Raw Exhaust PN Counting – Research Areas

For discussion…

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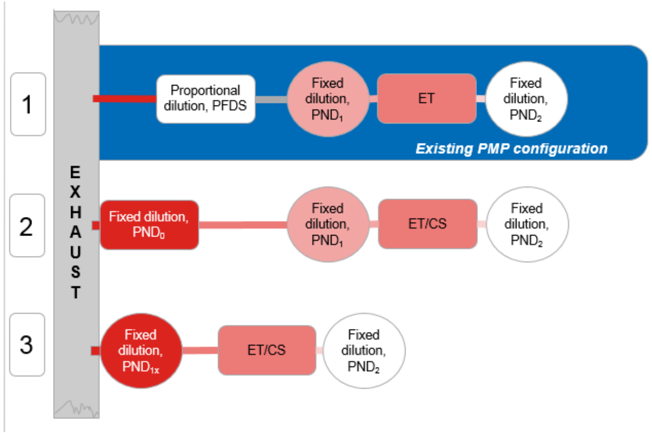
RD15/301701.1

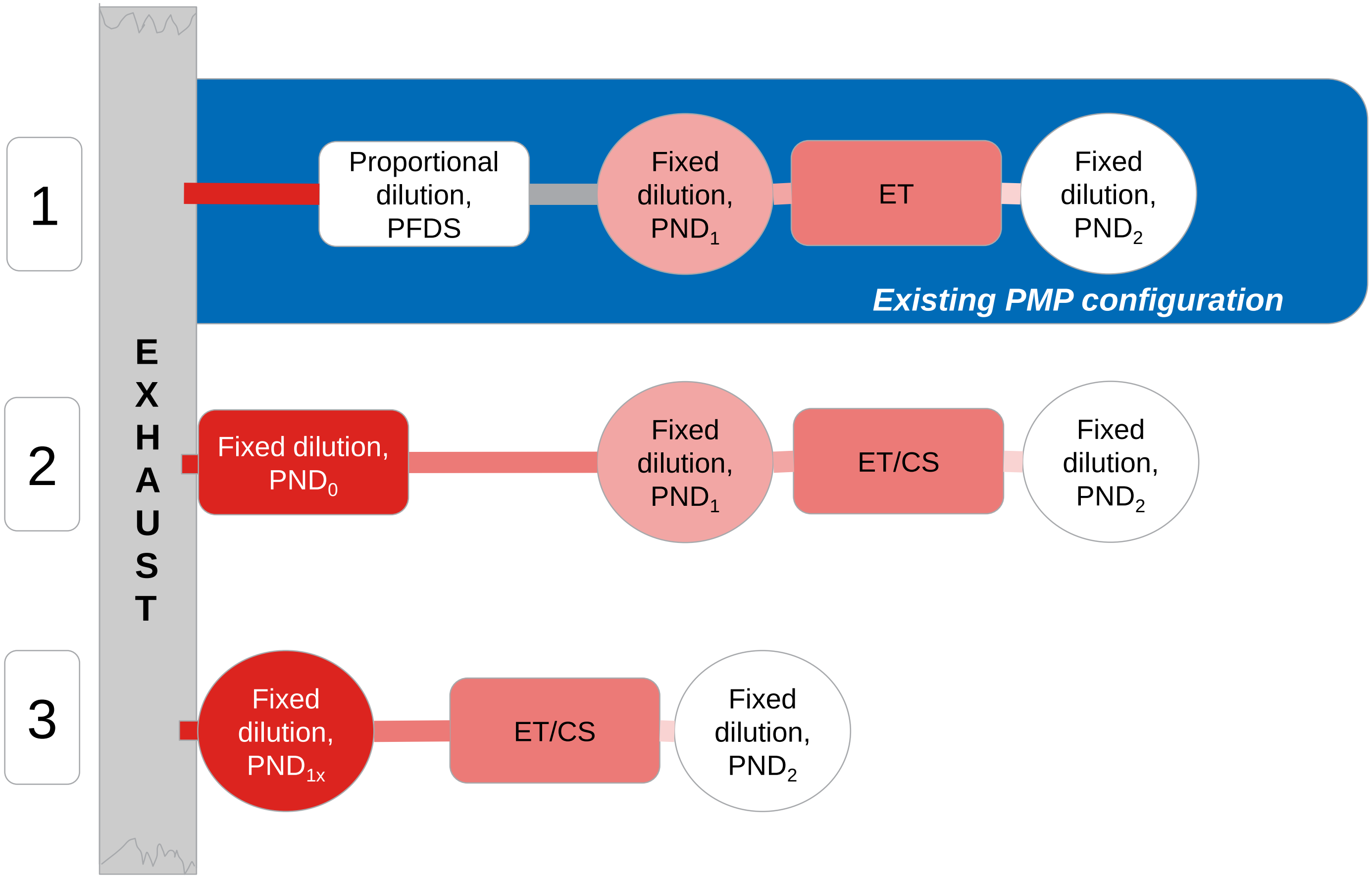
7 October 2015



PN from raw exhaust using fixed dilution

- There is considerable interest in the measurement of PN directly from raw exhaust for both regulatory and development purposes
- Introductions and potential issues with this approach have previously been provided at 35th and 36th PMP meetings, and some constructive comments subsequently provided by AVL
- Experimental investigation of a number of issues related to the use of this approach would be beneficial.
- Relevant topics are:
  - Effects of primary dilution approaches and temperature
  - Particle losses (diffusion, thermophoresis, coagulation)
  - Impacts of pressure pulses on instantaneous and average dilution factors
  - Importance of time-alignment
  - Volatile particle removal: evaporation or catalytic stripper

Possible Sampling Schematics



- Three possible approaches
  1. Existing PMP, with PFDS
  2. Additional dilution, with close-coupled "PND_0"
     - PND_0 could be PFDS at fixed DF
  3. Additional dilution but through wider-range PND_{1x}
- Close-coupled and additional dilution introduce specific changes
  - Residence time at temperature
  - Increased 'thermal stepping'
  - Dilution at very high sample temperatures, or line losses
  - Avoidance of condensation and nucleation
- Configurations could need careful specification

Areas for Investigation

- There are a number of areas that are worth exploring
- These are briefly explored in the following slides

- Primary dilution
- Particle losses
- Volatile particle removal
- Pressure effects
- Time alignment

Primary Dilution

- There are a number of primary dilution parameters that may have significant influence on measured particles
  - Dilution temperature
    - Low vs high
  - Dilution volume
    - Stability of flow and sample; homogeneity
  - Dilution rate
    - Residence time and method of dilution; homogeneity
  - Flow rate into diluter
    - Sample cooling: condensation and/or losses
  - Primary dilution ratio
    - Sensitivity, inhibition of condensation, maximisation of evaporation at PND_1

