**Notes 45th PMP Meeting**

**2 day meeting ISPRA, JRC**

**07-08 Nov 2017**

**Document list**

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| **Number** | **Title** |
| **45-01** | **Agenda** |
| **45-02** | **PMP progress report to GRPE 75 (June 2017)** |
| **45-03** | **PMP task force II – brake sampling / measurement** |
| **45-04** | **Subgroup for PMP CPC calibration** |
| **45-05** | **SWRI Gas Engines** |
| **45-06** | **H2020 Down to 10** |
| **45-07** | **SURREAL** |
| **45-08** | **Light Duty sub23 RR practicals** |
| **45-09** | **PEMS4Nano** |
| **45-10** | **Brakes TF1 activities** |
| **45-11** | **TU Ilmenau – influence of preconditioning** |
| **45-12** | **Brembo** |
| **45-13** | **AVL\_TUI Particle Emissions – Different Types Of Brake Pads** |
| **45-14** | **Brakes TF2 activities** |
| **45-15** | **LINK Design considerations for brake emission measurements** |
| **45-16** | **IFW-JARI brake emissions** |
| **45-17** | **Analysis of Influence Parameters**  |
| **45-18** | **SURREAL timeframe** |

1. **Introduction :**

2 day PMP meeting at JRC, Ispra. Day 1 dedicated to exhaust emissions. Day 2 to Non-Exhaust particle emissions.

Minutes of 44th meeting (draft) available together with the summary status report presented to GRPE 75th session (June 2017)

1. **Exhaust Particle Emissions**

**2.1 Calibration**

* Final report from RR1 should be shared in Dec 2017 and report presentation web conference in Jan 2018.
* New group kick off for PMP calibration RR (Andreas Novak PTB leading). Objective to renew calibration procedure guide (more practical version than the ISO documents) and reduce calibration uncertainty.
* Objective is for workshop to renew calibration procedure beginning Dec @ PTB Braunschweig, Germany. The procedure will be validated in 2nd RR starting in 2018.
* The uncertainty review will take place before the RR starts so it can be properly investigated and tested.
* Focus on soot like aerosol with more detail on this than in ISO because needed for a single application (automotive).
* Scope / roadmap for RR2 to be circulated asap and hopefully included in same RR2.

**2.2 Update on Raw Exhaust Sampling**

No update received. JRC is in discussions with ACEA to receive an engine and next week is a joint meeting (also covering HD PN-PEMS RR) to determine the start of the testing campaign with engines and instrument availability. Nov 14-15, 2017 ISPRA.

**2.2 Gas Engines**

Imad Khalek SWRI presentation (PMP-45-05) – PN and Ash emissions from HD-NG engines and diesel with DPF. Expect to publish SAE presentation March 2018 with more details. Work funded by CARB.

**Tested 2 engines meeting low NOx standards (0.0134 g/kWh)**

* diesel 2014 Volvo Euro VI with cooled EGR, DPF and SCR (scrf, and passive NOx absorber)
* CNG 2012 Cummins stoichiometric with cooled EGR and TWC

**Instrumentation**

* Real time ash number concentration measurement CPC 3025 (CPC spec 50% detection @ 3nm 90% detection at 5nm),
* SPSS for solid particle measurement
* Using EEPs rather than full PMP protocol

