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agenda item 2.)

Particle Measurement Programme (PMP).
Progress Report: Phase II.

(Transmitted by the Expert from the United Kingdom)

Introduction.
Phase II of the PMP is intended to evaluate particle measurement systems that have been considered to have the potential to for use in a regulatory role. To this end Informal Document 1 of the 42nd Session of the GRPE, indicated that the content of Phase II would be dependant upon the outcomes of Phase I.

The outcomes of both light-duty and heavy-duty testing during Phase I and discussions with experts during meetings of the Research Group, have all contributed to the activity that is now taking place in Phase II. This activity can be considered as comprising 2 elements:

- Thermosdesorber evaluation.
- System assesment on both light-duty vehicles and heavy-duty engines.

Currently one of the two thermodesorber programmes is complete and the report is available. Two of the three test programmes are completed but no reports are yet available. It is expected that the reports for all activities will be provided to the GRPE at their 46th session in May 2003.

Thermodesorber evaluation.
One outcome of Phase I was agreement that for a consistent measurement of, for example, particle size or number, only solid particles should be considered. It was also concluded that that "solid particle" would have to be defined. The systems considered during Phase I included thermodesorbing devices whose purpose is to remove volatile material from the sample in advance of measurement. It was concluded that the definition of particle would be agreed on the basis of the particle characteristic after exposure to the thermodesorber.

The use of the thermosdesorber raised other questions. For example, what were the particle losses that could be expected and how could the thermodesorbing effect be defined in performance terms?

A initial study, funded by the Swedish Government, considered the use of thermodesorbers; this programme was already underway before the PMP had finalised its questions. This report is summarised later in this report.

The Swiss Federal Roads Authority has agreed to fund a further project aimed at characterising thermosdesorbers. In particular this project will investigate:

- particle losses as a function of size, flow rate, and temperature.
- Thermodesorber efficiency:

    1) The efficiency to remove volatile material condensed on a solid core.
    2) The ability to completely remove particles having no solid fraction.

Additionally, the programme will consider a procedure to define performance characteristics of devices whose function is prepare particles for measurement by removing volatile material – this would apply to devices other than thermodesorbers as they are currently understood.

The programme commenced in January 2003 and testing is expected to finish in March with a report available in April.

System assesment on both light-duty vehicles and heavy-duty engines.
Three test programmes have been commissioned to evaluate candidate systems. Two of these programmes involve the measurement of emissions from both light-duty vehicles and and heavy-duty engines (Germany, UK) whilst the other was restricted to the heavy-duty sector (Switzerland). In total four heavy-duty engines, four light-duty diesel and three light-duty petrol vehicles will have been tested at the end of the programme.

The programmes sponsored by the governments of Germany and the United Kingdom employ the test protocols that were developed as an output of Phase I. These protocols were offered for comment in advance of Phase II and useful input was received from OICA members and incorporated into the current working procedures. In accordance with the protocols, these programmes also include an assessment of a gravimetric approach following as closely as practicable the requirements detailed for the US 2007 procedures.

In view of developments toward a world heavy-duty drive cycle these two programmes have included the proposed WHDC transient cycle. Other cycles include the European transient and steady state cycles and the US FTP transient cycle. For light-duty the programmes both European (NEDC) and US FTP cycles are included. Both the light and heavy-duty programmes include elements of steady state measurement.

The Swiss study, conducted at EMPA, involved 20 different instruments taking measurements simultaneously. Each instrument was supported by the instrument manufacturer during the measurement programme. The German and UK programmes employ between 5 and six instruments – depending upon the individual programme but with some commonality between them, e.g. Laser Induced Incandescence and Condensation Particle Counter.

Testing for both the Swiss and the German programme has been completed and analysis is ongoing. The UK test programme is continuing. No reports are yet available.

Set out below are brief descriptions of the various programmes that comprise the contribution to Phase II of the PMP. The original timetable envisaged that the test programme would be completed at this time and that a final report would be available. Delays in establishing the test protocol for Phase II have meant that this target has not been achieved, however, it is intended that a report of the testing activity will be available for the 46th session of the GRPE in May 2003.

Summary detail of the contributions to PMP Phase II.
Thermodesorbers Items 1 & 2
Emission Measurement Items 3, 4 & 5.

