# Gasoline Direct Injection Particulate Measurement with the DMS Series

## Introduction

This application note describes two studies with Gasoline Direct Injection (GDi) engine vehicles, measuring particulate emission with a Cambustion DMS500 Fast Particulate Spectrometer. It then goes on to give advice on measurement, including sampling directly from such vehicles without the use of a CVS diluter.

## Study A: Effect of ECU strategy; stratified / homogenous operation, $NO_x$ trap purging

Two engines were used in this study. The first was on a dynamic engine dynamometer, with a DMS500 sampling from the CVS dilution tunnel. Figure 1 shows data from the first 200 seconds of a New European Drive Cycle (NEDC) compared with the second 200 s. In the first phase, combustion is predominately homogenous (stoichiometric) as the engine warms up. The second phase has the same road loads, but the strategy demands stratified (lean) combustion for the majority of the period. It is clear that stratified operation causes a significant increase in accumulation mode particulate.

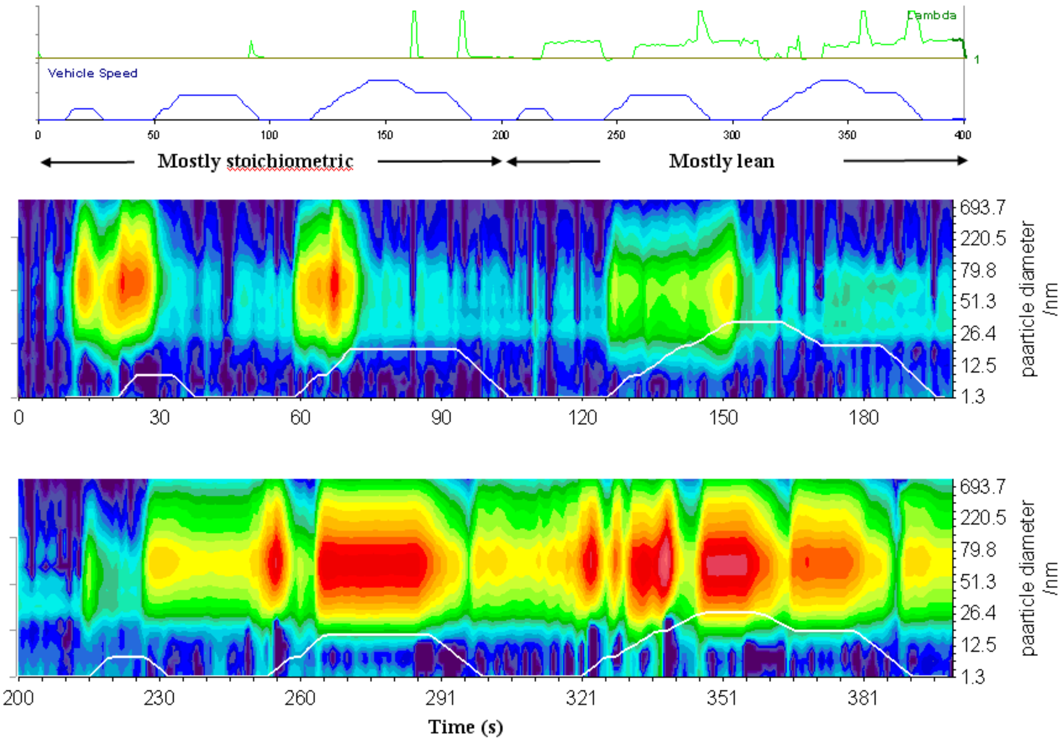



Figure 1: Homogenous vs stratified: effect upon particulates

Figure 2 shows data taken before the third set of cruises. Before 400s, the engine is idling in stratified mode with rather low particle emissions due to low engine load. During the acceleration from 402 until 406s the engine switches to homogenous combustion (as seen by the lambda trace). The mode switch causes a transient peak in particulate emissions settling briefly to a lower level. At the end of the acceleration the strategy switches back to stratified mode and there is a second, somewhat lower transient particulate event.

