UPDATE ON THE PMP PHASE 3 LIGHT-DUTY INTER-LABORATORY CORRELATION EXERCISE: SUMMER 2006

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J. Andersson (Ricardo UK, Shoreham Technical Centre, UK)
P. Dilara (DG JRC, Ispra, Italy)
R. Munoz-Bueno (DG JRC, Ispra, Italy)
B. Giechaskiel (DG JRC, Ispra, Italy)
Inter-laboratory Correlation Exercises
Summary

- Light-duty Exercise prioritised
- Commenced late summer 2004
- Completed August 2006
- 9 labs participated (11 repetitions)
- Project managed by DG JRC (Ispra, Italy)
- Golden Engineer funded by DfT (UK)
- Heavy-duty programme planned for late 2006 / early 2007
Overview of light-duty inter-laboratory exercise

- Repeated measurements made at several laboratories (with JRC bookends)
- Travelling ‘Golden Engineer’ + two of JRC staff to ensure best and reproducible testing practice
- Very low PM ‘Golden Vehicle’ at all labs

Repeatability/Reproducibility

- Tests on:
  - ‘Golden Measurement System’ for particle numbers
  - Pre-specified modified mass measurement system
  - Additional vehicles of various types
  - Alternative systems for particle numbers (constructed to PMP spec)
Vehicles tested

- PEUGEOT 407 HDi FAP 2000 cc (in all labs)
- BMW 525d catalysed DPF equipped, 2500 cc
- MAZDA Bongo catalysed DPF, 2000 cc
- TOYOTA Avensis D-CAT 2000 cc
- MERCEDES Vito Van DPF 3000 cc
- PEUGEOT 206 HDi FAP

- BMW 120d PMFC 2000 cc
- AUDI A2, TDi, EURO-4, Oxicat, 1500 cc
- HONDA Accord i-CTDi, Euro 4, Oxicat/deNOx, 2200 cc
- VW, GOLF TDi, non-DPF, 1800 cc
- KIA Pride, non-DPF, 1500 cc
- VAUXHALL Astra, CDTi, 1700 cc
- RENAULT Megane, 1.5 dCi, 1500 cc (Euro 3)

- MITSUBISHI Carisma, GDI, TWC/deNOx 1800 cc
- VW, GOLF FSI, TWC/deNOx 1600 cc
- TOYOTA Crown G-Di, 3000 cc
- FIAT, Idea, MPI, EURO-4, TWC, 1400cc

| DPF DIESELS * 6 |
| Conventional DIESELS * 7 |
| Lean DI SI * 3 |
| MPI |
Mass systems tested

- Pallflex TX40 mandated; single batch for all tests
- Inertial collection for protection of filter (2.5µm to 10µm cut-point)
- No back-up filter
- Single filter for entire NEDC for DPF equipped and gasoline vehicles
- Urban and extra-urban filters for conventional Diesels
- Modified filter holders for even deposition of material
- Lab modified systems with external heating tapes and mantles (most labs)
  - Sample passes through zone held at 47°C +/- 5°C for >0.2s
  - Temperatures recorded
- HORIBA HFU-4770 (Heated Particulate Filter Module) (2 labs)
  - Heated enclosure containing cyclone, transfer tubing and filter holders
    - Sample controlled to 47°C +/- 5°C for >0.2s
A particle number method employing a condensation nucleus counter (CNC), but using sample pre-conditioning to eliminate the most volatile particles which may contribute significantly to variability.
Alternative number systems tested

- **Clone GPMS**: Rotating Disc + Evaporation Tube + Ejector Dilutor (2 lab)
- **EJ**: Dual Ejector dilutor-TSI CPC 3010 lab modified (1 lab)
- **FPS**: DEKATI FPS (modified) - GRIMM modified CPC 5.403 (3 labs) or TSI CPC 3010 lab modified (1 lab)
- **EJ+TD**: Ejector dilutor or FPS + Thermodenuder - TSI CPC 3010 lab modified (1 lab)
- **SPCS**: HORIBA Solid particle counting system (2 labs)
Outline

- Vehicles tested
- Alternative systems tested
- Mass results
- Number results
- Regeneration effects
- Preliminary conclusions
Particulate Mass Emissions From Golden Vehicle Below 1mg/km

Repeatability level shows some dependence on proximity to ‘scheduled regeneration’
Particulate Mass Emissions (mg/km)

DPF and MPI well below 1mg/km emissions level; results of all DPF vehicles statistically similar to Golden Vehicle

Lean G-DI emissions ~2 to >10mg/km
Outline

- Vehicles tested
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Majority of Particle Numbers Emitted During Cold-Start Testing
Emissions dominated by Urban Phase/cold start
Particle Numbers from NEDC $\sim 10^{11}$/km

Apparent poor repeatability is manifestation of DPF fill effects
DPF fill state influences particle numbers – and repeatability!

