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PN and PM measurements for brake wear particle emission

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Requirements for common brake particle measurement

- There are some open questions and topics in the PMP meeting.
- JARI research is working to establish a worldwide harmonized measurement methodology for brake particle emission and to collect as much data as possible.

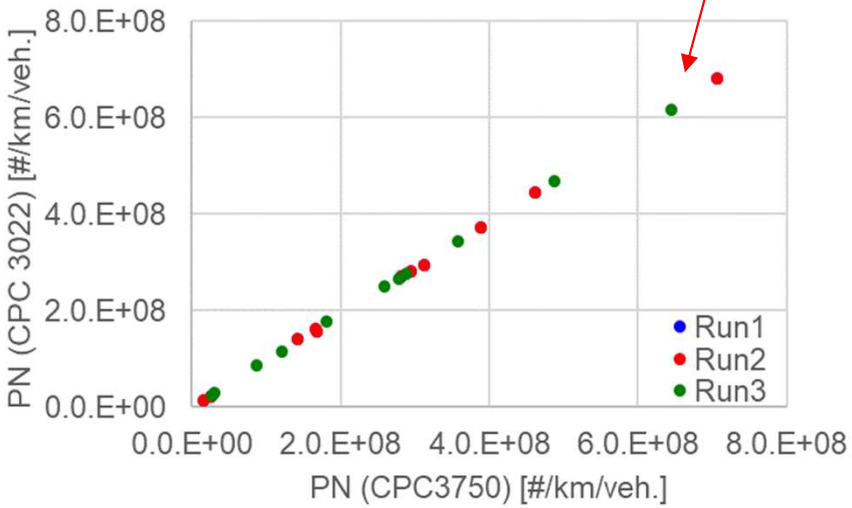
- **SOAK TIME and BRAKE COOLING:**
  Demonstrating the use of short cycle (1-h cycle) and checking of complementary.
  Finding the optimum tunnel flow rate for PN and PM.
- **CYCLE CONTROL:**
  Basically brake torque feedback control.
- **OTHER CYCLE ISSUES:**
  Inter-day and intra-day reproducibility to prevent decrease in sensitivity. (Demonstrating the use of 1-h cycle)
- **ISOKINETICS:**
  Basically need for PM_{10} measurement. (Low sampling flow rate is needed to obtain similar values without non-isokinetic sampling)
- **VOLATILE PARTICLES:**
  TBD (demonstration and planning stage)
- **DIFFUSION CHARGERS:**
  TBD (planning stage)

Total fine-PN measurement requirement

- Fine-PN measurements require the use of full flow CPCs to ensure high accuracy of sampling flow rate.
- However, full-flow CPCs frequently cause trouble due to clogging, high pulse error (sudden drop in sensitivity), and butanol trouble.
- Robust fine-PN measurements may require the use of partial-flow CPCs or dilutor.

Good correlation
with normal operations

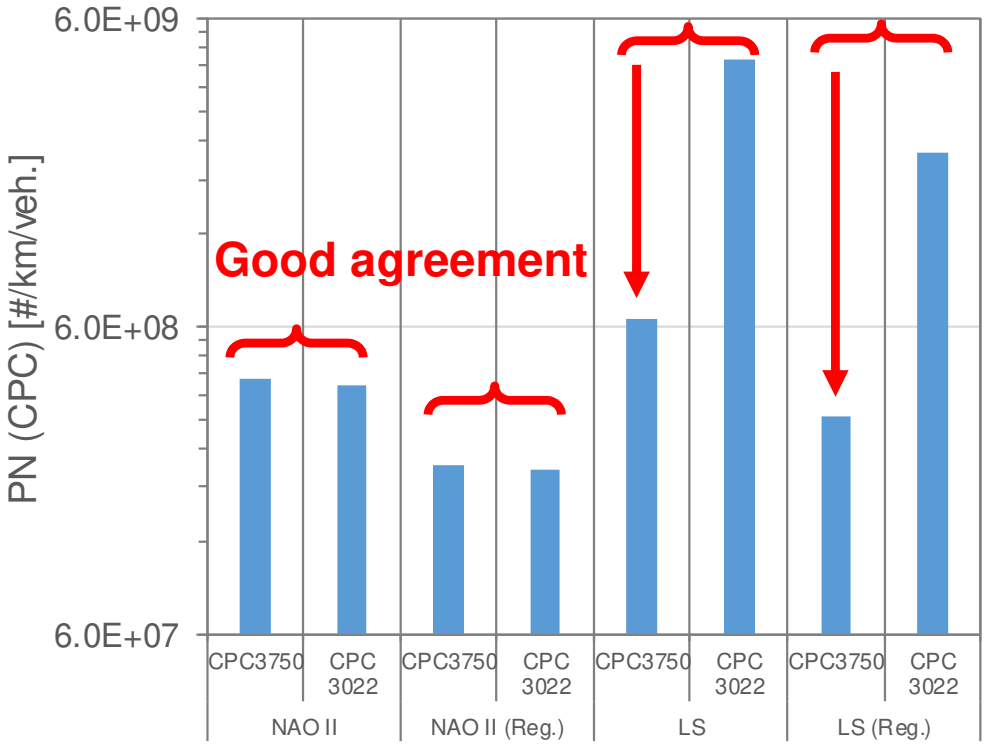
↓CPC 3022 (Dp >7nm)



