Introduction
PN Counting Directly From Engine Undiluted (Raw) Exhaust Gas

35th PMP Meeting

4th March 2015

GRPE PMP Current Topics

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- Light Duty Vehicles
  - Sub-23nm solid particles emitted from some vehicles
    - e.g. low temp combustion (HCCI), catalysts, metal oxides (oil)
  - Guidelines on how to measure sub-23 nm particles
  - Further investigations on how to measure
- PN measurement during Light Duty Active Regeneration
  - Issues related to the measurement of particle emissions during filter regeneration to be addressed with or without experimental programs
- Experimental investigation on particles from NRMM
  - Issues related to the measurement of particle emissions considering the wide power range and the test cycles
  - Guidelines on how to measure PN
- Non-Exhaust Particle Emissions (Brakes, Tyres, Clutch etc)
  - Summary of Literature study on non-exhaust emissions
  - Identification of issues to be further investigated
- Particle Number System calibration procedures

PMP ToR re PN Counting – an extract

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■ Particle Number (PN) exhaust measurement

– Existing scope of PN measurements to be adapted to technical progress as appropriate.

- Light Duty Compression Ignition Vehicles
- Heavy Duty Compression Ignition Engines / Vehicles
- Light Duty Positive Ignition Direct Injection Engined Vehicles
- Heavy Duty Positive Ignition Direct Injection Engines/ Vehicles

– Extension of scope

- Investigate Particle Number measurements for Non-Road Mobile Machinery exhaust emissions. Prepare report for GRPE
- Determine whether light duty diesel regeneration measurements can be accurately, reliably, repeatibly and reproducibly made using PMP equipment with d50 = 23nm.
- Investigate particle number emissions from Positive Ignition Direct Injection engined vehicles during regeneration when vehicles with such technology are available on the market
- Engine Dyno Raw exhaust PN measurements for heavy duty for use at Type Approval

PMP Report to GRPE : Geneva Jan 2015

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- New PMP WG task proposed

- Measurement of PN directly from the engine exhaust pipe as alternative to measuring from diluted exhaust using :-
  - CVS
  - Partial flow dilution tunnel used for the PM mass measurement
    - Sampling PN from the PFDS can interfere with the measurement of the PM mass and the accuracy / reproducibility of the proportional sampling
      - Can require significant additional time for optimisation / adjustment
      - PFDS performance for instantaneous real time proportionality can be affected by pressure changes at the PM sampling point during transient test cycles
      - Problems locating the PM and PN systems in size limited engine test cells
        - » Specific locations for the PFDS to meet regulations
  - Unlike PM Mass, PN is a real time measurement method and therefore has potential to be applied to the exhaust sample directly

- Topic will be introduced and progressed at the next PMP WG meeting (Brussels 4th March 2015)