**Results / Discussion**

* Work done on aged A/T system – 435k miles (thermally aged), engine was relatively new.
* Gas engine particles highest on cold start FTP. Sub 25nm particles constitute 30% of total number emissions for both cold and hot start FTPs. Showed on hot WHTC similar level of particles bigger and smaller than 25.5 nm. Natural gas engines in stoic steady state conditions are really low particle producers. Cold start produces more particles than warm start. FTP produces more particles than WHTC. PN seems to come from high acceleration events. Ash emissions 20-30% total PN but represents higher fraction of sub 25 nm. Cold start gave more ash than hot start and FTP twice as much as WHTC. Some discussion on ash particles / metallic content – previous work on lube oil studies means retain significant no of ash particles but not all are metallic – a lot of lube oil material which does not survive 550-600 deg C
* Diesel with SCRF – cold start FTP highest no of particles. Sub 25nm particles comparable cold and hot start FTPs, but 10% number for cold start and 30% for hot start FTP. WHTC emissions not available as system was damaged. Slide 17 shows comparison diesel and gas – natural gas has higher PN emissions above and below 25nm in both cold and hot start.
* Noted that SwRI will feed into USA rulemaking that mass and number does not meet the same thing. The gas engine meets PM very well and has many sub 25nm particles.
* Swiss representative Giovanni D’Urbano asked if PMP would also consider NRMM gas engines and also about generally lean burn gas engines.
* EU discussions are continuing on PN-PEMS – gas engines – artefacts etc. discussion at more political level at end 2017 with DG-GROWTH. PN might be included for HD in future.
* OICA mentioned a need for an RR with CNG. JRC always measure in the lab below 23nm. PN-PEMs typically does not. There is some measurement done. Type approval is done with 23nm, so this needs to be done on road and this is the prime focus to match TA. Other research will continue to come. JRC also collecting publications on CNG PN.

**Sub-23nm**

**Horizon projects on sub-23 nm particles (PMP-45-06, 07, 09)**

**Down to 10:**

Jon Anderson (Ricardo) presented Down to 10 update – objective measure down to 10 in PN-PEMS capable system, need also to do this in CVS environment. One aspect of the project is to find out whether there are unique situations with high particle numbers sub-23nm and therefore to determine whether this shift down to 10 actually is required. The project questions are defined on slide 7.

Work package 3 – screening existing vehicle technologies even under extreme operation with different systems to see if same or different results from the different instruments so it can be investigated if real or artefact.

Finding so far – thermophoretic losses are mainly caused by cooling down the sample with an ejector diluter – use of porous tube diluter (PTD) reduces this almost to zero. Diffusional losses from CS but minimised by downsizing CS. Equipment decisions will be made once screening is completed.

How to apply PCRF correction including <23nm ? Request to demonstrate that the 15nm particles from CAST are really solid.

Eventually will be able to have a good link between dilute sampling particles and those from raw-sampling to have technically correct correction factors.

Next steps : Further testing and data collection, stress testing of the equipment in the aerosol lab (pressure / variability), more characterisation of chemical composition from large number particle events below 23nm, more investigation of < 23nm artefacts and targeting to PN-PEMS demonstrator and implement and verify the simulation.

**SURREAL**

Includes technology testing and development – 6 new instruments – 2 of which are close to completion – half mini DMA and induced current aerosol detector (ICAD). Next steps are to develop a vehicle test matrix and evaluate equipment for PEMS concept.

Other concepts are SCL-MPAS super continuum laser in multi wavelength photoacoustic aerolosspectroscopy.

OICA enquired whether HD CNG could be included in the PEMS test matrix. Will be looked into whether can be included for the PEMS rather than lab dyno testing.

Expect to finish instrument evaluation by March 2018. Then will be testing instruments on vehicles – chassis or engine dynos – to get an improved understanding of the nature of the particles and final 6 months will be PEMS test.

Some discussion of catalytic stripper and regeneration procedures.

**PEMS4Nano**

Optimise sampling, dilution, volatile removal, counter and calibration.

Measurement technology down to 10nm for solid particles in the lab and on the road / mobile applications. Using CPC optimised for 10nm. Noted that using CAST which has a higher counting efficiency than calibrations with emery oil.

Further deliverables include calibration procedures and measurement integration into system development – using single cylinder and multi cylinder engines

Technically the CPC is very close to todays system – considering interchangeability with 23nm systems – the cut off curves are different and calibration by CAST instead of emery oil.

Next steps include chemical composition investigation both before and after the volatile particle remover.