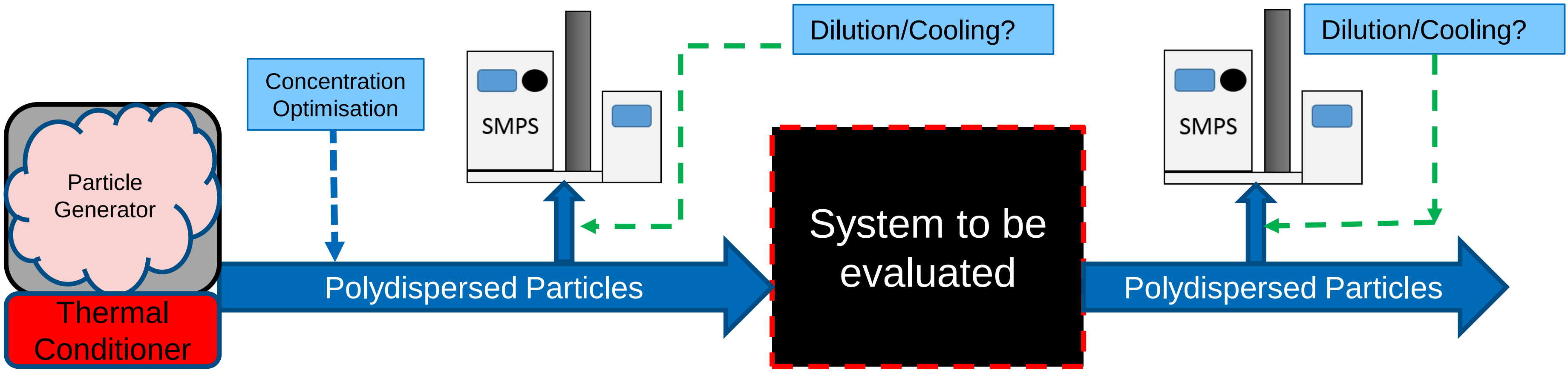
- Experimental Considerations
  - Diesel engine with DPF & SCR; Gas engine
  - Steady state testing, 3 different modes with different semi-volatile / solid PN mix
    - Stabilised hot idle, moderate load, passive regen (>550°C DPF inlet)
      - Various exhaust chemistries
  - Commercial PN systems in parallel at fixed operating conditions along with particle sizer (no volatile removal). Include CS-based system?
  - Alternative primary dilution (extremes): heated ejector, PFDS and CVS
    - Assess inherent differences under
      - Proportional sampling (CVS and PFDS)
      - Fixed dilution ratio sampling (PFDS ejector) – 10:1?
  - Heated ejector to explore primary dilution temperature effects (‘ambient’ to 350°C) with matched PMP system downstream
    - Split flow post ejector to evaluate higher in-flow rates and reduce residence time
  - Explore impacts on solid PN and particle size distributions downstream of PND_0 approaches, identify problem areas for further research

Particle Losses

- Particle losses to be explored
  - Coagulation
    - High concentrations before, during or after the initial dilution process; residence time
  - Thermophoresis
    - Large temperature gradients before, during or after the initial dilution process
  - Diffusion
    - Large surface to volume ratios during sampling; residence time

- Consider ejector and PFDS
- Likely to be a lab-based steady using stable high concentration non-volatile particle generator
  - Concentrations to be variable
- Establish upstream particle size/ number etc using sensitive particle measurement system (SMPS?)
  - Parametric study of operation
    - Flows, temperature settings etc
    - Establish impacts of operating parameters on measured downstream size distributions

Particle Losses Investigative Phase



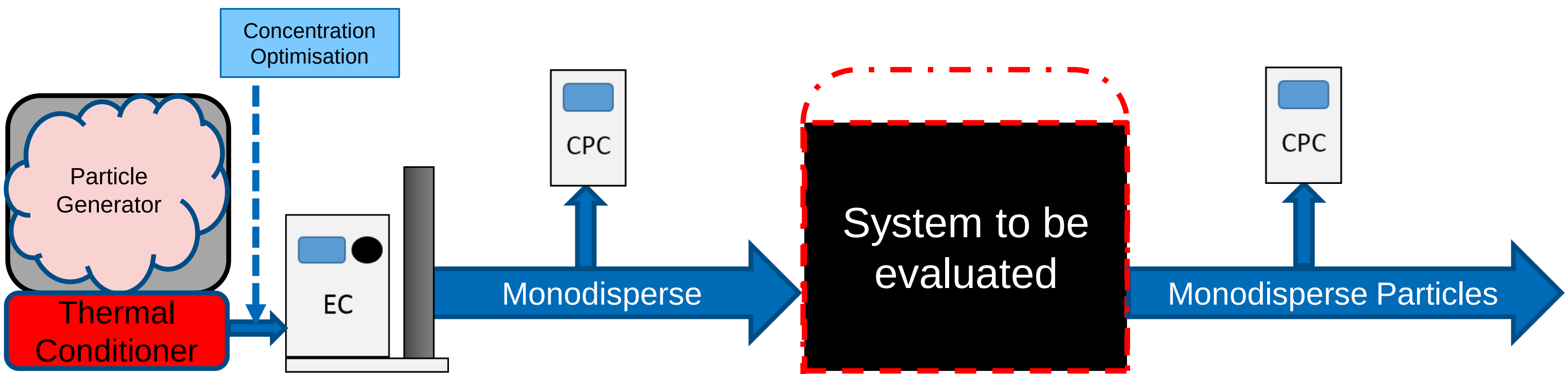
- Soot Aerosol used as closer to chemistry of vehicle emission particles.
- Determine the affected size range of particles lost in the system to focus on.
- Setup could be used in Evaluation phase if only looking at overall particle size distribution at the various investigative parameters.