Requirements of EURO VI for Particle Counting

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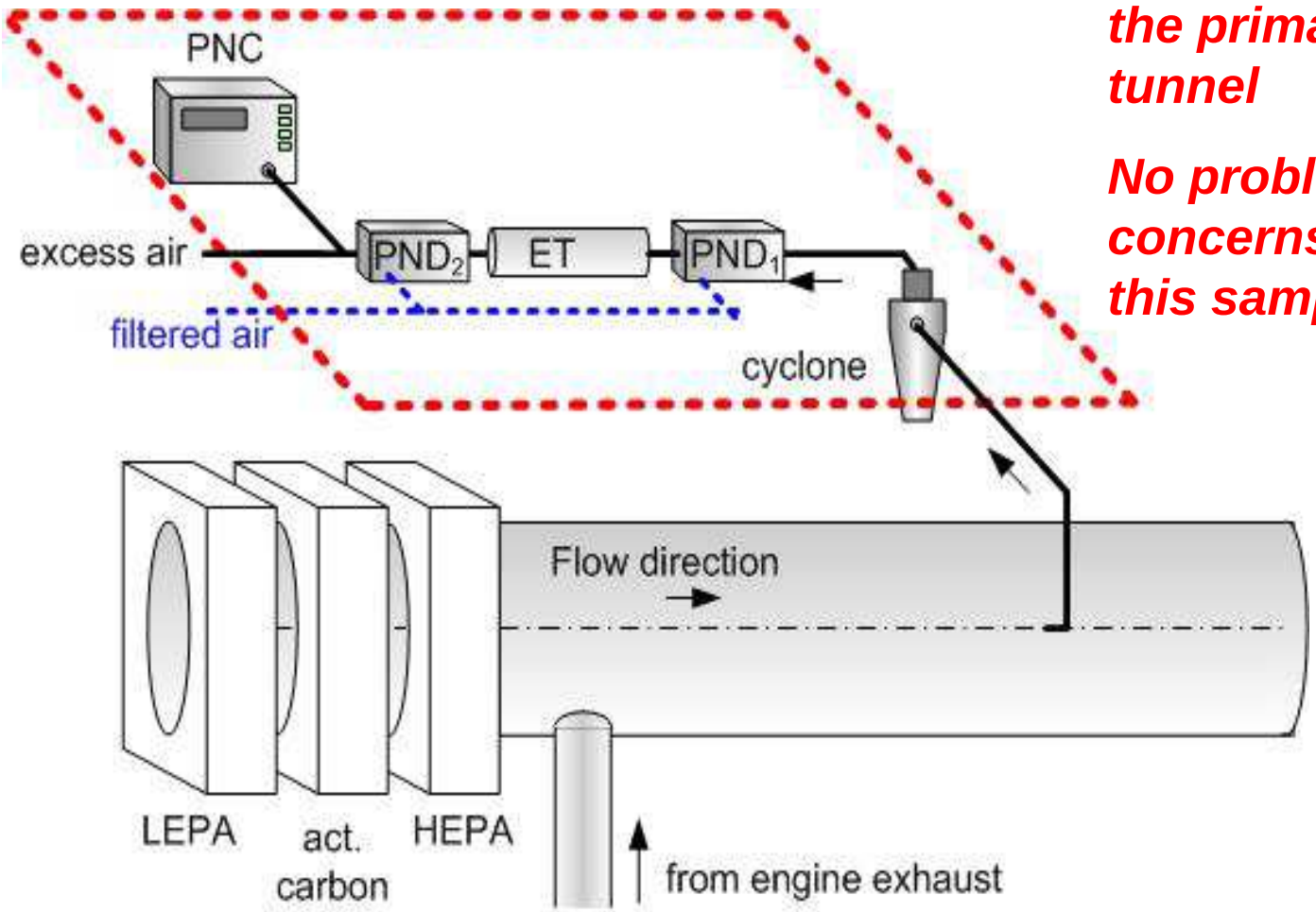
- PFDS systems for PM mass are accepted for EU HDD certification for all test types
- EURO VI has set a limit for Particle Number (PN) for the WHSC and WHTC test cycles
- PN must be measured from diluted exhaust, either from a CVS or from a PFDS
  - The control of the PFDS dilution factor must be adjusted or compensated for the diluted sample extracted for the PN counter
    - *Accuracy of proportional sampling must be unaffected by PN measurement*
    - *For PFDS sampling, the PM mass measured must be corrected for the amount of diluted exhaust extracted by the PN counter*