↑CPC 3750 (Dp >7nm)

Test Condition:
4.4-h cycle, flow rate 1 m³/min, n=3

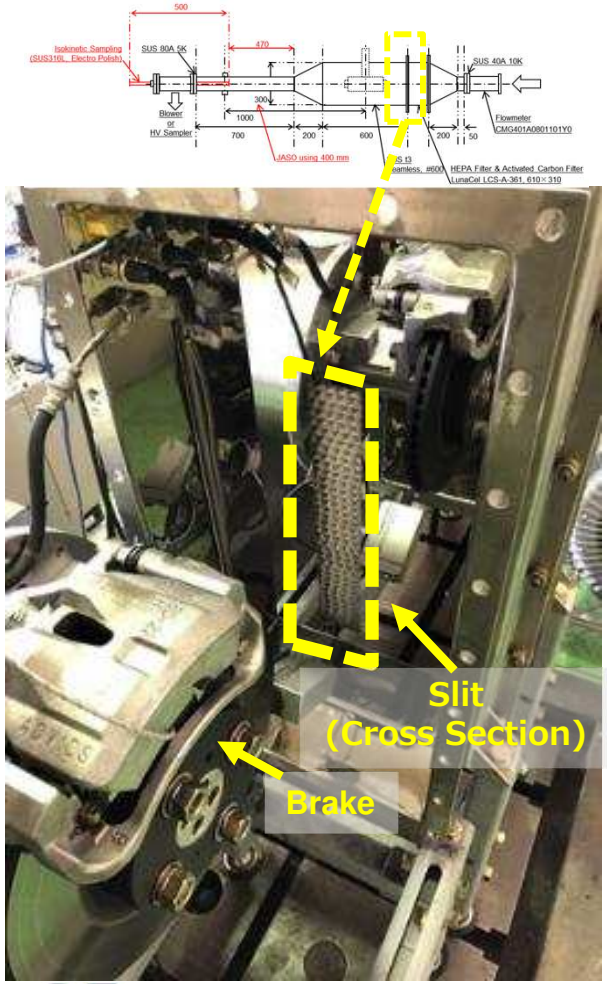
After butanol trouble, dry air was introduced throughout the day.
Did sensitivity change?

