8th ETH-Conference on Combustion Generated Nanoparticles, Zurich 16-18 August 2004

Progress within the PMP Programme

Jon Andersson, Ricardo Consulting Engineers, Shoreham-by-Sea, UK

The governments of France, Germany, the Netherlands, Sweden and the United Kingdom agreed to a collaborative programme aimed at developing analytical systems by which ultrafine particles could be measured to facilitate control in a regulatory framework. The eventual outcome would be a system, or systems, that would replace or complement the existing method of particulate mass measurement. This work has been taken forward in the UNECE forum where the government of Switzerland joined the consortium. Japan has also made a contribution.

The resulting Particles Measurement Programme (PMP) workgroup, chaired by the United Kingdom, developed a three phase approach to complete the work.

In the first two phases of the programme, a wide range of measurement instruments and sampling systems were assessed over standard regulatory tests.

In the PMP Phase 1 study, measurement systems addressing several key particle properties including mass, number, active surface and chemistry were evaluated along with appropriate dilution methods, sample conditioning and consideration of cost and logistical aspects.

Phase 2 subjected the best performing systems from Phase 1 to more rigorous evaluations in order to confirm the results of Phase 1 and determine fundamental levels of repeatability within a single laboratory during a variety of steady state and transient tests and both engine-out and post-DPF exhausts. The testing from Phase 2 concluded that a revised filter mass measurement method and a particle number method both based upon sampling from a standard dilution system best met the original objective of the programme.

The two recommended systems were:

- A filter method based broadly upon that proposed for the US for 2007 type approvals. This method offers significant improvements in repeatability compared to the current European filter method.
- A particle number method using a Condensation Particle Counter, but using sample pre-conditioning to eliminate the volatile particles which can contribute significantly to variability. This system proved to be robust to different engines and exhaust chemistries and showed good repeatability.

Draft revised versions of the light-duty vehicle (R83) and heavy-duty engine (R49) particulate sampling annexes have been prepared. These documents integrate the particulate and particle approaches into the existing regulatory framework and also form the bases for two test protocol documents written as laboratory guides for testing within PMP Phase 3, the “Inter-Laboratory Correlation Exercises”.

The final phase of the PMP programme will be the inter-laboratory correlation exercises. These will commence in late Summer 2004 with the light-duty (R83) exercise. R83 is prioritised since the legislative timetable proposed by the legislators in Brussels is currently focused towards Euro V for light duty vehicles. The inter-laboratory correlation exercises will be Project Managed by JRC at Ispra, Italy.

The light duty exercise will re-evaluate the repeatability and investigate reproducibility and robustness of candidate measurement and evaluation systems for particulate mass and particle

number exhaust emissions from light duty vehicles under transient conditions on a chassis dynamometer.

A repeated set of measurements will be undertaken in a number of laboratories around Europe, with a ‘Golden Measurement System’ for particle numbers, and a ‘Golden Vehicle’ transported from laboratory to laboratory. The ‘Golden Vehicle’ will be a wholly Euro IV compliant, DPF equipped Diesel vehicle with proven gaseous emissions repeatability. The ‘Golden Measurement System’ will be a best available technology approach to the meausrement of particles as defined in the draft R83 documentation. Regular and strict calibration and validation exercises will be undertaken in order to ensure the optimal performance of the Golden Measurement System and determine the real requirements for these exercises in a regulatory environment.

A modified particulate mass measurement system will also be evaluated.

A travelling ‘Golden Engineer’ will, along with JRC, ensure best measurement practice at each laboratory.

Following completion of the light duty exercise in Europe, it is anticipated that the Golden Measurement System will then move to Japan, where a similar exercise will be conducted. The Golden Engineer may also travel to Japan to assist in this programme.

The results of the light duty exercise will be employed to enable further revisions of the draft R83 and R49 annexes suspended at the end of PMP Phase 2. The final drafts will then be submitted to the EC in Brussels as protocols in regulation format for first adoption as part of Euro V.

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Job Title	Chief Engineer, Chemistry Department
Company	Ricardo Consulting Engineers, UK
Responsibilities and Research Interests	Graduated in 1991 with an honours degree in Chemistry with Analytical Chemistry from Kings College, London University, UK. Joined Ricardo in 1992. Currently responsibilities include financial and technical control of unregulated emissions research programmes at Ricardo. Research interests include sampling, measurement and analyses of particles and particulates from internal combustion sources and analytical methods for the determination of unregulated emissions species.