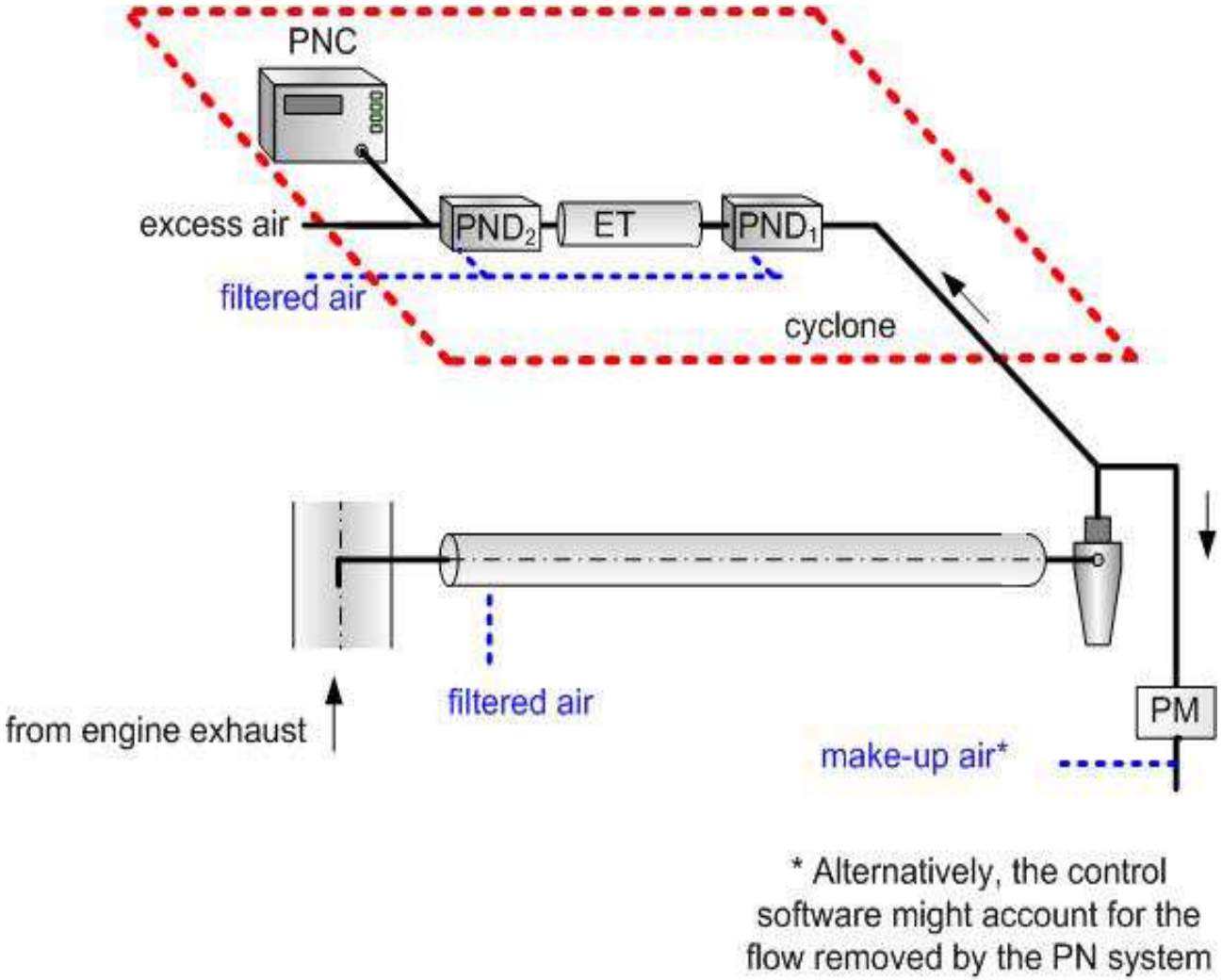
Sampling from HDD CVS Schematic



PN sample taken from the primary dilution tunnel

No problems or concerns reported with this sampling schematic

Sampling from PFDS for HDD Engines

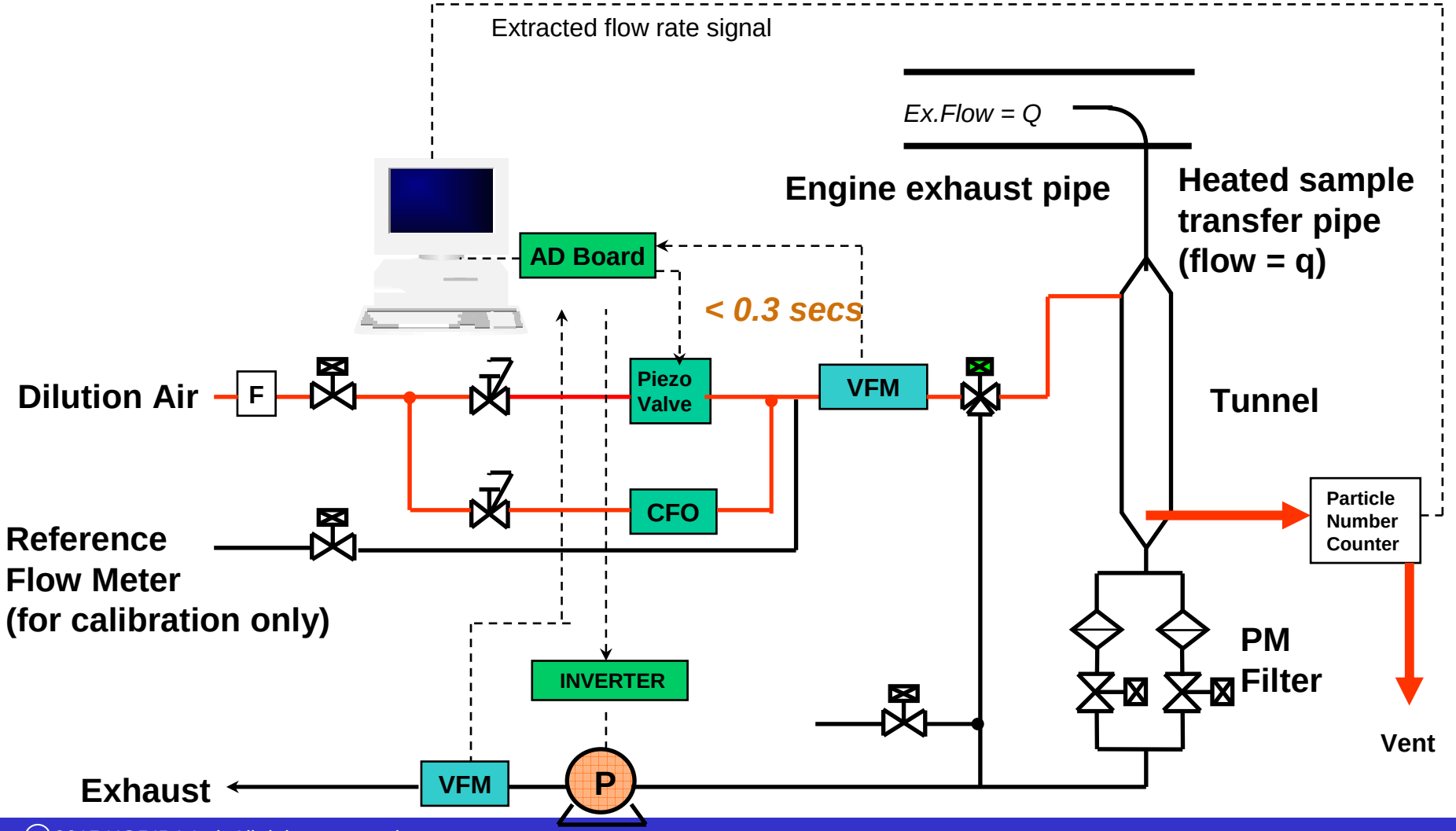


Partial Flow Dilution System requires modification for connection of the Particle Number Counting System