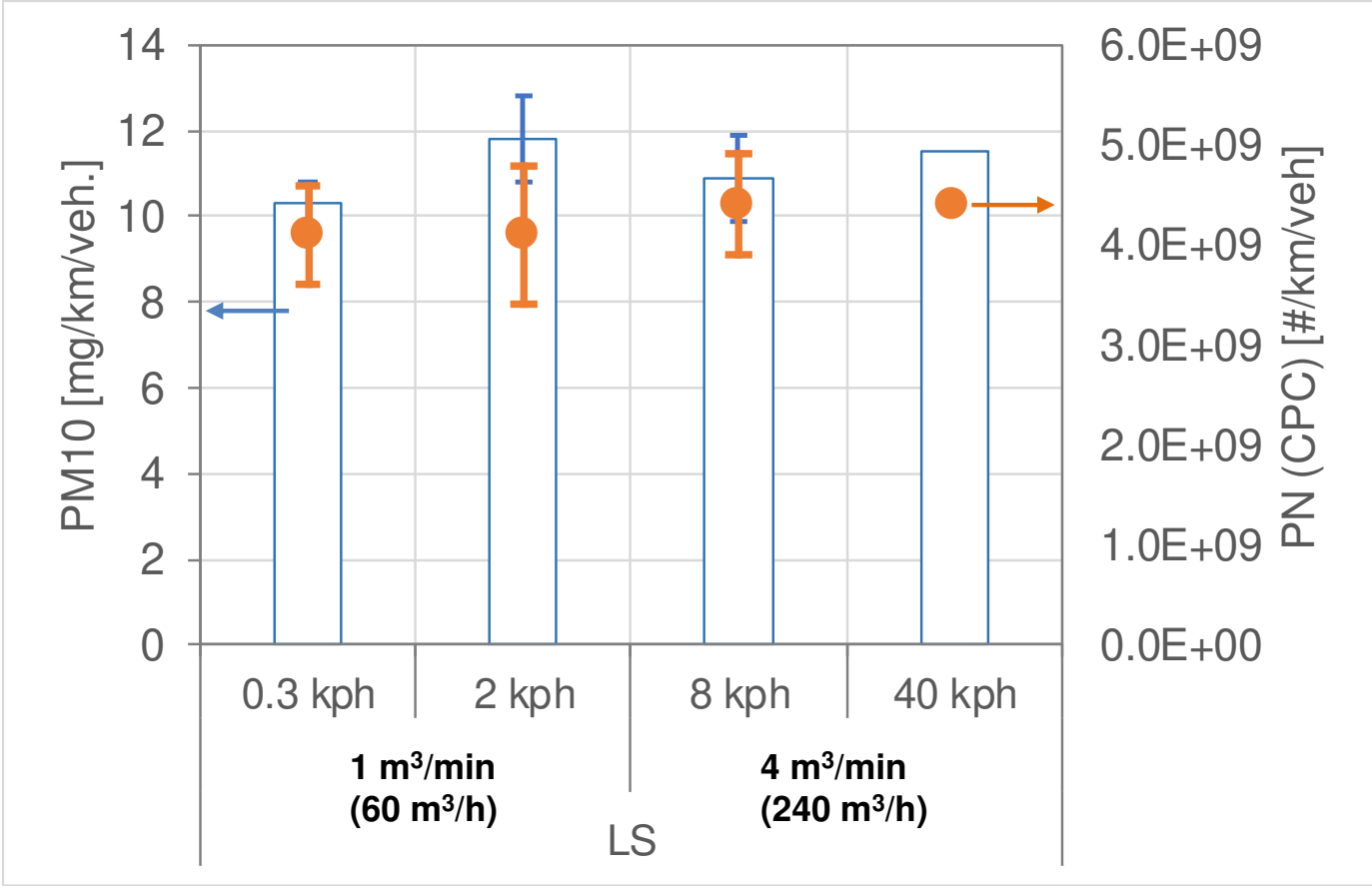


Test Condition:
4.4-h cycle, flow rate 4m³/min, n=1
Reg.: Simulated Regenerative Brake control

Air flow effect (1/3)

- There is no significant difference in emission levels from 1 to 4 m^3/min (0.3-40 kph equivalent of cross section) using JARI-JASO design.
- Further investigation is needed to evaluate emission levels using different sampling inertia and higher flow rate.

