Solid particle penetration calibration for the VPR in the solid particle counting system (SPCS)

Ichiro Asano, Montajir Rahman Horiba Ltd. 2 Miyanohigashi, Kisshoin, Minami-ku, Kyoto, Japan
Qiang Wei, Mike Akard Horiba instruments Inc. 5900 Hines Drive, Ann Arbor, MI 48108, USA

Summary

Horiba solid particle counting system (SPCS) is an instrument measuring solid particle number emission from gasoline and diesel vehicles. It is very sensitive, has a wide dynamic range, and is able to be used with vehicles having different technologies and after treatment devices. The instrument is sensitive to measure solid particle number emissions for post-DPF.

To ensure that the instrument works properly, Particle Measurement Program (PMP) in Europe recommends that the solid particle penetration on the volatile particle remover (VPR) in the instrument should be calibrated or verified once a year. Mono-disperse solid particles with 30, 50, and 100 nm diameters are recommended for the penetration test.

Mono-disperse and poly-disperse Sodium Chloride (NaCl) particles were used to calibrate solid particle penetration for the VPR in a Horiba prototype SPCS in this study. Prior to the calibration, dilution ratios on the SPCS are verified carefully with a Hydrocarbon analyzer. Then, NaCl poly-disperse aerosols with stable concentrations are sent into the VPR. Based on poly-disperse aerosols, the overall penetration are measured larger than 95%. Geometric standard deviations from the raw and diluted by the VPR are within ±1.5% difference. Thus, shapes of size distributions aren't changed after dilution. Geometric mean diameters shift a little and in average ±5% after dilution. Therefore, the VPR doesn't change the aerosol characteristics after being diluted and heated up to 320 °C.

Penetrations with mono-disperse solid particles achieve PMP recommendation. Minimum solid particle penetrations for 30, 50, and 100 nm are found at 78%, 91%, and 81.3% respectively. At 30 nm, penetrations show a big variation with dilution ratios. One of reasons may be due to higher sample flow to reduce diffusion losses in the system; and the other reason may be due to uncertainties induced by low detection efficiency at 30 nm for the condensation particle counter (CPC).

It may be a good practice to evaluate the penetration of the VPR by measuring upstream and downstream size distributions although it isn't recommended by PMP at this moment. It gives more information about the VPR performance than the mono-disperse particle. In the meantime, the poly-disperse aerosol is easier to be generated and handled than the mono-disperse aerosol.

HORIBA
Automotive Test Systems

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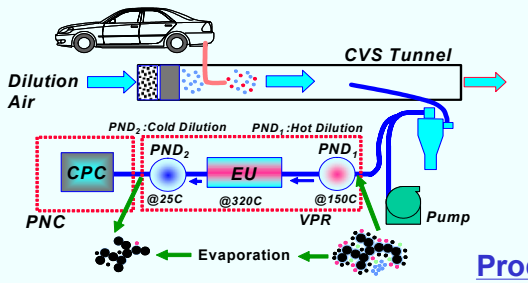
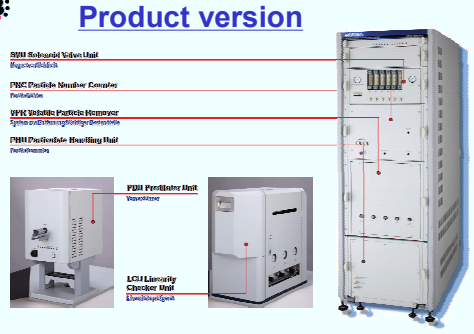
1. Solid particle counting system (SPCS)



Prototype

Product version



- Horiba SPCS is designed based on the PMP recommendation.
- Two Wide Range Continuous Diluters (WRCD) are used as PND1 and PND2.
- The prototype SPCS has been tested in many laboratories. Its performance achieves the PMP recommendation.
- The production version of the SPCS (MEXA-1000SPCS) will be launched soon. It can take sample from raw exhausts if a pre-diluter unit (PDU) is chosen.