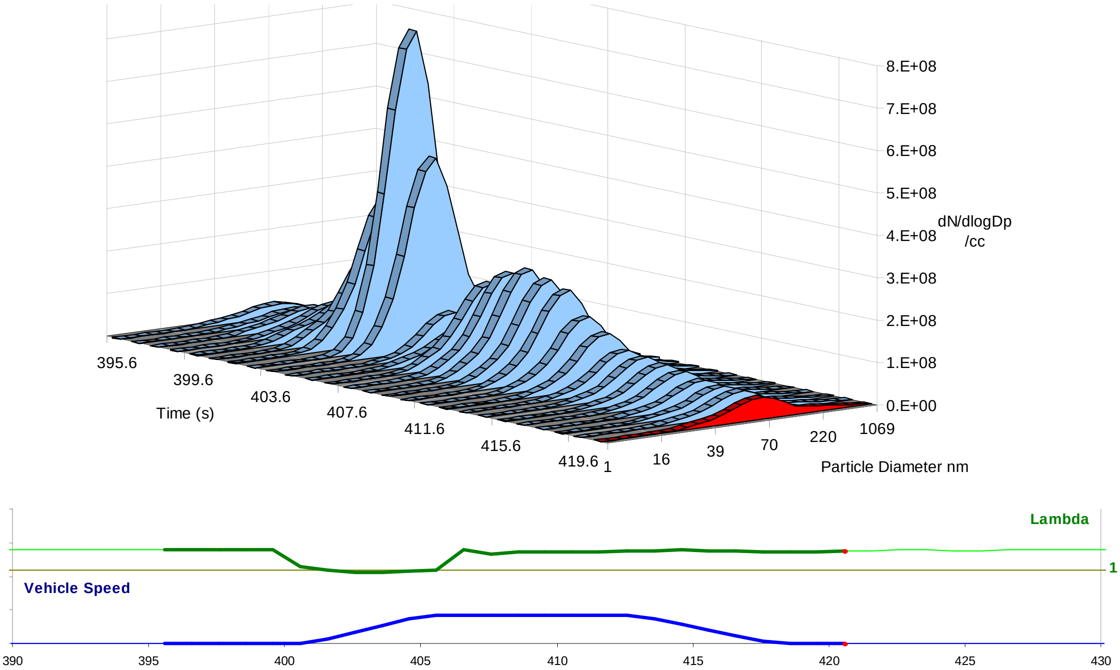



Figure 2: Transient effect of mode switches

The second engine was on an Audi FSI 2.0l vehicle on a chassis dynamometer, running a warm start NEDC. Figure 3 shows the lowest speed urban cruises occurring at 400 and 600 s. On this engine, generally, stratified combustion is used on these cruises. However, the large burst of particulate associated with the 600 s cruise is due to running rich during a partial regeneration of the $NO_x$ trap.

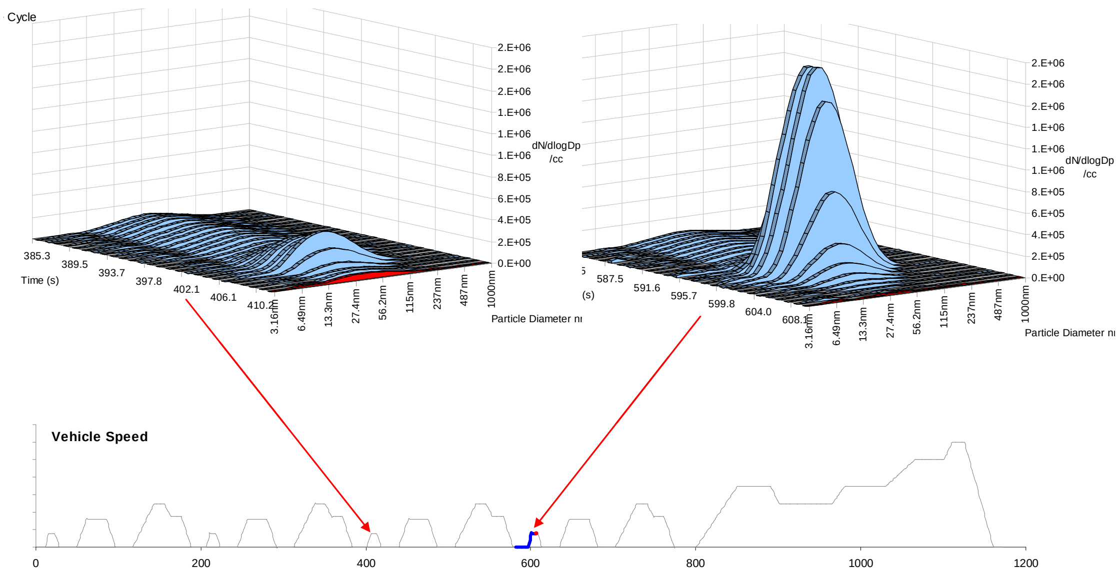



Figure 3: $NO_x$ trap regeneration

Finally, Figure 4 shows the second 200 s of the cycle. Most of this period is spent in stratified mode with occasional switches to homogenous during accelerations. There is significant variation in the accumulation mode size.