1. Investigation of Thermodesorber Effect

MTC 5201
Hua Lu Karlsson and Claes de Serves

This work was initiated by the Swedish EPA as a contribution to the PMP-program. The aim was to study the effect of a commercially available thermodesorber (TD) (Dekati Ltd), used at different operational temperatures, upon particle measurements from a low particle emission vehicle (Peugeot 607 with a diesel particulate trap).
The cycle used was the EDC (EU driving cycle)and a “warm” EDC, which was always started 1 h after a previous cycle. Sampling was performed using both the common CVS tunnel and a porous diluter (PDS) mounted at tailpipe position. Particle measurements was carried out using ELPI, CPC, and a diffusion charger, either with or without the TD. The TD was operated at a flow rate of 20 L/min with temperatures ranging from 22°C to 300°C.
The EDC cycle is associated with considerably higher particle emissions as compared to a warm EDC (1,16E+05 #/km, 2,75E+04 #/km respectively) without the TD, which is also consistent with measurements with the TD at 250°C (7,26E+04 #/km, 1,56E+04 #/km respectively). For the tests with and without TD, the particle size distributions between the two cycles are also different. The EDC is described by peak emission at around 80 nm particle diameter while the highest emissions in the warm EDC is described by a plateau at particle sizes smaller than 80 nm. Comparing the CVS measurements to the PDS measurements shows a higher fraction of the smallest particle sizes in the PDS system, possibly explained by a quicker and warmer dilution resulting in less coagulation. Both the CVS and the PDS measurements show reduced particle numbers at higher TD temperatures as an effect of the removal of volatile species. It is not clear, using the present set-up, if 300°C is a sufficiently high temperature in order to reach stable measurements of “dry particles“.

2. Characterisation of thermodesorbers and hot dilution to remove volatile material from diesel particles

Institut für Sensoren und Signale (ISS),
Fachhochschule Aargau, Klosterzelgstrasse, 5210 Windisch.

The main goal of this project is to obtain the information on the performance of thermodesorbers and hot dilution systems, which is required for their application to remove the volatile fraction from diesel particles in diesel exhaust measurements.

Planned experiments

Losses: To investigate the losses particles produced by a CAST, operated in a ‘dry’ mode are passed through a differential mobility analyser (DMA). The resulting monodisperse solid particles are fed into the thermodesorber/diluter. A condensation particle counter measures inlet and outlet concentrations. The ratio of the counting rates directly yields the penetration. This experiment is done for different sizes, selected by the DMA, different flow rates and temperatures. To limit the number of runs 4 sizes, 3 temperatures and 3 flow rates are planned.

Efficiency: Again dry CAST-particles are size selected by a DMA. They are then passed through a Sinclair-La mere generator, where a volatile species in condensed on their surface. The resulting change in size is measured by an SMPS. The size is also measured after passing them through the thermodesorber/diluter. If the initial size is reached again, the thermodesorber was able to remove at least almost all the volatile material. To see, whether even the last monolayer is removed, the coating experiment can be done with a photoelectrically active material (PAH). A measurement with a photoelectric aerosol sensor can then detect even traces of the material, remaining on the particles.
This experiment will be done with two dry particle sizes (30 nm and 60 nm). The amount of condensed material will be increased until the removal no longer is complete. This shows the limit of the thermodesorber. Material of three different boiling points will be used.

Systems to be investigated:
Thermodesorbers:
Presently two commercially available thermodesorbers exist

- The Model 3065 Low-Flow Thermodesorber by TSI
  Temp. Range 0 to 400°C ± 1°, Flow Range 0.2 to 2 l/min, optimal 0.5 to 1 l/min
- The Dekati Thermodesorber
  flow is first heated to 300 C, 10-20 l/min

In Addition some labs have their own constructions:

- ETH, also used by other Swiss groups, tested in detail, see Burtscher et al, 2001
- FHG (Dr. Pohlmann)
- Inst. For Tropospheric Research Leipzig, Germany (A. Wiedensohler)
- Ricardo

Hot dilution systems:

- The rotating disk Diluter MD19 by Matter engineering
- Ejector dilution systems by Dekati and Palas

This project will focus on the commercially available systems.

3. Comparison study of PMP instrument candidates. EMPA (Swiss Federal Laboratories for Materials Research and Testing)

The intention of the investigation was to gain a *uniform* overview of the performance and quality of the PMP measurement system candidates. Twenty measurement systems were compared during three weeks in June 2002. A Euro III HD-engine, equipped with diesel particle filter (CRT-System) and a combustion aerosol generator (CAST) provided and operated by the Swiss Federal Office of Metrology and Accreditation (METAS) were used as emission sources. The measurements were carried out *simultaneously* according to a standard test protocol close to type approval conditions. The study has addressed repeatability, linearity, time response and detection limits. Authorised representatives of the instrument manufacturers prepared, maintained and operated their own system during the test programme.

