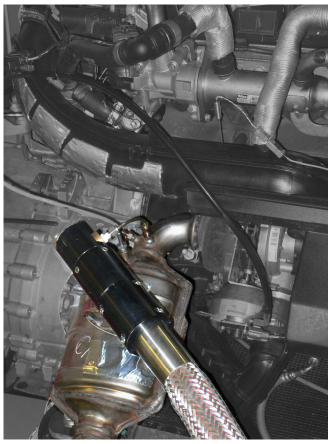
Cambustion Application Note DMS03

Sampling Engine Exhaust with the DMS500

Introduction



When comparing instruments for measuring particulate from engines the consideration given to sampling and dilution is of the utmost importance. The issues include:

- Necessity of dilution
- Pressure fluctuation tolerance
- Condensation of water vapour
- Agglomeration of particles
- Loss of particles due to electrophoresis, thermophoresis, diffusion and impaction
- Particle creation

The Cambustion DMS500 offers a complete “turn-key” engine particulate measurement solution for research and development. The DMS500 can be connected directly to an engine exhaust, even upstream of a Diesel Particulate Filter (DPF), with no requirement for further third-party sampling accessories or expensive Constant Volume Sampling (CVS) infrastructure. The DMS500 is designed and calibrated[1] to give good agreement with CPCs[2] and PMP type solid particle number systems[3,4], particulate mass measurement techniques[5,6], and size standards such as DMAs[2], on Diesel, gasoline and gas turbine engines; all from one instrument.

The remainder of this application note is structured as follows:

A. Sampling Issues with Solutions offered by the DMS500

1. Necessity of dilution

Many issues in engine aerosol measurement require dilution of the sample[7,8]. Some of these are discussed in more detail below in items 3 & 4. In addition to these, most instruments simply cannot tolerate the high concentrations of aerosol present upstream of a DPF without any dilution. A CVS dilution tunnel is not usually enough to reduce the particle concentration sufficiently for most aerosol instruments. Usually this necessitates the purchase and use of an additional dilution system.

Vehicle emissions from tailpipes are immediately diluted by the surrounding air; therefore for R&D studies requiring aerosols representative of the real-world, dilution is an advantage.

Solution: The DMS500 offers fully integrated two-stage dilution. The dilution factors in the user interface are set, and the data is automatically corrected for the applied dilution. A dynamic range indicator provides a guide to the user on how much dilution to use. Dilution can be set either from the user interface, or remotely via an analogue signal. Continuous feedback from the dilution system means that changes in sample pressure which may affect sample flow and hence the dilution ratios are automatically compensated for. Diligent use of dilution significantly reduces the cleaning interval.

Where a CVS tunnel is available, the secondary diluter alone can provide sufficient extra dilution. We supply unheated conductive silicon tubing for sampling from a CVS dilution tunnel.

2. Pressure fluctuation tolerance: Sampling pre-DPF

Transient pressure fluctuations can cause problems for many aerosol instruments and sampling systems. Removal of the DPF to either reduce the back pressure for direct measurement or allow the use of a CVS tunnel affects the engine's performance. Thus online optimisation of engine-out emissions of a DPF equipped vehicle is difficult or impossible with most aerosol instrumentation.

Solution: The DMS charger and classifier run at a fixed pressure, with the sample passing through a critical orifice. Therefore it is not necessary to correct for the effect of pressure fluctuations upon charging and classification, which would be difficult to achieve with highly transient fluctuations. Any changes in sample flow caused by pressure fluctuations are measured and dynamically compensated for both in terms of the operation of the diluters, and the operation of the classification system. The direct sampling system means that the benefits of a CVS are available, without losing the effect on the engine of back pressure. This powerful combination makes the DMS500 the first choice for pre-DPF particulate evaluation and optimisation.

3. Condensation of water vapour in a sensitive instrument.

Many instruments are sensitive to water ingress; in particular this affects the performance of mass flow meters and electrometer based detectors. Gasoline engine exhaust (at stoichiometric operation) has a dew point of 55 °C.

Solution: The DMS500 applies compressed air dilution at the point of sampling to reduce the partial pressure of water. This is further assisted by the sampling head and line operating at 250 mb abs. pressure. In addition, the sample line can be heated to up to 150 °C so that the sample remains above its dew point.