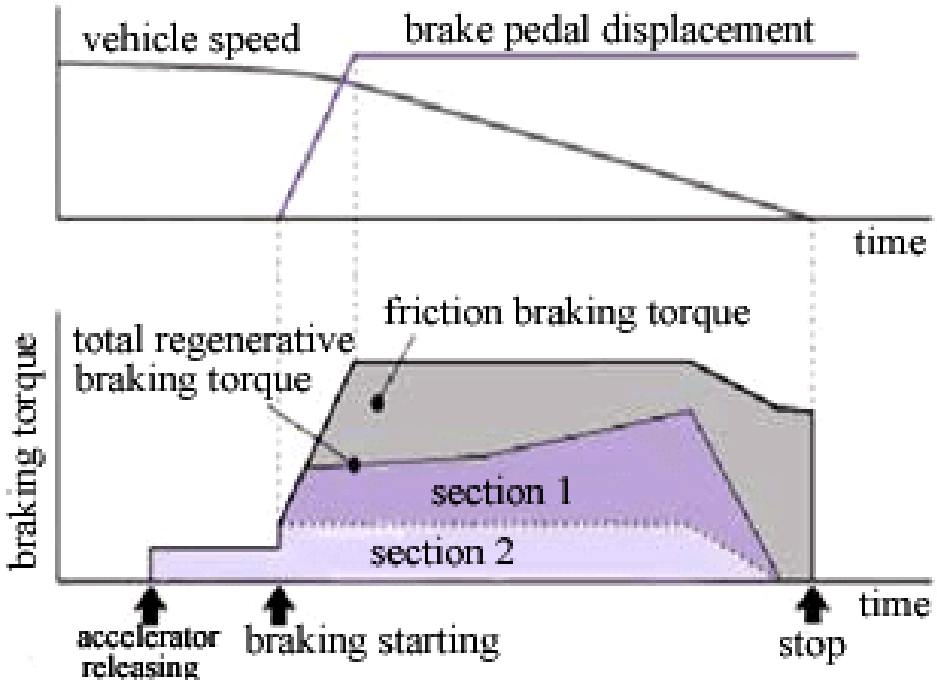




Test Condition:
4.4-h cycle, LS pad without regenerative brake control, n=3

Air flow effect (2/3)

- A next-generation brake technology (Simulated Regenerative Brake control) was demonstrated, and very low emission levels were detected.
- There was weak correlation between PN and PM under 4 m^3/min flow rate for short-trip (10 phases) emission factor evaluation.
- Further investigation is needed for short brake cycle (1-h cycle).

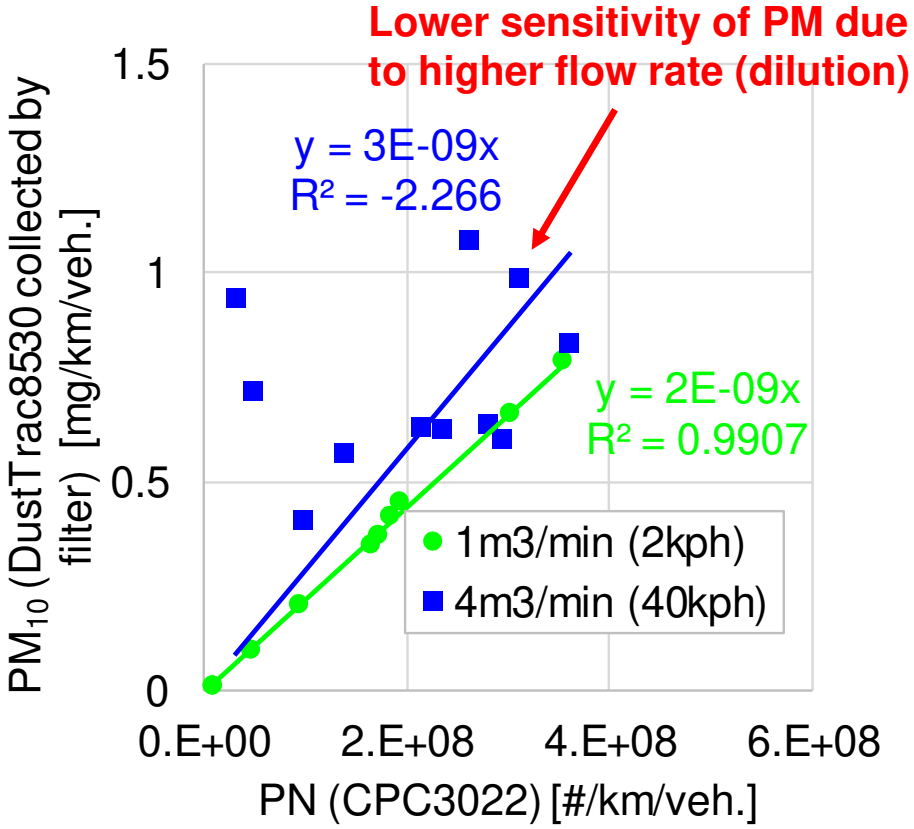


Ref. Ko et al., World Electric Vehicle Journal 6, 186-191 (2013)

Note:

- Regenerative Brake: Control of input brake torque profile for each brake operation in 4.4-h cycle
- There are significant differences between torque control strategies of different vehicles.