Discussion on 23 vs 10 nm calibration – emery oil vs soot - important if there is a fundamental change because this will increase PN results. PMP will continue discussions.

**Sub-23 Round Robin**

There is currently no window or attempt to introduce a regulatory framework in the short term – the purpose is to develop a suggested test procedure to monitor the technologies coming to the market. This is to explore the repeatability and reproducibility with the ‘close to the PMP’ system.

* 6 labs in EU, one in Switzerland and one in Japan. Starting Nov – one lab per month JRC in March or April.
* Labs participating : VTT, Bosman, Ford, EMPA, Italy, NTSEL, JRC
* Equipment and fuel shipped on pallets with golden vehicle.
* Vehicle : golden = Opel Astra GDI Euro 6 without GPF. : outlook is no GDI GPF vehicles available on market until nearly mid 2018.
* RR measurement APC 10 and 23nm, SPCS 10nm cut off + CS, AM10 10 nm cut off after lab PMP, TSI 23nm cut off after SPCS, TSI10 10nm cut off after lab PMP
* Evaluate uncertainties of PMP 23 and PMP 10 nm systems.
* Assess need for CS
* Data for evaluation of sub23 fraction of modern engines (labs requested to measure additional vehicles)
* 3 cold and 5 hot WLTCs and one steady speed test (high RPM points) – Ricardo and OICA mentioned that low particle number is more challenging than higher emitters. One of these points are very low concentrations, the different gear/speed combinations are designed to look at different levels of PN emissions. The steady speed is very useful for comparisons.
* JRC requested additional tests to be considered eg -7 deg C room temp for the other vehicles not the golden one to avoid affecting the preconditioning etc – but can be discussed in advance.
* Some question on measuring state of charge but actually charging before test 100%, ideally could be useful to collect the 10Hz driving data and run the driving dynamics indices.
* JRC will visit the labs who request support
* The plan was to run the HD before the LD but the engine was not available in time so this will come afterwards – discussion bilateral OICA / JRC next week to make progress.

**Day 2: Non-Exhaust Particle Emissions**

**Brake Particle Emissions Task Force 1 – Adoption/ Development of a Braking Test Cycle. Theo Grigoratos - JRC**

* WLTP database analysis and comparison with industrial cycles completed.
* First draft cycles on WLTP and LACT completed.
* Includes urban, rural and motorway parts with urban parts dominating as per WLTP database.
* Next steps to determine environmental boundary conditions / inertia / impact of coastdown effect. Still under discussion if time / speed / pressure control to get the temperatures, correct.
* Validation of the cycles – repeatability assessment of dyno and real-world) and round robin reproducibility (assessment on different dynos).
* Round Robin scheduled to start beginning of Dec 2017 and should finish April 2018 – will be 7 labs
* The RR should be contained in TF1 and released to the wider group

 ***“Influence of different process parameters during the bedding in-procedure on the emission behaviour”*** based on a common project from BMW and TU Ilmenau (David HESSE – TU Ilmenau) PMP-45-11

* How does preconditioning (run-in) impact the measured emission levels. Influence of materials, temperature, brake pressure and number of brake events examined. Lifetime of the pads is very long so important that the pad is running in normal conditions. A fast and intense preconditioning might affect the materials and hence particle emissions after. Run in conducted with real world cycles – eg 30 times WLTP approx. 15 hours.
	+ This different preconditioning shows up in surface characterisation differences. Question from PMP whether this has been studied in real world vs preconditioned pads – physically and chemically.
	+ PMP group asked for an approximate quantification of proportion of bedding in emissions compared to stabilised running in order to later decide if should be in or out of the procedure. 60k km typical life, running in here is approx. 600 km.
	+ The term preconditioning here has been used as ‘running in’. Also needs to be determined in the case of a round robin whether a specific preparation prior to testing in each lab is additionally needed.