This method has created problems and concerns for some users as indicated in the introduction

Correction of PFDS for PM Extracted Flow

- **Signal from the PN counter to the PFDS Controller to indicate the amount of diluted exhaust extracted for PN counting.**
  The accuracy of the PN System flow measurement / signal should be less than 0.1% of total diluted exhaust flow (e.g. 47 mm filter @ 60 lpm = 60 cc/min)



Correction of PFDS for PM Extracted Flow

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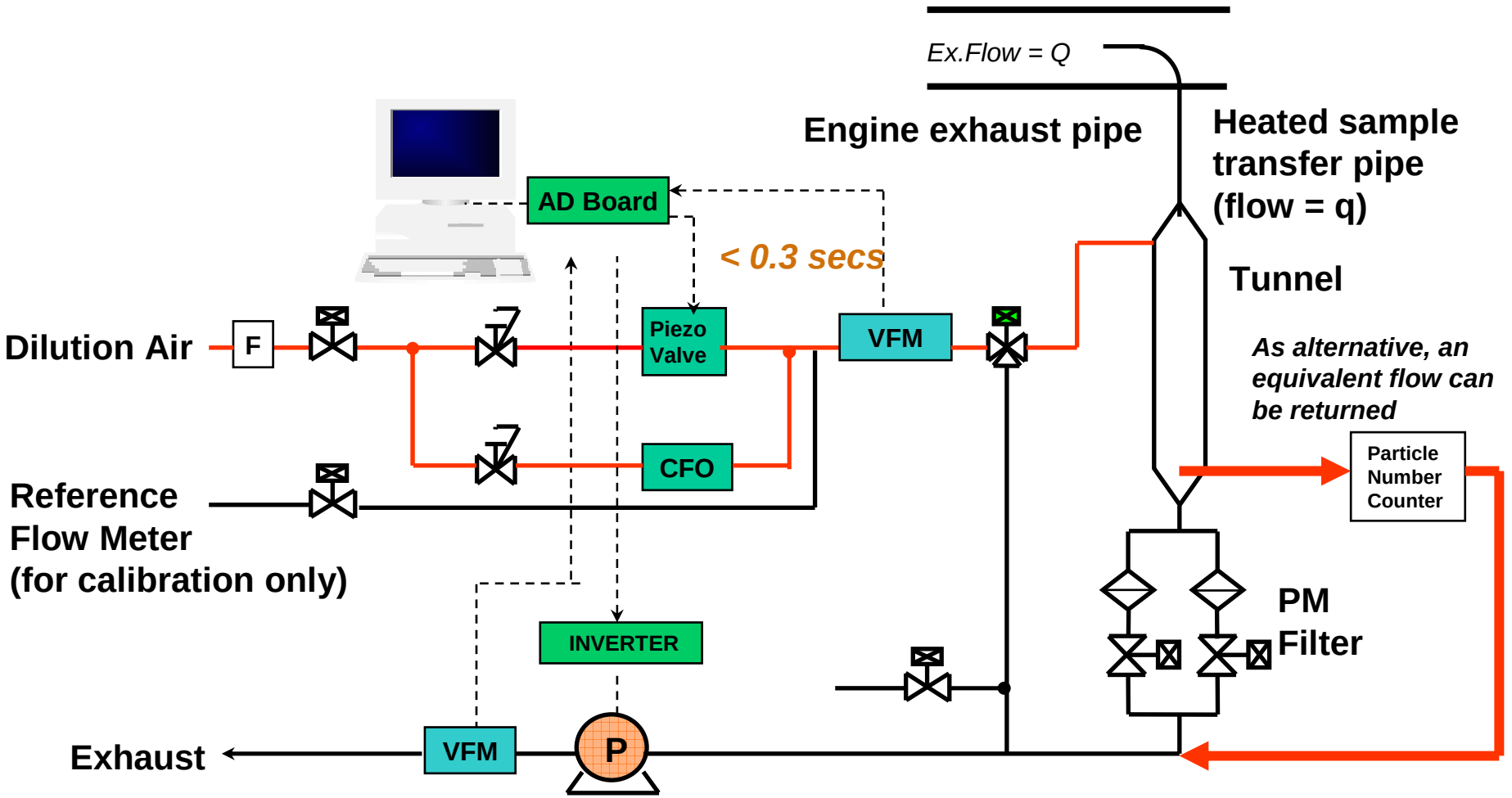
- **Extracted diluted exhaust can be returned to the PFDS or an equal flow rate can be returned**
  The accuracy of the flow returned should be less than 0.1% of total diluted exhaust flow (e.g. 47 mm filter @ 60 lpm = 60 cc/min)



