ON ROAD PARTICULATE EMISSIONS FROM A DIESEL PASSENGER CAR AROUND CAMBRIDGE

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Introduction

A Peugeot 406 2.2l HDi passenger car was driven around Cambridge and its environs whist monitoring the particulate size spectrum in real-time using a Cambustion DMS50 mobile fast particulate spectrometer. As well as the full spectrum, nucleation and accumulation mode number, CMD and GSD and accumulation mode mass were calculated. Using the logged road speed, the tests were then repeated on a more traditional chassis dynamometer (“rolling road”) facility to compare real world emissions with those in a laboratory environment.

Instrumentation and Experimental Details

The DMS50 is a new differential mobility analyser which classifies aerosol particles from 5 nm to 560 nm from their electrical mobility, producing both a size spectrum and multi-lognormal fits to instrument response in real time, with a time response of around 500 ms and data rate of up to 10 Hz. Particles are charged with a unipolar diffusion charger and pass into a classification column, where a radial electric field diverts them from a sheath air flow until they land on any of 22 detection rings, each connected to an electrometer circuit (Fig.1). The instrument transfer function is used generate a 34 channel size spectrum from the 22 electrometer signals, assuming a smooth continuous spectrum.

A Bayesian statistical algorithm fits up to two lognormal functions, chosen to maximise a posterior probability given by the product of the likelihood of currents synthesised from these functions matching the measured currents and an assumed prior probability based upon the CMD and GSD of the particles [1]. By tuning the map of prior probabilities, the algorithm can distinguish between the nucleation (volatile) mode (~<30nm, narrow GSD) from the accumulation (soot) mode (~>30nm, wider GSD) in diesel combustion aerosols. Only statistically significant modes are returned, based upon the noise base of the instrument.

The use of lognormal functions helps to suppress noise in the spectrum, which when present in the large end tail of a size distribution can lead to large errors in volume or mass weighted spectra. Accumulation mode particulate mass is calculated directly from the lognormal parameters by application of the Hatch-Choate equations, using a fractal dimension of 3.19 for Diesel agglomerates. This value was arrived at by considering existent literature data on DMA...
and Aerosol Particle Mass analyser (APM) which gives a fractal dimension of 2.34 [2], and adjusting this for differences in sizing of agglomerates between bipolar charging (e.g. DMA) and unipolar diffusion charging (e.g. DMS) instruments in the > 100 nm region [1].

The DMS50 samples directly from the exhaust of the vehicle, post Diesel Oxidation Catalyst (DOC) (except for drive “E”). The Diesel Particulate Filter (DPF) was removed for these tests. A DLC50 dilution controller provides 4:1 heated primary dilution at the point of sampling to reduce condensation. The aerosol passes through heated conductive silicone tube to the DMS50 in the vehicle. The instrument contains an integrated rotating disc diluter, for these tests set to give 100:1, giving a total dilution factor of 400:1 (corrected by feedback).

Road speed, engine normalised air:fuel ratio (Lambda) and engine intake air flow signal were logged to the spectrometer’s analogue input. It uses the air flow signal to convert its volumetric mass output to a mass rate, which it then integrates over time to give total mass. A GPS system was present to log the route, and provide calibration for the road speed. Gear changes were announced by the driver and recorded with a video camera.

The logged road speed was presented on screen to a driver in the chassis dynamometer facility, so the cycles could be repeated as closely as possible. An on road “coast down” test was performed to establish the speed-load relationship for the dynamometer. For these tests, as well as the in-car DMS50, a DMS500 (non-mobile, 200 ms, 5 nm – 1 μm antecedent of DMS50 [3]) sampled from the constant volume sampler (CVS) of the dynamometer facility.

**Results and Discussion**

Each of the two main road tests (“B” and “D”) were preceded by a short warm-up drive. An alternative route (“E”), sampling pre-DOC was also undertaken (with no chassis dynamometer repeat). Fig. 2 shows a map of route B, route D being essentially the same but slightly different at the start. Speed repeatability on the dynamometer was excellent, though slight differences in fuelling were observed.

![Figure 2: Route "B"](image)

Considering drive “D” first, the cumulative soot mass trace shows some difference between the real-world drive and the dynamometer repeat (Fig 3.). Comparison of accumulation mode number and size shows that whilst the concentration is very similar, the on-road particles tend to be slightly smaller (concentration weighted mean CMD of 61.8 nm) than those on the dynamometer (65.2 nm). Accelerating down the slip road onto the A14 generates around 10% of the total particulate mass emission of the 26 minute drive.

As an example, Fig. 4 shows the nucleation and accumulation mode concentrations in the final section of the drive. Whilst accumulation mode concentrations are very similar in all three examples, more nucleation material is generated in the direct sampling system than in the CVS system.
Nucleation mode bursts seem in general to be correlated with high engine load (fuelling), even more so than for soot bursts. Where there is a lack of correlation between particulate emissions and fuelling it is probably due to the indeterminate effect of Exhaust Gas Recirculation which whilst reducing NOx can promote P.M. formation.

Drive “B” shows much better repeatability between the on-road and dynamometer tests (Fig. 5.) A repeat of the dynamometer test for this drive was attempted, however during the extra-urban section the engine management system tried to regenerate the (not fitted) DPF, by instigating post-injection fuelling designed to raise the temperature of the DPF and oxidise the soot. This caused a large amount of nucleation material to be formed (especially in the CVS tunnel), with
size of up to 50 nm (Fig. 6). A previous study on this vehicle with the DPF fitted [4] also saw such an effect, which could have been due to thermal desorption of volatiles from the DPF. In this case with no DPF fitted, the nucleation material could be due to desorption from the DOC (known to absorb sulphate) or possibly from un-burnt post-injected fuel. Chemical analysis performed in [4] would tend to support the former.

![Figure 6: Nucleation events during regeneration attempt](image)

Drive “E”, on a different route but similar traffic conditions, sampling pre-DOC shows much higher average levels of nucleation material than the post-DOC tests (Fig. 7). This contrast is probably due to the effect of the oxidation catalyst removing un-burnt hydrocarbons from the exhaust which would otherwise condense and nucleate.

![Figure 7: Nucleation mode, drive "E"](image)

Conclusions

These experiments show rapid acceleration and deceleration to be the biggest cause of urban transient P.M. emission, whilst high speed cruises generally produce more soot mass than low speed cruises. The use of an oxidation catalyst reduces nucleation matter. DPF regeneration events can cause large amounts of nucleation material. It is remarkable how closely it is possible to reproduce on-road tests in a laboratory environment. This is probably especially true in Cambridge due to the lack of gradients on the roads. The vehicle easily complies with Euro Stage III particulate emissions (~0.03 g/km cf. 0.05 g/km), even when not driven on a legislated drive cycle.

References