**Brake Particle Emissions Task Force 2 – brake dust sampling and measurement. Theo Grigoratos JRC**

Task force 2 has a wide range of membership including OEMs, Brake manufacturers and Instrument and brake dyno manufacturers, other Governmental organisations and academia.

Following selection of the test methodology there is comparison of existing systems leading to test rig configuration selection and definition of testing parameters. Then will move to validation. TF has common understanding that particles need to be measured / sampled that is representative of the real world rather than characterised immediately at the generation point. PN, PM10 and PM2.5 are of interest.

Summary report to PMP expected during Q1 2018 or PMP-47.

**Selection of the most suitable sampling method and the most suitable methodology for Brake Wear Particles Measurement and Characterization**

* PMP-45-12 Presentation on ***“Frictional couple emissions: Evaluation procedure from the REBRAKE Project”*** based on the FP7 Project REBRAKE organized by BREMBO
* Characterisation using 47mm QC filters for PM. PM10 measured – coarse fraction dominates. Approx half or more than half of the mass lost from pad and disc was measured as PM10. Next steps review 3 stage impactor for PM1, PM2.5 and PM10. QC filters used because additional analysis was being performed.
* Testing based on SAE J2707 with some modifications. Car tested on the road on a summer day, stops grouped by energy content and initial disc temperature. Lowest deceleration is 0.16g, note extreme braking events are characterised as 0.17g upwards so this study focussed on extreme braking events rather than normal driving.
* The tested friction material had very bad wear - 44mg/km PM10 emissions. Higher than seen in literature to now. The new pad and disc on the vehicle, driven for 1000 km normal driving and then started 1000 km of the road test. Then disassembled one pad / disc and mounted in the dyno, ran test procedure twice and then measured the particle emissions. Results are highly material and test cycle dependent.
* [www.rebrake-project.eu](http://www.rebrake-project.eu) and www.lowbrasys.com

***“Feasible Methodology for Brake Wear Particles Measurement and Characterization”*** based on the results of the JARI Research Project (Japan Automobile Standards Internationalization Centre (JASIC)) (Dr. Hiroyuki HAGINO – JASIC)

* Hypothesis of brake particle emission mechanism and characterisation of uncertainties. Proposal that test methodologies should correlate to wear mass. Comparison of sampling / measurement status for various organisations. For JSAO, PM is the highest priority because of links to WHO Air Quality guidelines.
* JARI recommendations and conclusions from the study
	+ Low flow rate (<2.5m3/min) reduces uncertainty for PM and PN.
	+ Sampling point 1.5 and 2.5 m – no influence on particle size
	+ Good correlation between PM and PN behaviour on simulated city cycle
* JSAE will complete JSAO standard by end 2019
* 4 labs tested NAO disc using existing brake dynos and simulated WLTC. Repeatability showing error +/- 50% or more on both mass and number.

**PMP-45-15 Presentation on *"Sampling Ducts and Design Considerations for Brake Emission Measurements using Inertia Dynamometer Testing"* from LINK and TSI (Carlos AGUDELO – LINK Engineering)**

* If a test is not repeatable, it is only an anecdote (Nature –weekly journal of science)
* It is not about knowing more – it is about putting together what we already know.
* Challenge 1: continuous data recording
* Challenge 2: variability
* Challenge 3: air handling (including coagulation)

Discussion / Proposal for the Work Structure:

* What do we want to measure ? emission metrics, indexes (km or by kg, vehicle or fleet)
* Which particle size ranges ?
* Then look at potentially 3 work packages on air handling / minimum spec for PMS / calibration uncertainty and sign-off
* At this stage excluding commercial vehicles, toxicology and regulation / rulemaking
* Link proposal is to consider testing equipment as an upgrade to existing brake dynos – presentation includes examples of do’s and don’ts.
* Discussion whether a single set up can handle best measurement for PN and PM10 in terms of losses, coagulation etc. Brakes particles are more solid which is easier but the size range is a lot wider than for exhaust emissions nanoparticles to 2.5 microns. Losses dependant on sizes.
* Request for data sharing on GSD etc within task force
* Alternative measurement setups discussed as way of correcting for losses – disadvantage is increasing complexity. Task force will continue this discussion topic.