Correction of PFDS PM Mass

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- The PM mass collected on the filter must be corrected for the flow rate extracted from the PFDS for the PN Counter
- The formula for the correction is as follows :-

$$m_{PM,corr} = m_{PM} \times \frac{m_{sed}}{(m_{sed} - m_{ex})}$$

where

$m_{PM,corr}$ = mass of particulates corrected for extraction of particle number sample flow, g/test,

m_{PM} = mass of particulates determined according to Annex 4B paragraph 8.4.3.2.1 or 8.4.3.2.2, g/test,

m_{sed} = total mass of diluted exhaust gas passing through the dilution tunnel, kg,

m_{ex} = total mass of diluted exhaust gas extracted from the dilution tunnel for particle number sampling, kg,

HORIBA SPCS flow compensation for R49

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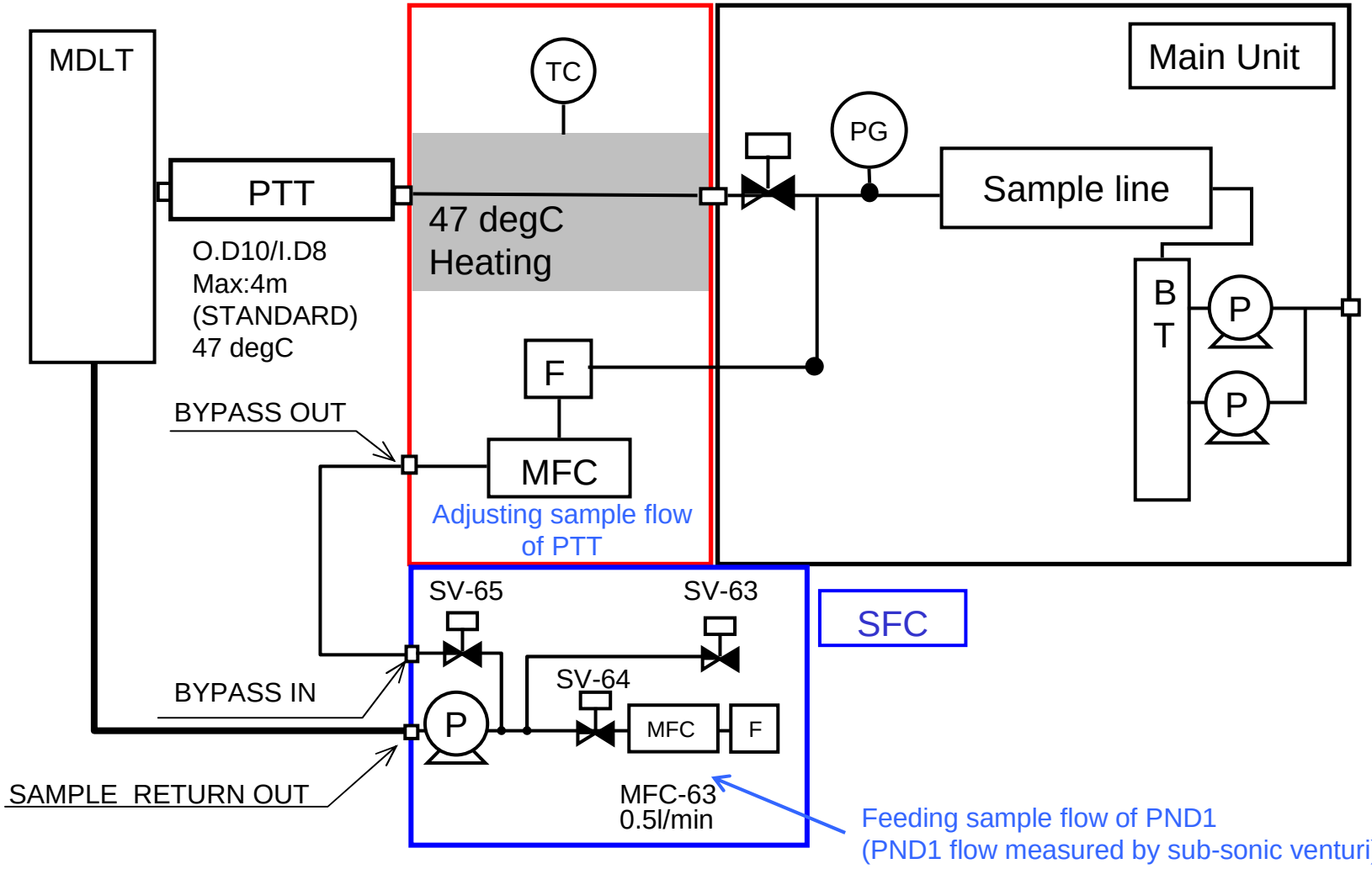
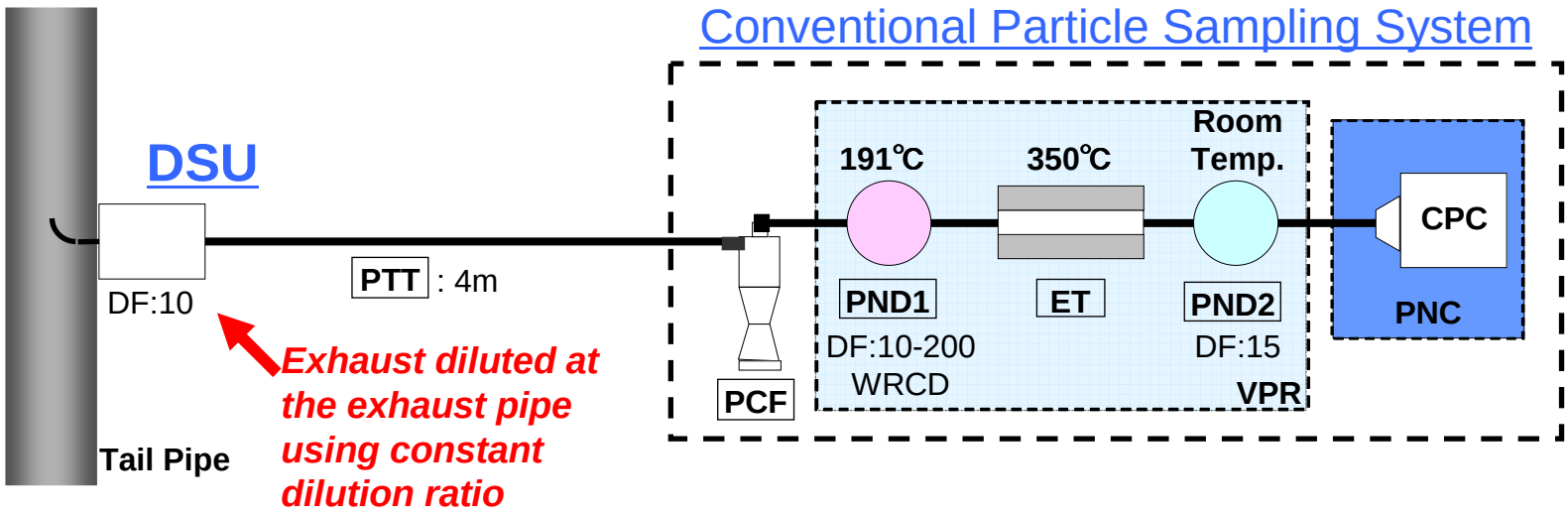
MEXA-2300SPCS