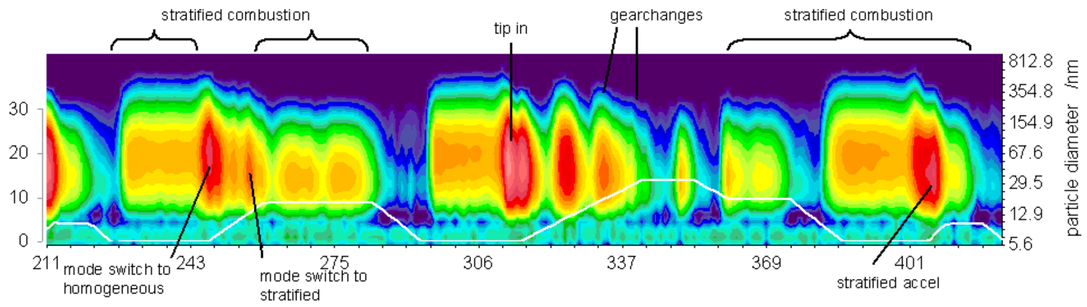



Figure 4: Size spectrum variation as a function of load

## Study B: Comparison with PMP type system

In the following study, a GDi equipped passenger vehicle on a chassis dynamometer was instrumented with a DMS500 and a PMP-type solid particle number counting system, both sampling via the CVS tunnel (Figure 5). The engine of this vehicle uses only stoichiometric operation. The schematic for the PMP system is shown in the appendix. The volatile particle remover is only present pre-CPC, the DMS removes the nucleation mode in software as described in application note DMS06. The PMP diluter was set with $PND_1$ dilution factor = 100, $PND_2$ DF = 10, and the DMS's secondary dilution factor set to 20.

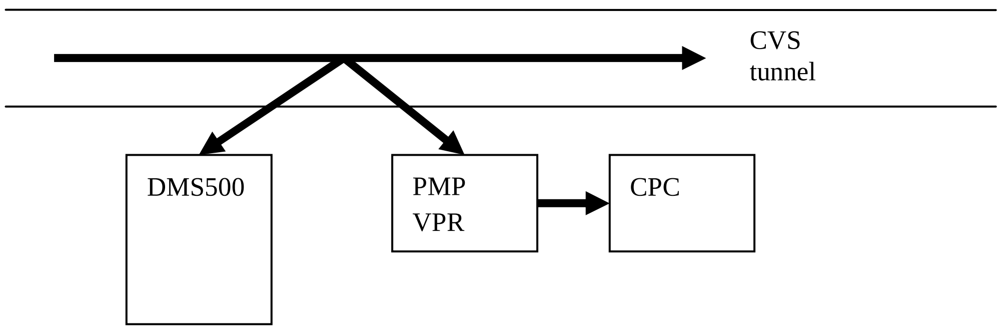



Figure 5: Sampling arrangement of DMS and PMP system

The DMS series is available with a special calibration for Diesel engines which takes into account the difference in particle charging between agglomerates and spheres in instruments with a corona charger giving more accurate absolute number measurements[1]. However, particles from GDi engines are thought to be more "sphere-like" than Diesel engine particles[2]. Hence the standard calibration, based upon NIST traceable PSL spheres, DMA cut aerosol and a standard electrometer was used in this study.

Figure 6 shows solid particle emissions from three cold start NEDCs, whilst Figure 7 shows the specific emissions. The data have not been scaled in any way, except to correct for diluter losses, and shows the DMS under the standard calibration to be within 9–12% of the PMP system in terms of total solid particle number.

[1] *Calibration of a Differential Mobility Spectrometer*, J.P.R. Symonds & K.St.J. Reavell, *European Aerosol Conference 2007* **T02A034**, Salzburg.