【PN vs PM_{10} for 10 trips in 4.4h cycle】

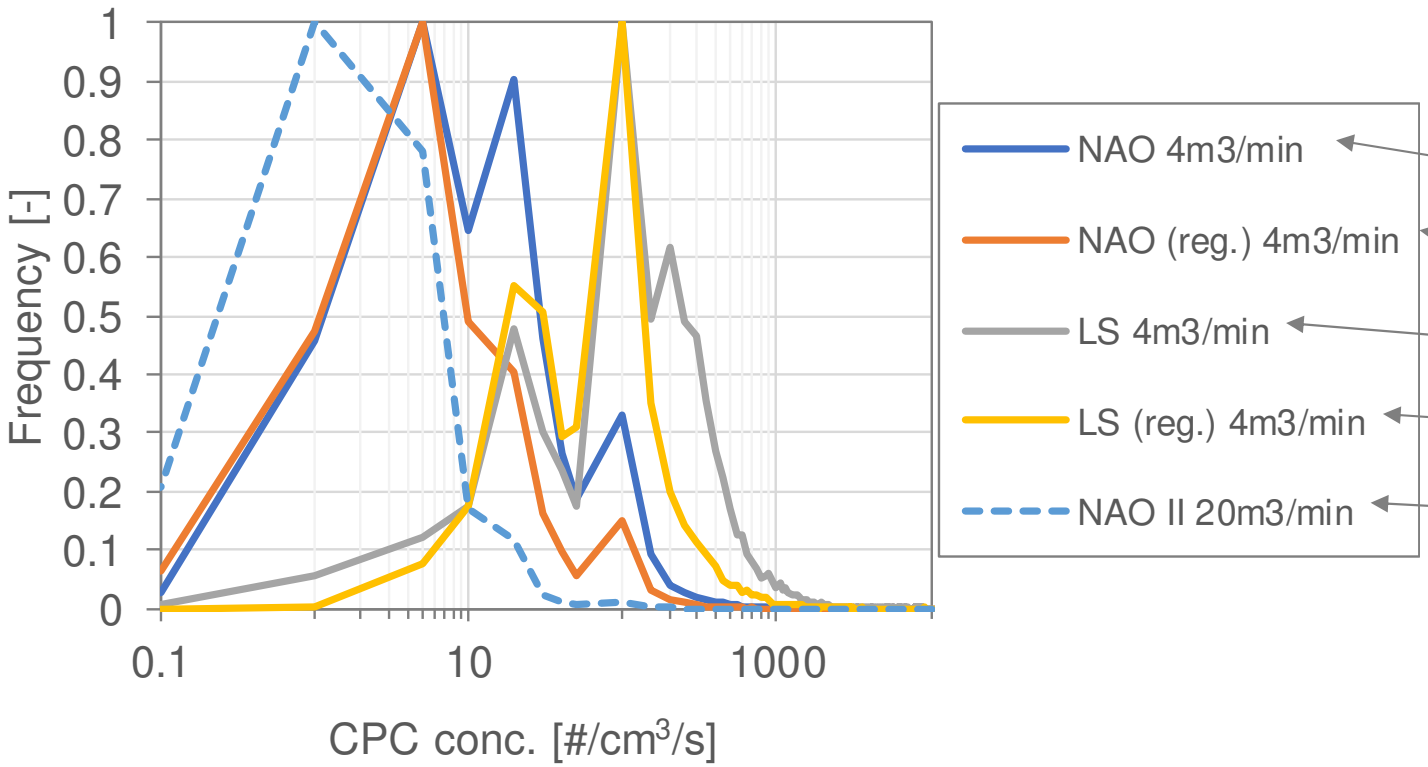


Test Condition:
4.4-h cycle, NAOII pad with regenerative brake control, n=1

Air flow effect (3/3)

- The CPC average concentrations ranged from 17 to 374 #/cm^3 at 4 m^3/min.
- It is necessary to use optimum tunnel flow rate condition for PN measurement.
- Due to the wide range of PN measurement, further investigation is needed for large vehicles.