2. Experimental setup

Ploy-disperse aerosol

- Temperatures on the SPCS
  - Sample flow: 47 ° C
  - Dilution air for PND1: 150 °C
  - Mixer for PND1: 150 ° C
  - Evaporation unit (EU): 320 ° C
- Aerosol and generator:
  - Horiba Linearity Check Unit (LCU)
  - Sodium Chloride (NaCl)
  - Pure water
- SMPS for size distribution measurement
  - TSI 3081 DMA
  - TSI 3025A CPC; running at high flow
  - 10 lpm sheath air; 1.0 lpm sample flow; 1.0 lpm mono-disperse aerosol; 120 s up-scan
  - At least 5 scans for upstream and downstream respectively

Mono-disperse aerosol

Temperatures on the SPCS
- Sample flow: 47 ° C
- Dilution air for PND1: 150 ° C
- Mixer for PND1: 150 ° C
- Evaporation unit (EU): 320 ° C

Aerosol and generator:
- Horiba Linearity Check Unit (LCU)
- Sodium Chloride (NaCl)
- Pure water

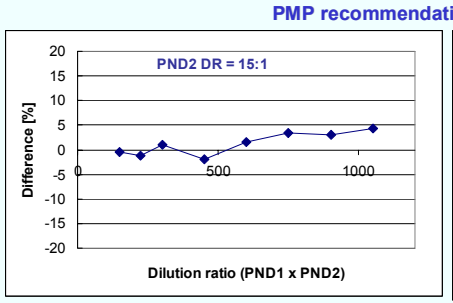
DMA
- TSI 3081 DMA
- 10 lpm sheath air; 1.0 lpm sample flow; 1.0 lpm mono-disperse aerosol
- Particle size: 30, 50, and 100 nm

CPC for number concentration
- The CPC in the SPCS
- TSI 3010D
- Cutoff size: 23 ±3 nm
- 5 minutes data record for upstream and downstream respectively

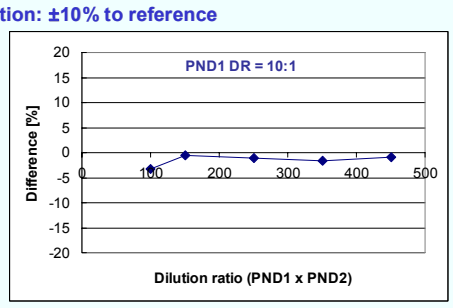
3. Dilution ratio verification

- Prior to the penetration calibration, dilution ratios are verified.
- The SPCS runs at the normal test condition. Thus, temperatures for sample flow, PND1 dilution air, the PND1 mixer, and the EU are controlled at 47 °C, 150 °C, 150 °C, and 320 °C respectively.
- Propane span gas and a hydrocarbon analyzer are used for the verification.
- Dilution Ratio = (PND1 DR) x (PND2 DR)

PMP recommendation: ±10% to reference

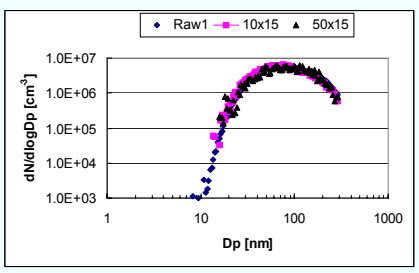


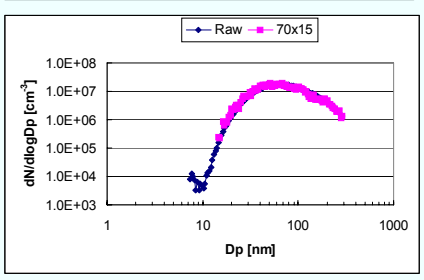
PND2 DR was run at constant (15:1); PND1 DRs were changed.