[2] *Density of particles emitted from a gasoline direct injection engine*. J. Symonds, P. Price, P. Williams, R Stone. *12$^{th}$ ETH Conference on Nanoparticles*, 2008

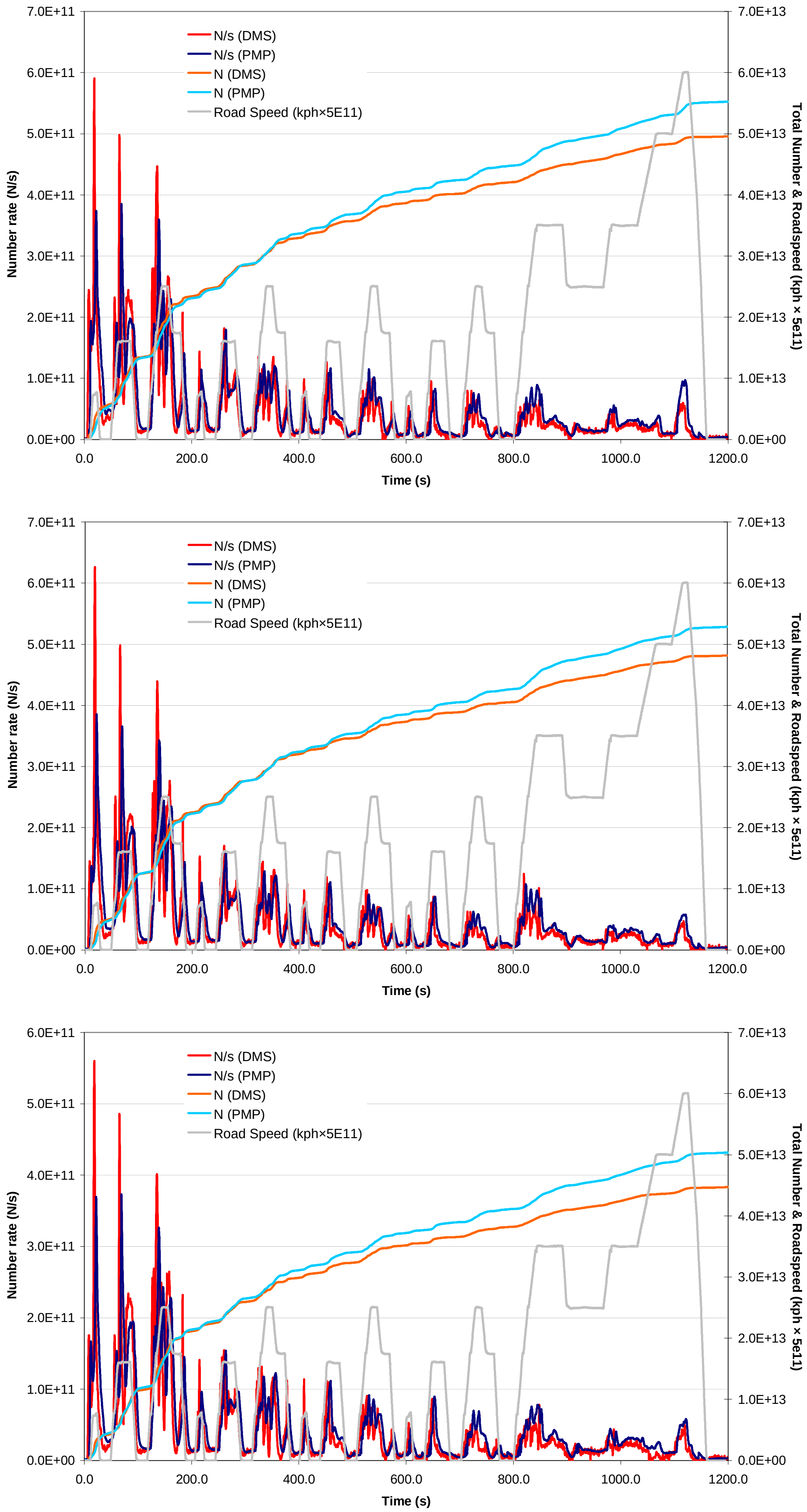



Figure 6: Comparison of DMS500 and PMP type system on GDi exhaust: 3 × cold start NEDCs

