GDI measurements with a Fast Particulate Spectrometer

Presenter:	Dr Tim Hands -	Cambustion Ltd, Cambridge, UK
Co-Authors	K St J Reavell, C Nickolaus -	Cambustion Ltd, Cambridge, UK
	Prof N Collings –	Cambustion Ltd, Cambridge University Engineering Dept.

Abstract:

Dilute measurements made from the CVS tunnel for a GDI vehicle on a chassis rolls running a New European Drive cycle are presented and discussed. The data indicates significant effects of the ECU strategy on particulate emissions in particular; Combustion mode emissions are significantly higher from stratified operation than stoichiometric operation, significant transient particulate emissions are associated with mode switching between stratified and stoichiometric – including switches associated with NOx trap purging, there is some evidence for a variation in the size of the combustion mode emissions – which is not generally seen for Diesel combustion

Gasoline Direct Injection (GDI) is a combustion system which offers some potential for improved efficiency over normal spark ignition combustion. Particulate emissions from GDI combustion systems are receiving increasing attention. GDI combustion systems are currently under Spark Ignition legislation, which has no particulate limits. However, GDI particulate emissions can be significant in some circumstances.

Data is presented from a new instrument which can resolve transient particulate emissions spectra. The instrument is shown schematically in slide 3 and is described fully in [1].

Data from two GDI engines running the New European Drive Cycle (NEDC) is presented. Slide 5 shows the generally much higher particulate emissions associated with GDI (stratified) combustion – comparing the first 200s with the second 200s of the NEDC. Transient particle emissions associated with mode switches between stratified and homogeneous combustion are shown in slide 6.

Slide 8 shows the effect of a NOx trap purge on particulate emissions by comparing two identical accelerations at ~400s and ~600s seconds.

Slide 9 shows some evidence for the shifting of the mode size to lower particle diameters as the load is increased in stratified mode.

Slide 10 shows how the total particle concentration across the size range of the instrument can be used to identify interesting aspects of the particle emissions and slide 12 shows how small load changes and driver performance can be significant when operating near to the high load extreme of the stratified operation envelope.

References

[1] K S Reavell, T Hands, N Collings, 'Determination of Real-Time Particulate Size Spectra and Emission Parameters with a Differential Mobility Spectrometer'; Proc. 6th Int. ETH Conf on Nanoparticle Measurement, Zurich August 2002

1. Title

GDI measurements with a Fast Particulate Spectrometer

Tim Hands

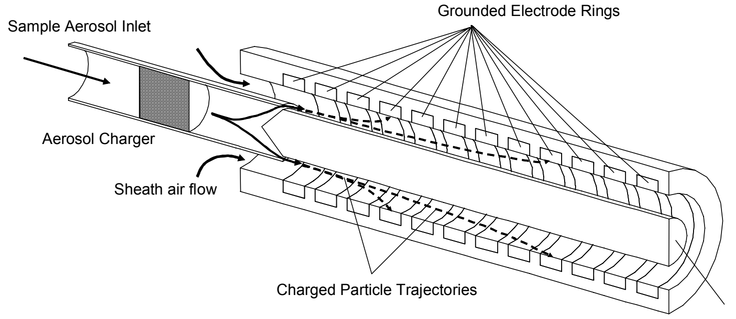
2. Overview

Presentation Overview

- GDI – gasoline combustion system with 2 modes
  - Stratified lean - fuel concentrated in part of the cylinder
  - Homogeneous stoich (or rich) – fuel and air mixed
- Introduction to Differential Mobility Spectrometer
- GDI spectral data 2 vehicles
- Discussion and conclusions

3. DMS Concept.

Differential Mobility Spectrometer.



- Engine Exhaust sample drawn through charger
- Charged aerosol enters classifier surrounded by clean sheath flow
- Strong electric field causes particles to drift towards electrometers around channel
- Larger particles, with more drag, drift more slowly and are detected further downstream.

NEDC– vehicle #1

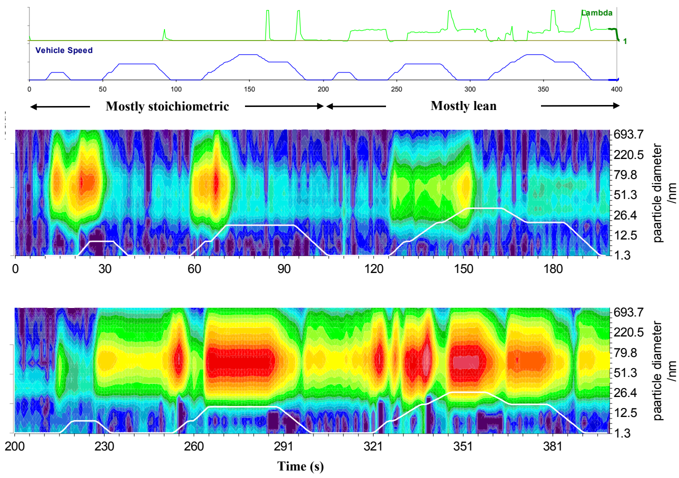
Data from CVS dilution tunnel of engine on a dynamic dynamometer:

- Homogeneous vs stratified effect on particulates
- Transient effect of mode switches

4. Vehicle #1 data

Aerosol is sampled from a dilution tunnel from a GDI engine on a dynamic dynamometer running the NEDC. The data demonstrates the general effect of the combustion mode on particle emissions and also shows the transient effect caused by mode switches”

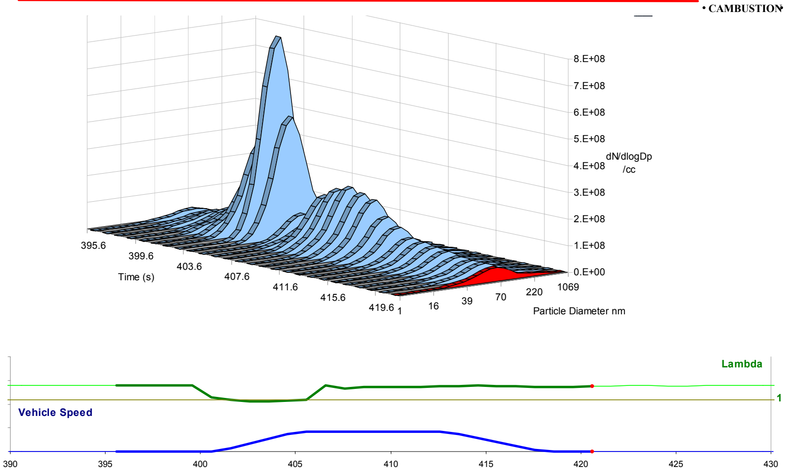
Homogeneous vs stratified effect on particulates



5. Homogeneous vs stratified effect on particulates

This is data from the 1st 200 s of the cycle compared with the second 200s. The top plot shows the vehicle speed and the exhaust lambda from a UEGO sensor. The combustion in the first phase is predominantly homogeneous (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 the stratified combustion causes a significant increase in accumulation mode particles.

Transient effect of mode switches



6. This data is taken from the start of the third set of cruises. Before 400s, the engine is idling in stratified mode with rather low particle emissions due to the low engine load. During the acceleration from ~402 to 406s, the engine strategy switches to homogeneous combustion (as seen by the UEGO trace). This mode switch causes a transient peak in particulate emissions settling briefly to a lower level. At the end of the accel, the strategy switches to stratified mode and there is a second, somewhat lower, transient particulate emission event. During the decel the particulates are generally reducing, but note that the measurements in the CVS tunnel can show significant 'hang-up' – particularly when the engine flow is small and exhaust system purge times can be significant

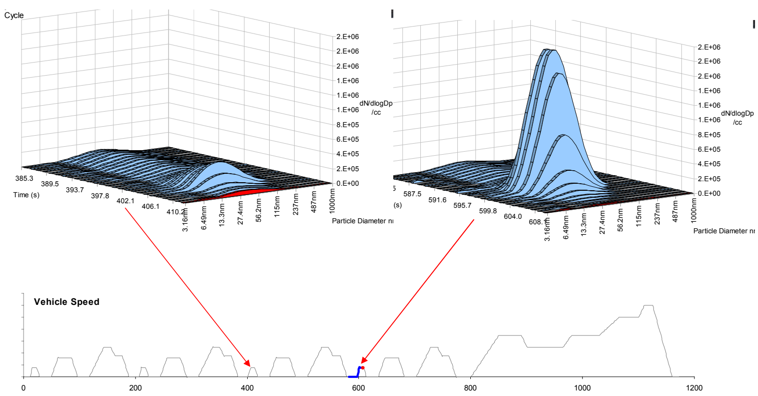
Warm NEDC – vehicle #2

Data from CVS dilution tunnel of vehicle on a chassis rolls:

- NOx trap regeneration
- Accumulation mode size variation as fn(load)
- Total particle number

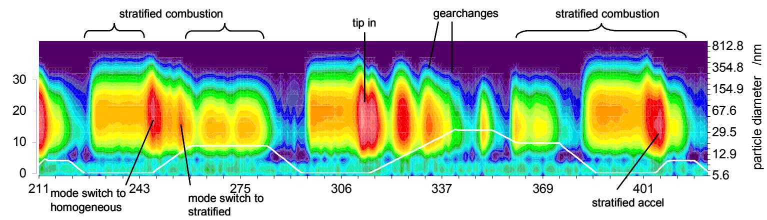
7. This is data taken on an Audi FSI 2.0l vehicle on a chassis roll at AEA Technology in the UK – again running the NEDC following a warm start. Unfortunately, no engine UEGO sensor was available for these tests. The data demonstrates the effect of NOx trap purging on particulates. It is also notable that the average accumulation mode size seems to change significantly (not typically noted in Diesel combustion). Further, information from looking at Total particle number is demonstrated.