Golden Vehicle

Particle emissions (#/Km)

BEFORE

AFTER

Post regeneration particle numbers \(>10^{11}\)

Particle numbers decrease as DPF fills

Mean of tests before regeneration

Regeneration during precond

TEST 1

TEST 2

TEST 3
EEPS measurements show that large numbers of <30nm particles are released during regenerations, but usually almost all particles are >30nm.

**Diagram:**
- **120 km/h (regeneration):**
  - Number Concentration: \(10^7\) to \(10^8\)
  - Mobility Diameter: 10 to 100 nm

- **32 km/h (cold start):**
  - Number Concentration: \(10^5\) to \(10^6\)
  - Mobility Diameter: 1 to 10 nm

*Many particles are both small and volatile: see next slide.*
Solid Particle number emissions increased by 50% max during NEDC regeneration, but small and volatile particles increased by ~125x

EEPS data measured directly from the CVS
Strong similarity between GPMS and Alternative particle measurement systems: DPF and non-DPF vehicles
Alternative systems for Au-Vehicle

- clone GMPS (AVL_MTC)
- clone GMPS (RWTUV)
- clone GMPS (NTSEL)
- FPS (RCE)
- FPS (SHELL)
- FPS+TD (LAT)
- EJ (AVL_MTC)
- EJ+TD (LAT)
- SPCS (NTSEL)
NEDC Particle Numbers (#/km)

Factor of 500 –1000 between DPF & Non-DPF Diesels

Particle Number emissions [km⁻¹]

- Au-Vehicle
- DPF#1
- DPF#2
- DPF#3
- DPF#4
- DPF#5
- MPI
- GD#1
- GD#2
- GD#3
- non-DPF#1
- non-DPF#2
- non-DPF#3
- non-DPF#4
- non-DPF#5
- non-DPF#6
- non-DPF#7
Mass shows better apparent repeatability than number for DPF Diesels!

Mass method is insensitive to DPF fill state, so mass appears repeatable

G-DI PM Chemistry is unique – soot plus oil plus very volatile HCs – all retained by filter medium

True indication of system repeatability comes from non-DPFs, where Euro IV number data can be significantly better than mass

PM have improved CoV

N has improved CoV
Outline

- Revised timetable
- Vehicles tested
- Alternative systems tested
- Mass results
- Number results
- Regeneration effects
- Preliminary conclusions
Preliminary Conclusions

- Mass method sufficiently sensitive to permit repeatable measurements at well below 2.5 mg/km level
  - Significant questions remain regarding sampling and retention of volatiles by filter media in absence of carbon

- Number method ~20 times more sensitive than mass
  - Emissions of ~$10^{11}$/km achievable with DPF Diesels, similar as modern MPI
  - GDIs between $10^{12}$ and $10^{13}$/km
  - Conventional Diesels ~ 500 times higher ($5 \times 10^{13}$/km) than DPF equipped ones

- PMP Solid Particle Number method less variable than mass for EURO-4 non-DPF diesel cars

- Mass method insensitive to DPF fill state, ‘true repeatability’ masked
Mass and number measurement equipment presented no significant functional or maintenance challenges during the programme.

Both mass and number sufficiently sensitive to discriminate between a DPF equipped Diesel and non-DPF equipped Diesel:
- Number metric provides best sensitivity and avoids uncertainties with volatile components.

Current technology GDI emissions fall between DPF Diesel and non-DPF Diesel both in mass and number.
Next Steps

- Compile full PMP results including Alternative Systems
- Analyse all data and prepare final reports for PMP WG
- Further revision of draft regulatory documents
  - Fine tuning
  - Integration of necessary validation and calibration procedures for number measurement equipment
- Submission of drafts to EC in Brussels as protocols in regulation format for consideration as part of Euro V
- Heavy Duty Inter-lab exercise – Kick-off meeting late in 2006
Thank you for your attention