4. Agglomeration (coagulation) of particles.

Highly concentrated aerosol streams can promote agglomeration of soot particles, thus changing their size and number concentration[9].

Solution: Dilution (factor of 5) at the point of sampling reduces the concentration, and hence reduces then likelihood of agglomeration. Low pressure operation of the sample line further reduces this likelihood, as the mean free path between particles is reduced, and because the transit time in the 5 m sample line at this pressure is < 100 ms less time is available for coagulation to occur. Once the sample reaches the main body of the instrument, a further dilution factor of up to 500 can be applied. The total particle transit time from sample point to measurement electrometer is < 2 s.

5. Loss of particles due to electrophoresis, thermophoresis, diffusion and impaction.

Nanoparticles can suffer comparatively large losses to the walls of sampling systems due to the above effects[10]. The build up of static electricity can precipitate particles from a stream. Thermophoretic force can also cause losses, especially if a hot aerosol stream is allowed to cool slowly. Diffusion losses become important for the smallest particles. Particle impaction affects larger particles travelling at high velocities undergoing abrupt changes in direction, and is a consideration for sampling system design.

Solution: Firstly, the rapid transit time in the DMS500 sample line reduces the likelihood of all three of these effects; there is simply less time for deposition on the walls. Secondly, the use of conductive tubing in the sample line prevents problems caused by static electricity. Thirdly, pre-heating the primary dilution air before dilution means that the engine aerosol is *rapidly* cooled to the temperature of the line, thus reducing thermophoresis. We (and others) have studied[11,12] the effect of diffusion losses in our instruments' sampling systems in detail so we are able to offer those customers interested in the smallest particles a spreadsheet to calculate size-dependent losses in our sample lines.

6. Particle creation.

Condensation of volatile species (e.g. hydrocarbons, sulphate) can cause measurement artefacts in aerosol instrumentation. This is especially true when sampling from gasoline engines. Certain materials emit particles when subjected to heat and stress due to decomposition.

Solution: Primary dilution and low pressure sample line operation reduces the partial pressure of volatiles. The DMS500 heated line can be run at 150 °C which can reduce the likelihood of condensation. In addition, an activated charcoal HEPA filter can be added to the secondary diluter to remove hydrocarbons. For more information please see application note DMS08. The heated line does can be safely run at 150 °C without particle generation.

B. "Out of the Box" Steps to Making Engine Particulate Measurements with the DMS500

1. Wheel DMS500 and vacuum pump to test site (no need to carry around or have a dedicated aerosol bench)
2. Connect sample line, compressed air supply, vacuum pump mains and computer leads to DMS500
3. Connect sample line to exhaust pipe tapping via a short stub of stainless steel pipe using standard Swagelok® or ISO/BSP fittings.
4. Connect any required analogue inputs or outputs. By default the DMS is configured to give solid particle number and mass as signals from two of its analogue outputs, and also summarised in the data file. Analogue inputs can be used to provide an exhaust or CVS tunnel air flow signal to allow number or mass rates to be directly calculated by the DMS software in real-time; even cumulative emissions can be. Vehicle speed or any other signal can also be logged for instant presentation of data and time alignment with other instrumentation.
5. Switch on the DMS and start the software on a PC or laptop (up to 100 m away).
6. Set the required heated line temperature (settings are remembered for next time once initially setup). Allow to warm up for 20–30 mins.
7. Set to high gain (for most purposes.)
8. Set required sample averaging and dilution. We would recommend keeping the primary dilution set to 5 to prevent condensation and agglomeration, and then set the secondary dilution to e.g. 50–200 for pre-DPF work and 1–50 for post DPF studies. The dilution can be changed if necessary during a test in response to the dynamic range indicator.
9. Click "Autozero". After a few seconds the measured sensitivity level is displayed on the screen.
10. Click sample.
11. Set a filename, start your engine and click "Start Logging". Click "Stop Logging" at the end of the test.
12. Open the non-proprietary tab-delimited data file in Excel (or Matlab or any package), and either plot data using your software's usual facilities, or with a couple of clicks use the supplied and freely distributable Excel macros to create summary data, contour plots, 3D animations and more.