NOx trap regeneration



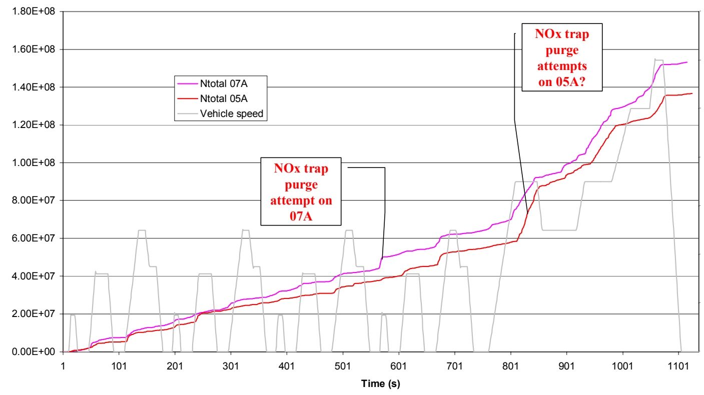
8. The 2 graphs correspond to the lowest speed urban cruise occurring at 400 and 600s respectively. For this vehicle, the strategy generally causes stratified combustion for these cruises. However, the large particulate emissions associated with the 600s cruise are due to a partial regeneration of the NOx trap during the (rather short) acceleration. When the engine load is too low to accomplish the NOx purge, stratified combustion is resumed. Once again, tunnel hang-up obscures the details.

Accumulation mode size variation as fn(load)



9. This corresponds to the second 200s of the cycle. For this vehicle, most of this period is spent in stratified mode with occasional switches to homogeneous during the accelerations. It is notable that there seems to be significant variation in the accumulation mode size. During the (stratified) idles, the particle diameter is around 65nm. The engine mode switches to homogeneous for the accel at 244s and the mode size is similar (~65nm). As the load is increased in stratified mode however (during the 10m/s cruise and the accel at 402s), there is some evidence that the average accumulation mode particle diameter is reduced to nearer 35nm

Total particle concentration in dilution tunnel

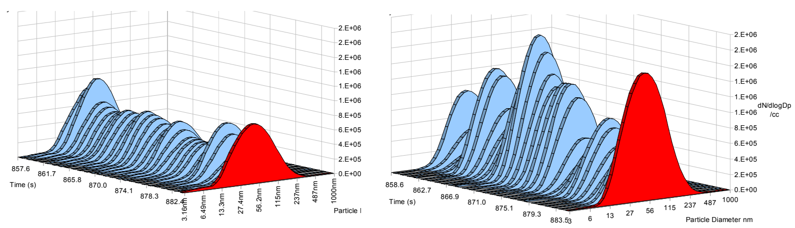


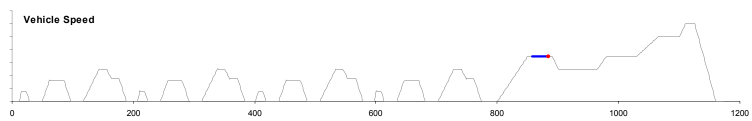
10 This shows the total particle concentration from 5 – 1000nm determined from the datafile. The data corresponds to 2 warm NEDC cycles. The effect of the partial NOx trap purge is clearly seen at ~ 600s on test 07A. Also, Test 05A shows significantly higher emissions during the first cruise of the EU part of the cycle. Examination of the corresponding particulate spectra can show the cause of this.

Spectral data from 1st EU cruise

Cycle 07A

Cycle 05A





11. This is the corresponding data taken from Cycle 05A and Cycle 07A. The data from Cycle 07A indicates an accumulation mode associated with the stratified combustion during this cruise. The remnant of the transient associated with the transition from homogeneous mode during the accel can be seen at the start of the cruise.

For Cycle 05A, a similar feature associated with the transition from homogeneous to stratified at the end of the accel is evident, but the spectral data is generally much less stable. These variations may be due to NOx purges or correspond to variations in load due to relatively poor speed control due to the human driver. This data shows the general sensitivity of GDI combustion near the extreme of the stratified combustion operating envelope.

.

GDI particulates conclusions

- Stratified (lean) combustion is not premixed and produces an accumulation mode like a Diesel
  - particle size is more variable than for Diesel
- Homogenous particulate emissions are generally lower than stratified
- Poor combustion during the transient mode switch event often produces a large burst of particulates - especially the switch from stratified to homogeneous
- Purges of the NO_x trap where the engine runs rich for a short period also produce large particulate bursts
- GDI particulates appear to be especially calibration sensitive.