Note : The length of the PTT is limited by the residence time (less than 3s) and Reynold Number (<1700)



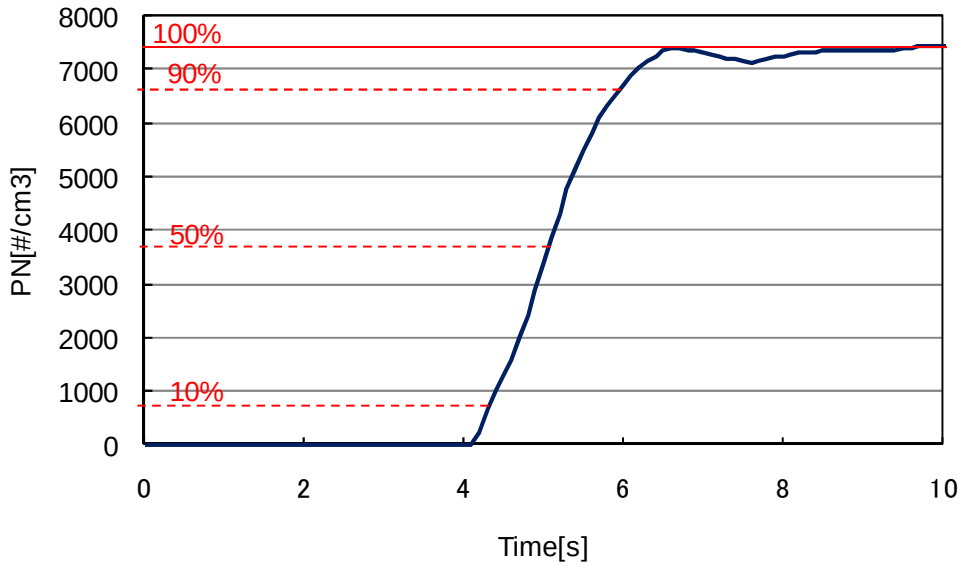
System Configuration for Direct PN Measurement from exhaust



- Sample gas is introduced into particle sampling system via direct sampling unit (DSU), without other dilution systems.
- DSU works as a pre-diluter to reduce sample temperature and concentration, and also restricts sample flow with making particle sampling system inlet pressure low enough.
- Diluted sample flow rate meets the specifications for residence time and Reynolds Number