Frequency Histogram of CPC concentrations

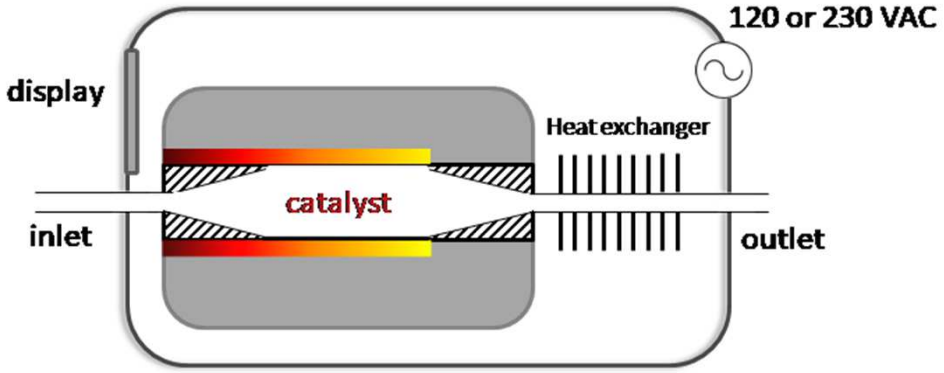


CPC conc.: #/cm^3		
average	median	max
30	11	1570
17	5	1010
374	183	19400
175	59	9300
3	1	202

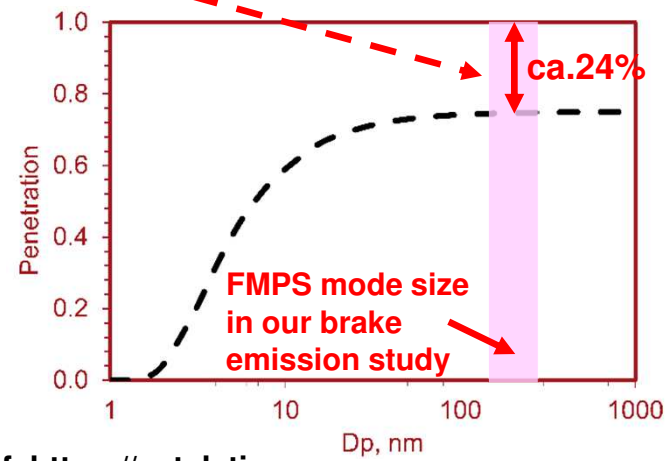
Test Condition:
4.4-h cycle, tunnel flow 4 m^3/min, n=1
(reg.): regenerative brake control
20m^3/min: calculated by 4 m^3/min data

Solid PN measurement

- The use of catalytic stripper (350 °C) to measure non-volatile PN was demonstrated.
- PN (CS + CPC) ~13% without loss correction, which was lower than total PN.
- This is reasonable because it was observed during an episode of thermophoretic loss.
- Further investigation is needed for different friction material (e.g. those materials with lower melting points).