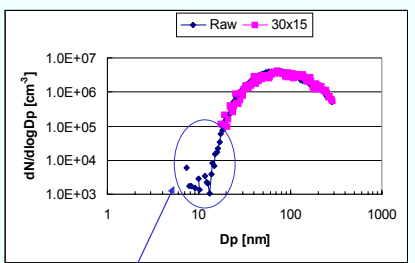


PND1 DR was run at constant (10:1); PND2 DRs were changed.

4. Size distributions with poly-disperse

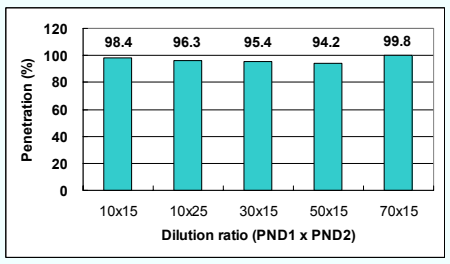






Low concentration in the raw size distribution. They are too low to be detected after dilution.

5. Penetration with poly-disperse



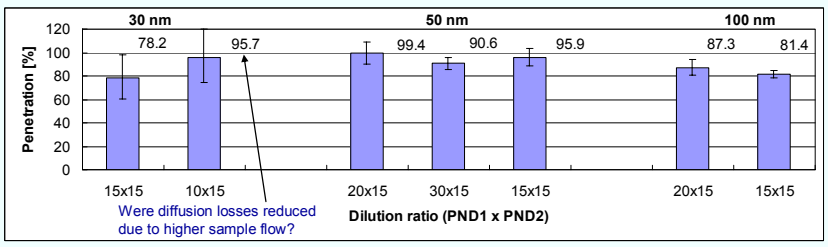
- Size distributions measured from SPCS show good agreement on Geometric Mean Diameter (GMD) and Geometric Standard Deviation (GSD) by comparing to Raw.
- No significant difference on GMDs and GSDs between Raw and Diluted.
- Thus, shapes for size distributions are no change.

- Assume that log-normal size distributions are for raw and diluted aerosols.
- With a poly-disperse aerosol, the raw concentration should be high enough to get accurate diluted size distributions.
- The VPR in the SPCS shows high solid particle penetrations with poly-disperse particles.

	GMD [nm]	GSD	Total number* [cm-3]
Raw 1	79.7	1.79	4.138.E+06
10x15	74.4	1.80	4.071.E+06
50x15	80.7	1.81	3.896.E+06
Raw 2	76.7	1.77	2.600.E+06
30x15	82.1	1.78	2.480.E+06
Raw 3	70.1	1.76	1.113.E+07
70x15	66.3	1.77	1.111.E+07

* --- Corrected with dilution ratios

6. Penetration with Mono-disperse



- EU PMP proposed that solid particle penetrations with diameters 30 nm, 50 nm, and 100 nm for the VPR should be larger than 50%, 55%, and 60% respectively.
- PMP recommends that the cut point (50% detection efficiency) for the CPC is 23nm. And, the detection efficiency for 30 nm particles is about 80% for the CPC based on the PMP recommendation. Thus, the solid particle penetration at 30 nm may not be a good parameter to characterize the performance of the VPR.
- CPC 3010D in the SPCS is used to measure particle concentrations. It may cause big uncertainties for calibrating penetration at 30 nm. A higher detection efficiency CPC for 30 nm could be used for the calibration. However, it makes calibration more complicate.
- SPCS achieves the PMP recommendation.

Conclusions

- The SPCS VPR shows accurate dilution ratios. It is recommended that the dilution ratio should be verified prior to the particle penetration calibration.
- The SPCS VPR presents over 95% penetrations for solid particles based on poly-disperse aerosols. Size distributions measured downstream of the VPR have the same characteristics as raw aerosols.
- Minimum solid particle penetrations by 30, 50, and 100 nm mono-disperse are 78%, 91%, and 81.3% respectively. It achieves PMP recommendation.
- The penetration calibration with a poly-disperse aerosol isn't recommended by the PMP currently. It gives overall penetration, geometric number mean diameter, and geometric standard deviation, etc. Thus, multiple characteristics are obtained for the VPR with the poly-disperse aerosol calibration.