Progress in the GRPE Particulate Measurement Programme (PMP) – Summer 2004

Jon Andersson
Ricardo Consulting Engineers, UK

"There is a lot of knowledge on particles and particle measurement - so what are we going to do about it?"

Mike Dunne, UK DfT - 4th ETH Nanoparticle Conference, 7 - 9 August 2000

The Particle Measurement Programme (PMP)

Initiating Governments:

- France, Germany, Netherlands, Sweden & UK. Joined by Japan and Switzerland.

Forum UNECE

- UN/ECE - GRPE

Key Objective:

- Development of type approval test protocols for assessing vehicles fitted with advanced particulate reduction technology that would complement or replace the current legislative measurement procedure for particulate mass.

Expected Completion:

- 2004/2005

PMP

Working Protocol and Programme Content

- **A co-operative programme,**
  - **i.e. National participants to conduct their own programmes on an agreed time-scale**
- **Intermittent meetings of researchers to exchange technical information**
- **Regular updates of progress to GRPE**
- **The three phases of the PMP test work:**
  - Phase 1: Technology Screening
    - of many possible candidate systems
  - Phase 2: Robust evaluations and technical development
    - of most promising candidates
  - Phase 3: Inter-laboratory correlation exercises
    - Confirmatory testing: repeatability, reproducibility, practicality

PMP: UNECE LD and HD Testing

- Light-duty vehicle measurements made on NEDC and FTP test cycles.
- Heavy-duty engine measurements made on ETC, ESC, WHDC & FTP test cycles.
- More than 20 measuring instruments/systems have been investigated in programmes.

PMP UNECE Phase 1

In PMP Phase 1

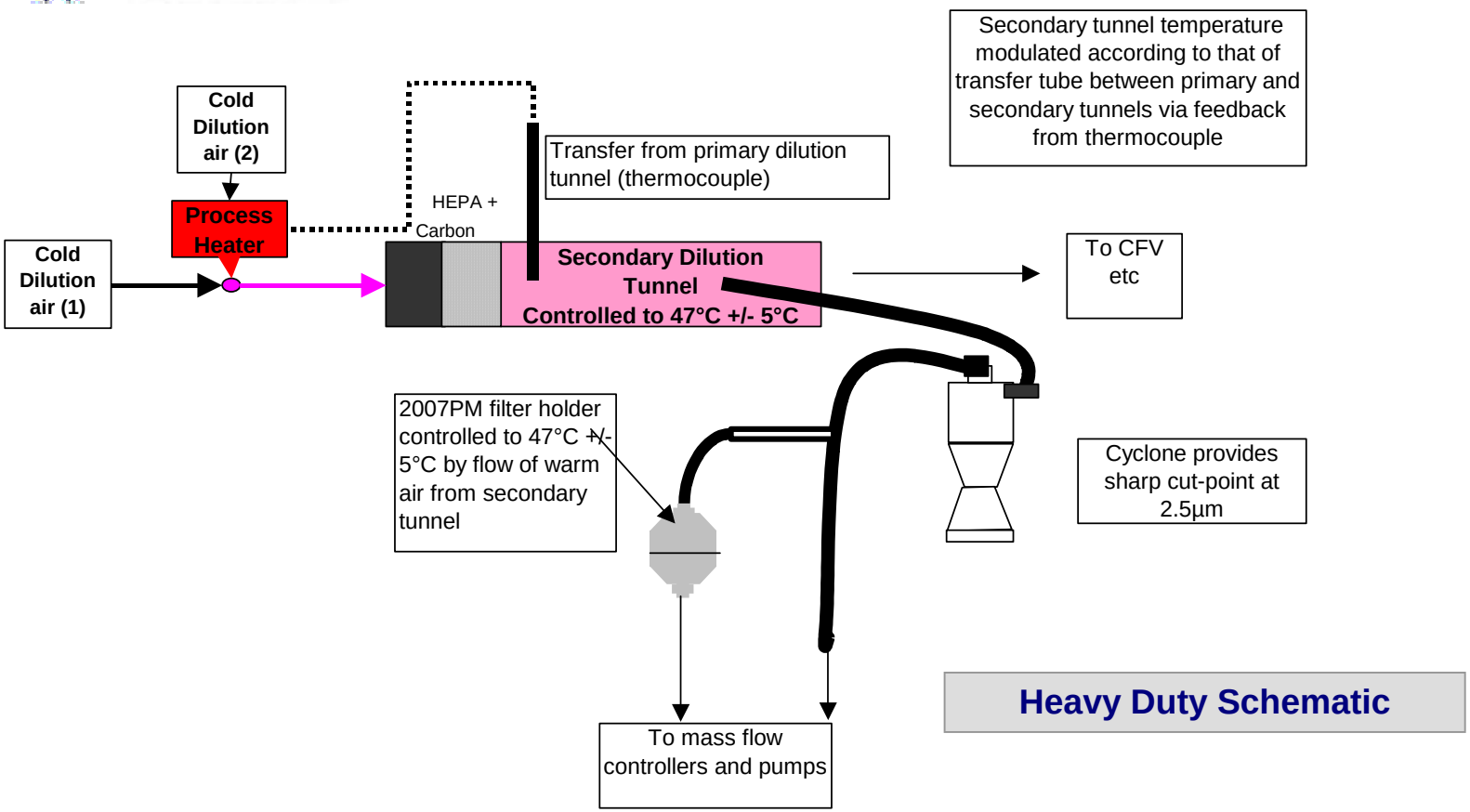
- Many measurement systems evaluated
  - Different metrics: Mass, Active Surface, Number, Size Distribution
- Many sampling approaches included
  - First stage dilution: Raw exhaust sampling, conventional CVS
  - Secondary dilution alternatives: ejectors, rotating disc
  - Sample conditioning: thermodenuders, hot dilution
- Logistical and functional aspects considered
  - Integration of new equipment and procedures within existing test laboratories
  - Cost
  - Ease of operation
  - Understandable metric
  - Repeatability
  - Sensitivity

