car$_3$ (P = 160 mb, Ta = 8.2 °C, Q = 2.5 slpm, Re = 461), (b) Cand and Salt$_1$ (P = 160 mb, T_a = 26 °C, Q = 2.5 slpm, Re = 461), (c) Salt$_2$ and Salt$_3$ (P = 250 mb, T_a = 26 °C, Q = 8 slpm, Re = 1409), and (d) average of (a) and (b). Acronyms P, T_a, Q and Re represent the sample line pressure, ambient temperature, sample flow rate and Reynolds number, respectively. Figure is taken from Kumar *et al.* [7].

During any aerosol measurement consideration of sample line losses is important. Particle measurements in street canyons often require long sampling tubes. Failure to appropriately correct for these losses may significantly change the measured PNDs, since losses are greatest in the ultrafine range (<100nm) where most ambient particles exist in number weighted spectrum. This study provided an opportunity to measure various types of aerosols (i.e. from a burning candle, salt aerosols generated by a nebuliser and emissions from an idling car) under different operating conditions of the DMS500 (see caption of Figure 6 for details). These experiments [7] suggested that even when the Reynolds number indicated that the flow was laminar in sampling tubes of different lengths, the turbulent penetration model of Wells & Chamberlain [11], and Lee & Gieseke [12] best described particle losses, as illustrated in Figure 6. This agrees with an independent study by Symonds *et. al* [13]. Correction for particle losses in sampling tubes were made in these studies (see corrected PNDs in Figure 2 and Figure 5) as presented in Figure 6.

Summary

There are no standard guidelines for instruments to measure particle number distributions and concentrations in the ambient urban environment. The DMS500 represents a useful option for making fast response particle size, number and mass measurements at a sampling frequency up to 10 Hz in the ambient urban environment. An additional advantage for ambient particle measurement is the wide size range of particles detected (5–1000 or 5–2500 nm).

The automatic data handling and Microsoft Excel based data presentation macros supplied with the instrument speed and simplify the analysis of the large amount of data available.

For 2009, the sensitivity of the DMS series of instruments has been significantly improved, thus making them even more suitable for ambient measurement (Figure 7).

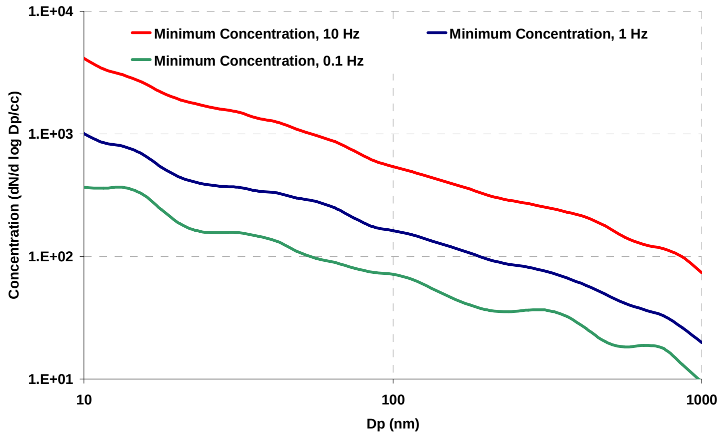

Figure 7: DMS500 *Mk II* Sensitivity Limits, 1 µm size range, 2009

Acknowledgements

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