**PMP-45-17 Presentation on *"sampling system for brake dust particle emissions"* and *“Particle emissions from different types of brake pads”* from TU Ilmenau (David HESSE – TU Ilmenau)**

 Reporting on progress in developing CVS 2nd generation

**PMP-45-13 Presentation on *"* *Analysis of influence parameters by sampling of brake dust particle with a constant volume sampling system”* from the on-going PN – PM measurement campaign on a common project from AVL and TU Ilmenau (Dr. Thanasis MAMAKOS – AVL)**

* Reporting on progress from experimental campaigns focussing on PN. Next steps campaign on PM, electrical (ELPI and DMS500) and thermogravimetric. The CPC was calibrated to R83 requirements.
* Compared modified AK Master to WLTC-B. WLTC-B’s were employed as run in procedure – PN dropping even after 16 repetitions.
* No evidence of volatiles over WLTC-B with measured mean # diameter 110-160nm. DMS500 overestimated at all concentration levels - need transparent inversion algorithms and calibration. Low background level important for PN measurements
* 120-80 km/h decels showed nucleation mode appearing with high mean braking pressures especially with ECE and ECE copper free pads. Large part of nucleation is solid particles.
* Sub 10nm particles – sub 5nm are produced by some braking events and do not grow. 2.5nm CPC recorded higher concentrations than 23nm COC and 10nm APC and no evidence in DMS500 (>5nm)
* 100-0 km/h decelerations – repeats to raise temperature. Nucleation mode forms for all particles, number concentration increases by factor 4. Particles appear to be solid because survive thermal treatment at 300 deg C (TD at 300 deg C). Nanoparticles appear typically above 150-160 deg C temperatures.
* Some artefacts have been detected at the start of the tests – origin so far unclear. Importance of pad handling and conditioning of sample air etc.
* Conclusions: WLTC solid particles > 100nm, more aggressive braking events bring nucleation mode (non volatile) sometimes peaking below 5nm. Concentrations exceeded full and partial flow CPCs – therefore dilution essential.
* Emission rates from this one ECE conditioned pad,
- 5 mg/km i,e, above EU 6 tailpipe emissions standard
- 5E+9 #/km – approx. 1% of EU 6 tailpipe emissions standard

Discussion whether TD can itself introduce artefacts below 30nm, confirmed that these particles have been seen also without TD. Some participants have seen artefact solid particles from TD under some conditions.

**NEXT STEPS / Recommendations**

Continue TF1 – next steps round robin and then to share cycle with all

Continue work in TF2 to identify the systems and capabilities – will proceed to create work packages to split the tasks (eg as per Link proposal) – expect results or outcomes in March or April 2018. Recommend TF2 continues to look at optimised measurements for each of parameters rather than common method that is sub-optimal for all (eg mass / number)

Therefore propose instead to postpone the next F2F to May 2018

**Marie Curie Activity**

JRC-TU Liminau consortium – workshop with students as observers to the meeting. Discussed on both days. May be a 3 year activity. UN Secretariat had previously confirmed PMP leadership team is allowed to invite academics to participate. PMP agreed to proceed with JRC to brief the students appropriately to ensure the work of PMP is not adversely impacted.

**Tyres**

Requested additional study information

**End of Day 2 @ 16:00H**

**Arrangements for the next meeting**

PMP 46: Proposed Wed 10 Jan 2018, AM ½ day at GRPE 76

~~PMP 47: 25 Jan 2018 2-4pm CET webconf on PMP RR1 report and scope of RR2~~

PMP 48: F2F March in Brussels or Ispra 16-17 May 2018 (this would be closer to REBRAKE on 20th …)