Real Time Transient Response Time

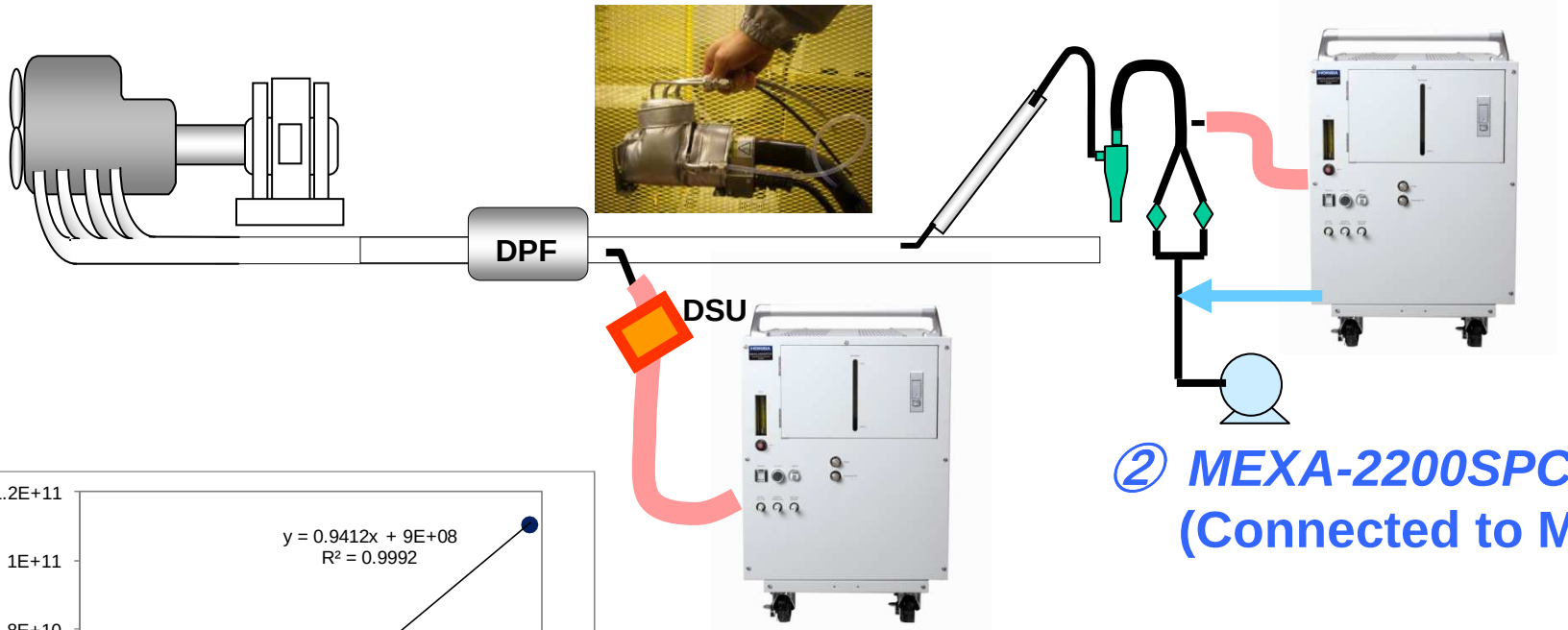
System response with DSU when HEPA filtered air was switched to raw exhaust gas at the sample inlet



■ System response

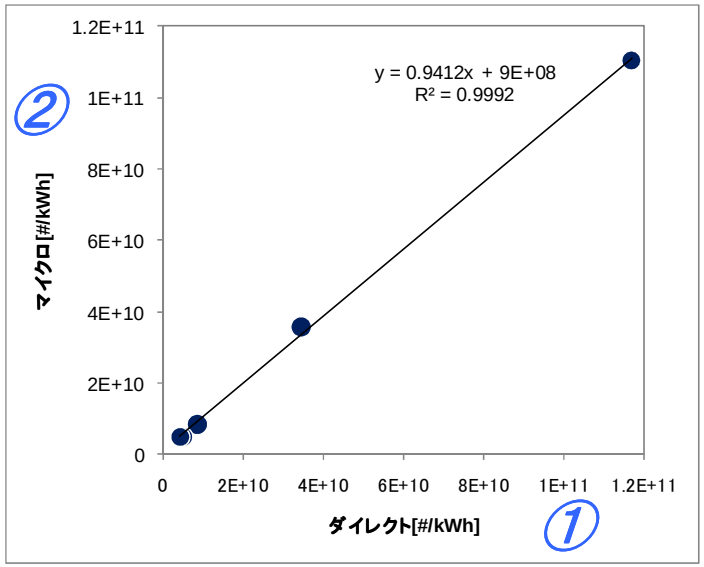
- Response time (t_{90}) : 6.0 s (Not to exceed 10 s)
- Rise time (t_{10}-t_{90}) : 1.6 s (Not to exceed 2.5 s)
- Transformation time (t_{50}) : 5.1 s
- Meets dynamic response requirements for raw gas sampling

Raw and Diluted Exhaust Measurement



② MEXA-2200SPCS
(Connected to MDLT)

① MEXA-2100SPCS
(Connected to tail pipe)



- PN of raw and diluted exhaust gas measurement were compared (ETC)

⇒ Good correlation

Summary

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- Is exhaust flow proportional dilution (CVS or PFDS) necessary for solid particle number concentration measurements ?
  - Formation of the solid particles ?
  - Reproducibility of the test measurement ?
- Direct PN sampling from raw exhaust is technically feasible and is commonly used for engine PN emission R&D and calibration
- Data taken during the original HD PN Round Robin program showed reasonable correlation to the diluted exhaust methods
  - http://publications.jrc.ec.europa.eu/repository/bitstream/JRC60870/pmp%20hd%20validation%20exercise%20final%20report.pdf
    - Section 6.3
- Direct PN sampling is currently being proposed, tested and the data evaluated for RDE-LDV PN emission measurements against the legislative PMP method from LD CVS

Thank you
and
any questions ?

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