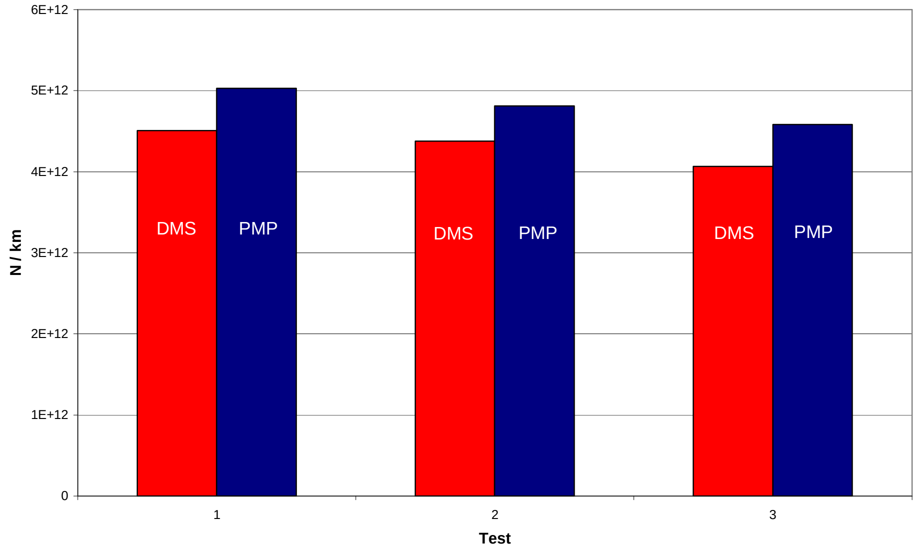



Figure 7: Specific emissions for the 3 tests

## Sampling and measurement advice for GDi engines

### Direct Sampling

Sampling from a CVS tunnel is straightforward, as shown in the examples above. For direct sampling from the exhaust, we recommend running the heated line at 150 °C to prevent condensation artefacts in the spectrum caused by hydrocarbons[3] (Figure 8).

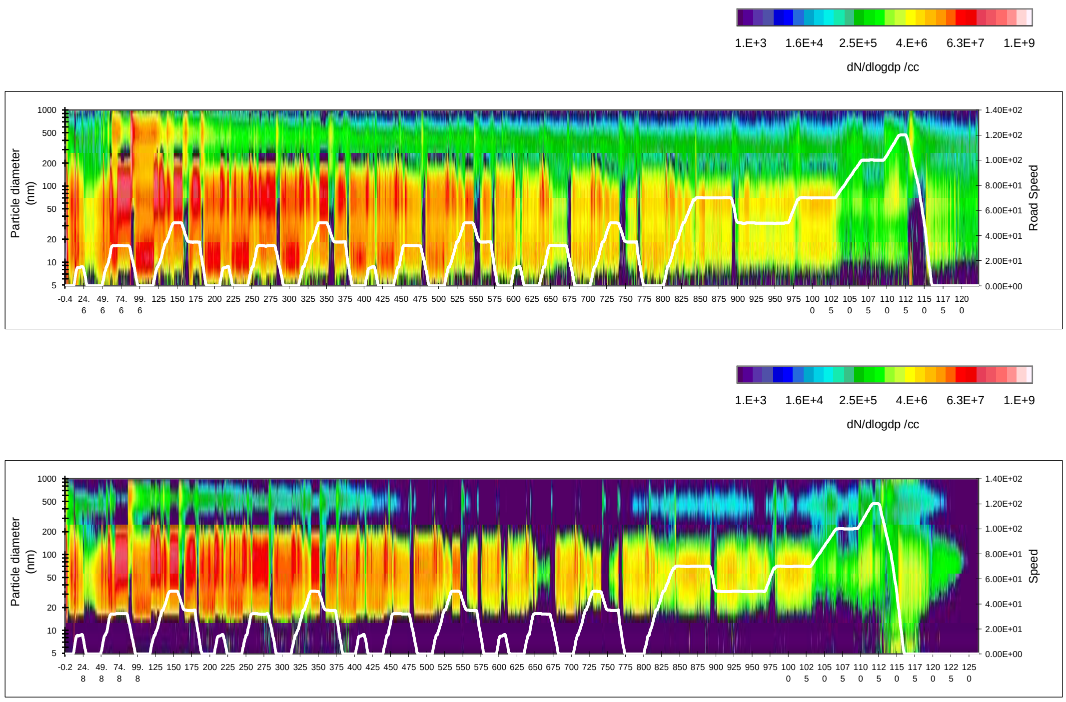



Figure 8: Direct sampling with a heated line: Upper, line at 55℃, lower, line at 150℃

[3] Current specification DMSs are supplied with a PTFE sample line inner tube, and can be safely run at this temperature. Older units were supplied with a silicone rubber inner and should not be run hotter than 100 °C. For clarification, or to request an upgrade, please email cambustion@cambustion.com.