PMP UNECE Phase 2

In PMP Phase 2 Testing

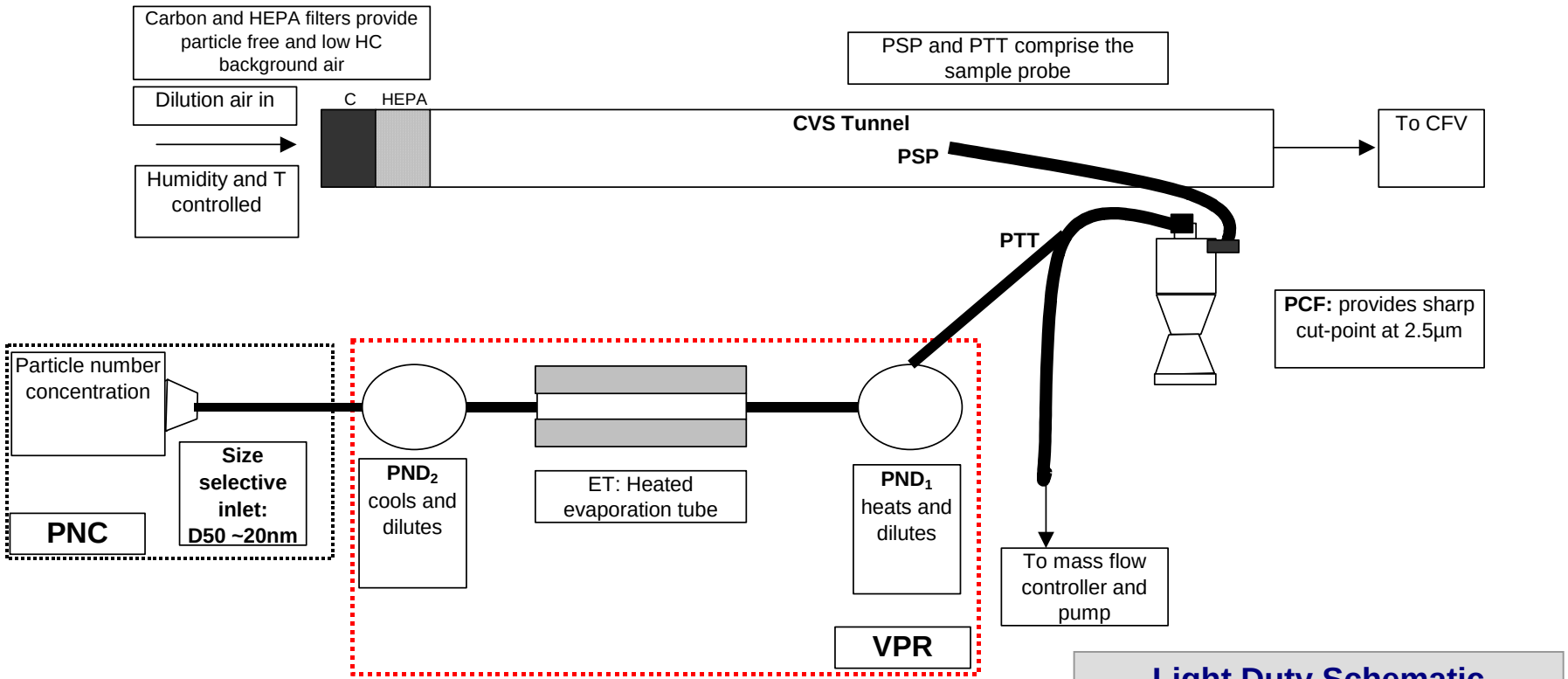
- Best performing systems from Phase 1 subjected to more rigorous evaluations
  - Steady state and transient drive cycles
  - Post-Diesel Particulate Filter (DPF) and Engine-out exhaust aerosols
- Aims
  - Confirmation of Phase 1 results
  - Determine fundamental repeatability levels within a single lab
  - (Very limited) reproducibility data
  - Establish robustness of measurement approaches to different exhaust chemistries
- Recommendations
  - Revised filter mass measurement
  - Particle number method (measuring defined particle volatility; >20nm)
  - Both based upon standard CVS dilution system