Particle Losses Evaluation Parameters

- Establish particle sizes of interest
- Investigate the impacts of operating parameters on measured downstream particle size or distribution.

1. Coagulation – Range of initial Particle concentrations
2. Thermophoresis – Range of Temperature gradients
3. Diffusion – Dependent on system tested

Particle Losses Evaluation Phase



Variables to be investigated at Particle Sizes of interest:

- **Temperatures**
- **Flows**
- **Dilutions**
- **Residence time**

Live counting method at specified particle sizes of interest is better at this stage due to the more accurate counting ability the CPCs have over scanning mode.

Particle Losses and Particle Removal – Catalytic Stripper

- Particle losses to be explored
  - Coagulation
    - High concentrations before, during or after the initial dilution process; residence time
  - Thermophoresis
    - Large temperature gradients before, during or after the initial dilution process
  - Diffusion
    - Large surface to volume ratios during sampling; residence time

- Consider PN system with CS and with ET
  - Evaluate minimum inlet concentrations required for reliable measurement at the PNC
  - Compare with typical tailpipe concentrations from gas and diesel applications
- Are greater CS losses an issue for reliable measurements?
- Too few solid particle counts after CS for good measurement confidence?
  - Is there a trade off between solid penetration and volatile removal?
    - Possibility to use CS as 1st stage dilution as well as volatile removal?
  - Advantage of particle removal without adding diluent
- Experimental investigation largely as for losses
  - Include semi-volatile particle removal
  - More severe challenge than n-C40 required?
- Some issues may have already been explored within PMP and PN-PEMS studies…

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Exhaust Pressures

- Exhaust pressures may impact instantaneous dilution ratios
- Evaluation during real engine testing, but with specially constructed cycle
- Measurements of particles referenced to tracer gas

- During engine testing, undertake various vigorous transient excursions from a steady state baseline that will generate large and frequent pressure pulsations
  - Variable pulsation magnitudes
  - Variable frequencies
- Compare downstream particle concentrations from PND0 options: PFDS and ejector operating in fixed dilution mode, with a reference CO_2 signal
- Evaluate impacts of transients on gas v particle dilution for different dilution approaches
- Establish deviations from gas dilution in various systems
- Establish acceptable deviation

Gas Engine Time-alignment

- With gas engines (non-GPF) the peak and range of PN concentrations are greater than post-DPF diesel
  - Inaccuracies in time-alignment will have a greater impact and the outcome of the calculation will be much closer to the limit value
  - Alignment of gas engine signal needs to be accurate
  - Largest issue on time-alignment anticipated to be transport delays

  - During engine testing, compare conventional exhaust measurement approaches with pitot tube situated very close to take-off point for raw PN sampling
    - To include CVS as reference, with transient cycle engine testing
  - Compare flow measurements from various methods
    - Assess differences
    - Steady states and transients
  - Compare calculation of PN emissions from PND_0 options using other flow measurements, with the PN data from the pitot flow meter as reference
    - Assess magnitude of differences in context of known PN system to system differences