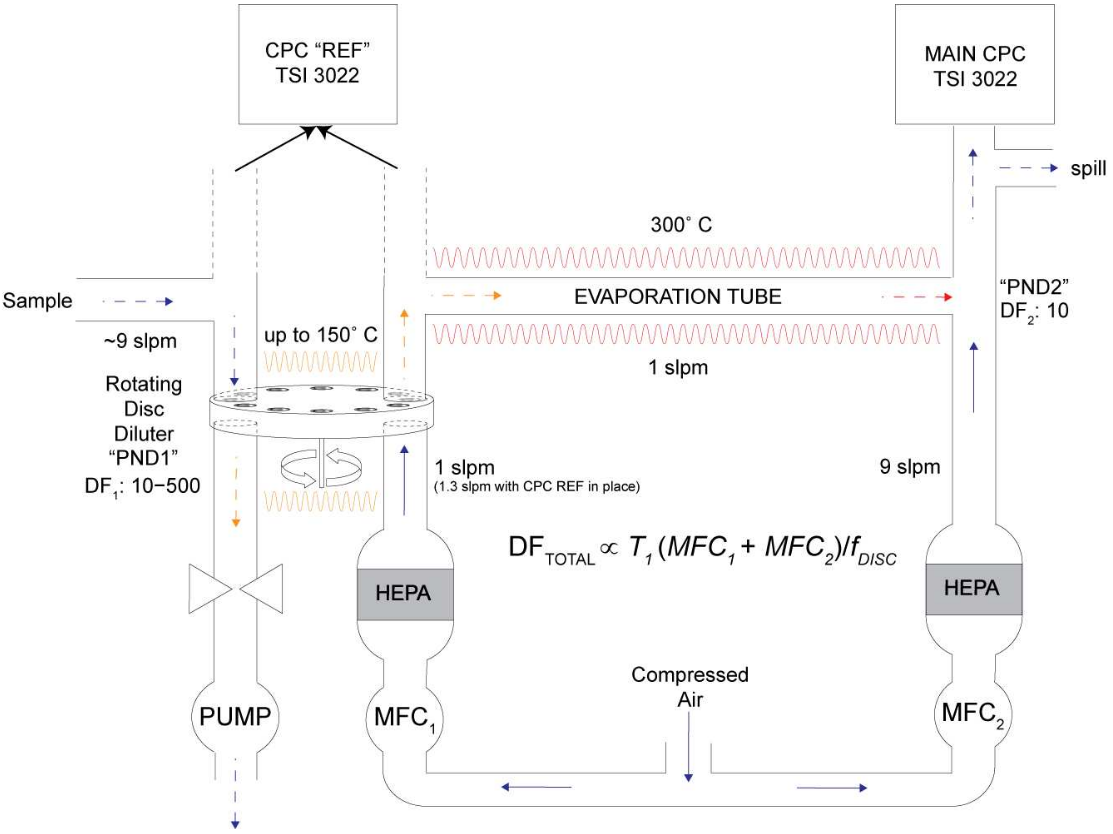
If hydrocarbon condensation artefacts are still seen, an activated charcoal HEPA filter is available to replace the standard HEPA filter in the DMS500 rotating disc diluter path. This step is not necessary for the DMS50 as the dilution air is atmospheric.

As with Diesel direct sampling, run the primary diluter to at least a factor of 4.

### Lognormal fit and mass calculation

In most cases we find that the “Diesel…..dmd” aerosol description file still gives good discrimination between the nucleation and accumulation modes for the lognormal fit. As GDi accumulation mode particulate is thought to be less “fractal like” and more “sphere like” than Diesel[2], we advise using a density closer to that for water, i.e. Mass ≈ $5.20\times10^{-16} \times D_p^3$, for size expressed in nm and mass in µg. This can be entered manually in the analogue output setup window.

## Appendix: PMP type system used




CPC “REF” was not connected in this study.