PMP UNECE Phase 2



- **PMP Phase 2 Recommended Mass System**
  - A filter method based broadly upon that proposed for the US for 2007 type approvals.
    - This method offers significant improvements in repeatability compared to the current European filter method

PMP UNECE Phase 2



Light Duty Schematic

PMP Phase 2 Recommended Number System

- 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.
  - This system proved to be robust to different engines and exhaust chemistries, and demonstrated high sensitivity and repeatability

PMP UNECE Phase 2

- **PMP Phase 2 Draft Regulatory Protocols**
  - Revised versions of existing type approval regulations drafted with input from Governments, research institutes and industry
    - R83 : light-duty vehicles
    - R49 : heavy-duty engines
  - Draft documents
    - Integrate recommended mass and number procedures into regulatory framework
    - Some restructuring of R83 and R49 also undertaken to create more accessible, readable documents and converge the light and heavy duty procedures
    - Form the basis of PMP Phase 3 – The Inter-lab Correlation Exercises

PMP UNECE Phase 3

- **Inter-laboratory Correlation Exercises (1)**

  - Project Managed by DG JRC (Ispra, Italy)
  - Commence late summer 2004
  - R83 prioritised
  - 5 labs in Europe (plus several in Japan?)
  - Travelling ‘Golden Engineer’ to ensure best and reproducible testing practice

- Aims
  - Re-evaluate repeatability
  - Determine reproducibility of recommended candidate systems
  - Evaluate robustness of draft test protocols for mass and number

- Content
  - Repeated measurement set at several laboratories (JRC bookend)
  - Test proven repeatability, very low PM emitting ‘Golden Vehicle’ at all labs
  - Optionally test other Euro IV vehicles (with/without DPFs)
  - Test ‘Golden Measurement System’ for particle numbers

PMP UNECE Phase 3

- **Inter-laboratory Correlation Exercises (2)**

- Content
  - Evaluation of modified PM method
  - Regular and strict calibration protocols for particle number measurements
  - Validation exercises for key measurement system components
    - Volatile Particle Remover
    - Particle Number Counter
    - Diluters

PMP UNECE Phase 3

- Next Steps
  - R49 Inter-lab exercise
  - Further revision of draft regulatory documents
    - Fine tuning
    - Integration of necessary validation procedures
    - Integration of necessary calibration procedures
  - Submission of drafts to EC in Brussels as protocols in regulation format for consideration as part of Euro V

PMP UNECE Phase 3

Outstanding Issues

- Calibration
  - Particle Number Concentration Standards
    - Stable chemistry, size distribution, number concentration
  - Diluters
    - Low losses across PMP measurement range
    - Characterised losses
    - Selectable dilution
  - Volatile Particle Remover
    - High penetration for solid particles (>90%)
    - High efficiency for volatile particle removal (>99%)

- Some of these will be addressed during and in parallel with PMP Phase 3
  - Perhaps some of these questions will be answered in the next 3 days?

Thank you for your attention