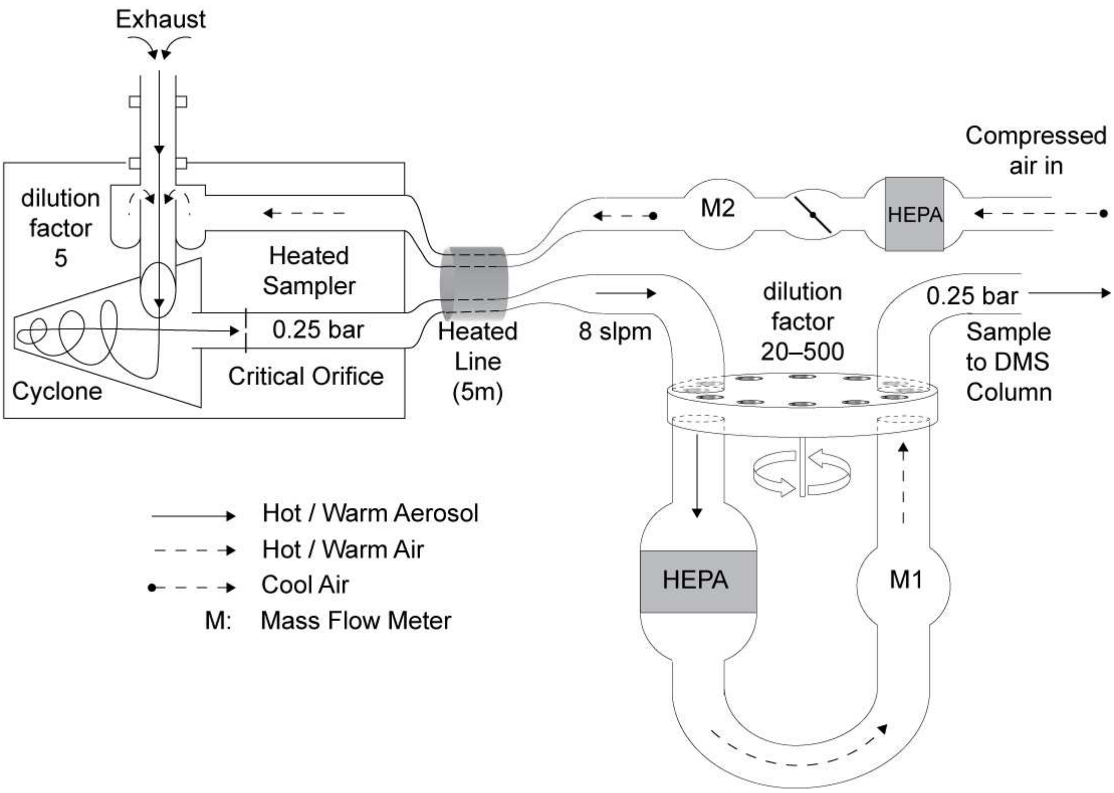
C. Summary of DMS500 capabilities for engine particulate measurement

- Simultaneous real-time measurement with one instrument of: particle number including solid particle number measurement by virtue of the unique aerosol mode differentiation feature[3,4], particulate mass[5,6] and size spectrum.
- Fully integrated 2-stage dilution for direct exhaust sampling. No need for any further dilution, no expensive CVS infrastructure needed.

- Good tolerance to pressure fluctuations pre-DPF.
- Ability to automatically calculate emission rates and specific emissions in real-time if appropriate flow signals are available.
- Unrivalled time response[13] (200 ms T_{10-90}, 300 ms with 5 m sample line). 10 Hz data rate.
- Easy test cell integration: 4 non-linearly scalable analogue inputs and 4 programmable analogue outputs, digital control input, remote analogue control of secondary dilution.
- Built in dilution combined with two gain ranges gives a dynamic range of 9 orders of magnitude, suitable for light duty pos-DPF measurements through to heavy duty Diesel feedgas applications.

Cambustion have over 20 years experience in automotive emissions instrumentation and consultancy and offer a joined up approach to sampling advice, technical support and helping customers make sense of their emissions data.

D. DMS500 Sampling System in Detail



E. References

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