Test facilities

- HD-test bench with asynchronous motor for transient testing
- full flow CVS dilution unit for gravimetric measurements (as close as possible to US2007 regulations), partial flow dilution
- access for several measurement systems to undiluted exhaust and CVS diluted exhaust

Emission levels

- 100% of exhaust flow through particle trap
- part of exhaust flow through bypass of particle trap that particle emission about 40% below Euro 4 level was achieved

With CAST four defined concentration settings for two different size distributions (Modes at 35 nm and 140 nm) were tested.

Test cycles

- Transient cycle: ETC (7 tests)
- Steady state modes: 5 operation modes of ESC: idle, A50, B25, B100, C75; duration about 15 min per mode (3 tests)
- step change test (SCT) (own definition): step change of exhaust mass flow by load change 10% → 90% → 10% at 1630 rpm speed (3 tests)
- Steady-state test cycle: ESC (3 tests)

Engine conditioning following the EPEFE protocol

List of investigated instruments

Method	**Instrument**	**Size information**
light extinction	DPSO(B), DQL(L)	Yes
light scattering	CPC(L), Dust monitor(L), PM-300(L)	no/yes
LII	LI2SA	Yes
Photoaccoustic	PASS	No
electr. mobility	DMA, DMS, MASMO	Yes
Aerodyn. mobility	MASMO, ELPI	Yes
electr. charging	DC, DMS, EDB, ELPI, MASMO, PAS	no/yes
Diffusion mobility	EDB	Yes
oscill. Microbalance	TEOM	No
IR absorption	Mexa 1370PM	No
Titration	Coulometry	No
Microbalance	gravimetric filter method	No

4. GRPE / PMP; German Contribution to Phase II (status December 2002)

Umweltbundesamt, Berlin
RWTÜV Fahrzeug GmbH, Essen

Within the German Contribution to Phase II (validation and ranking of selected systems) of the GRPE-Particle Measurement Programme a selection of alternative PM characterisation and measurement systems was compared. The systems and candidates used for the programme were: LII / PASS / SMPS / CPC / DC / PAS as well as standard CVS systems and CVS systems modified to meet US 2007 requirements. For the gravimetric measurements CVS systems were used both as reference and internal standard (including pre- and/or post-sample-treatment).

The scope of the project was to compare and correlate the selected measurement systems and measurement metrics with respect to the applicability for type approval of very low emission vehicles and engines. Investigations and measurements on all PM fractions (volatile, non-volatile etc.) were performed in order to define possible influences on correlation.

For the laboratory measurements two Otto-DI and two DPF equipped Diesel passenger cars were used for the investigations. For the heavy-duty engine test programme one engine with CRT-System was used.

For the chassis-dynamometer tests the New European Driving Cycle (NEDC) and the U.S.-FTP-cycle were performed as well as some steady state measurements. The European Steady State Cycle (ESC), the European Transient Cycle (ETC) as well as the U.S.-HD-FTP transient cycle were used on the HD engine. Further on some steady state modes and cycles based upon the WHDC programme were subject to the works.

The measurement programme is finalised and all data is in the evaluation phase. The first draft report is expected for the end of February 2003.

5. UK Contribution to PMP Phase II.
Ricardo Engineering and EMStec (formerly AEA Technology)

Building upon the programmes completed in Phase I, the UK Government is funding further evaluation of candidate systems for both light-duty and heavy-duty applications. The scope of the programme includes both light-duty vehicles and heavy-duty engines and requires that the candidate measurement systems be evaluated using the measurement protocols developed as an output of Phase I. This includes, as far as is practicable, the gravimetric approach detailed for the US 2007 standards.

Ricardo Engineering will be measuring emissions from two heavy-duty engines both of E-III standard but equipped, additionally with particle filters. EMStec will be testing three light-duty vehicles. These will include E-V compliant diesel vehicles and also a Gdi vehicle.

For the light-duty programme the NEDC and FTP cycles will be employed, in addition, some steady state modes will be selected. This programme will also further investigate the effects of early dilution considered in Phase I. The heavy–duty programme will employ the European ESC and the European, FTP and WHDC transient cycles. A selection of steady state modes will also be used. Instruments under consideration include, condensation particle counter (CPC), differential mobility spectrometer, (DMS), laser induced incandescence (LII), Nanomet, Masmo and quartz crystal microbalance. Not all the instruments will be used on both the light-duty and on the heavy-duty programmes.

The test programme for the second heavy-duty engine may be adjusted in the light of knowledge gained from the first part of the UK programme or from emerging knowledge from other contributions the PMP.