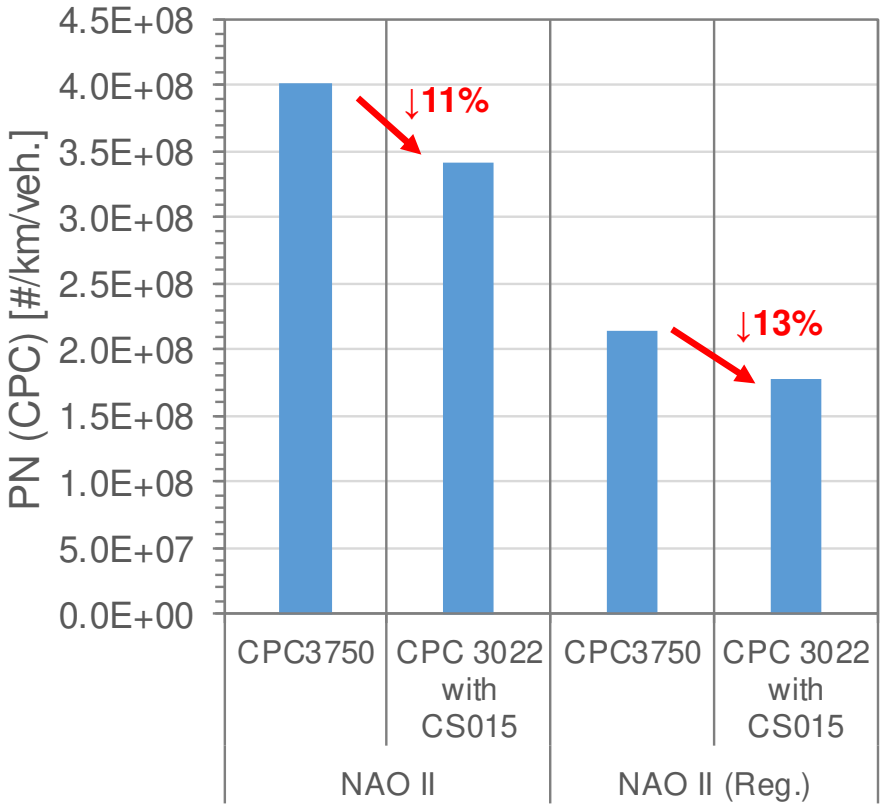


Thermophoretic losses



Ref. https://catalytic-instruments.com/?product_cat=catalytic-stripper

【CPC vs CS + CPC】

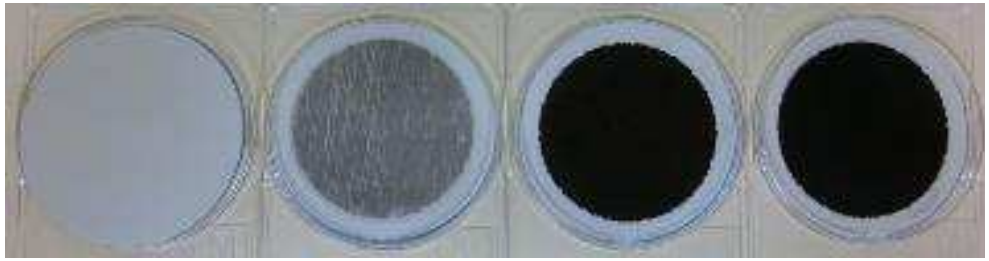


Test Condition:
4.4-h cycle, NAO II pad (popular friction material), n=1

Off-line filter measurement (1/2)

- ◆ High-filter sampling flow is needed to maintain sensitivity under higher tunnel flow rate.
- ◆ Sampling (aspiration) probe design from tunnel is also important!
  (It is important to consider the combination flow rate, tube size, length, and angle)

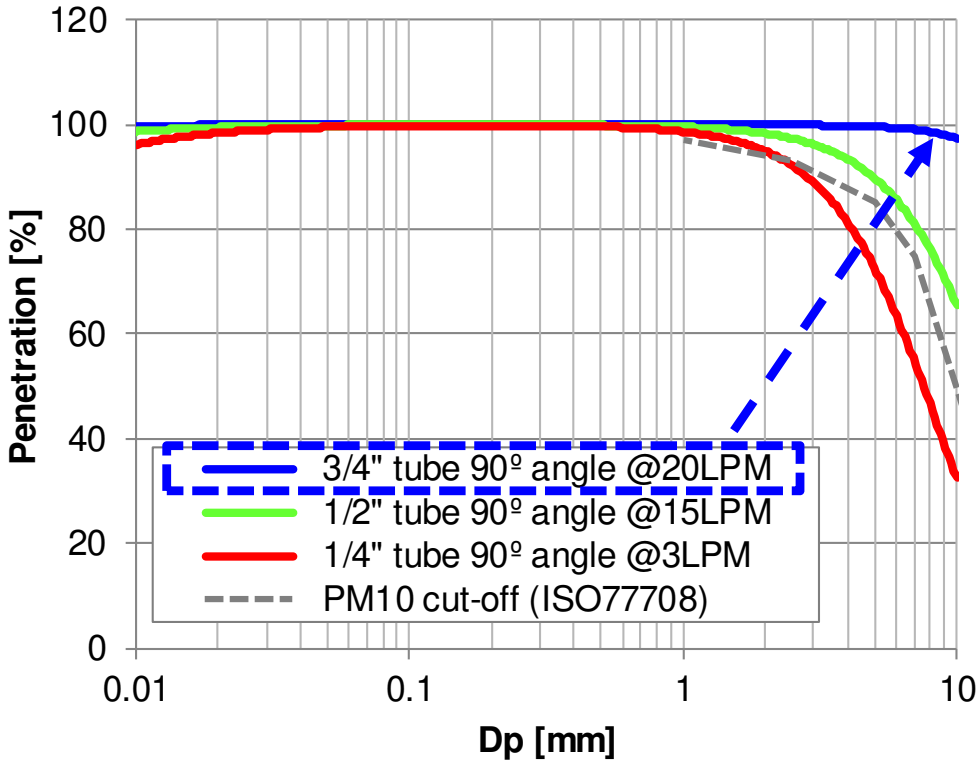
【Eg. Off-line filter sampling】



Before sampling	NAO II 0.4 mg-PM_{10}/filter	NAO I 5 mg-PM_{10}/filter	NAO I 15 mg-PM_{10}/filter

Test Condition:
4.4h cycle
PM_{10} Filter sampling flow rate 20L/min
CVS tunnel flow rate 1m³/min

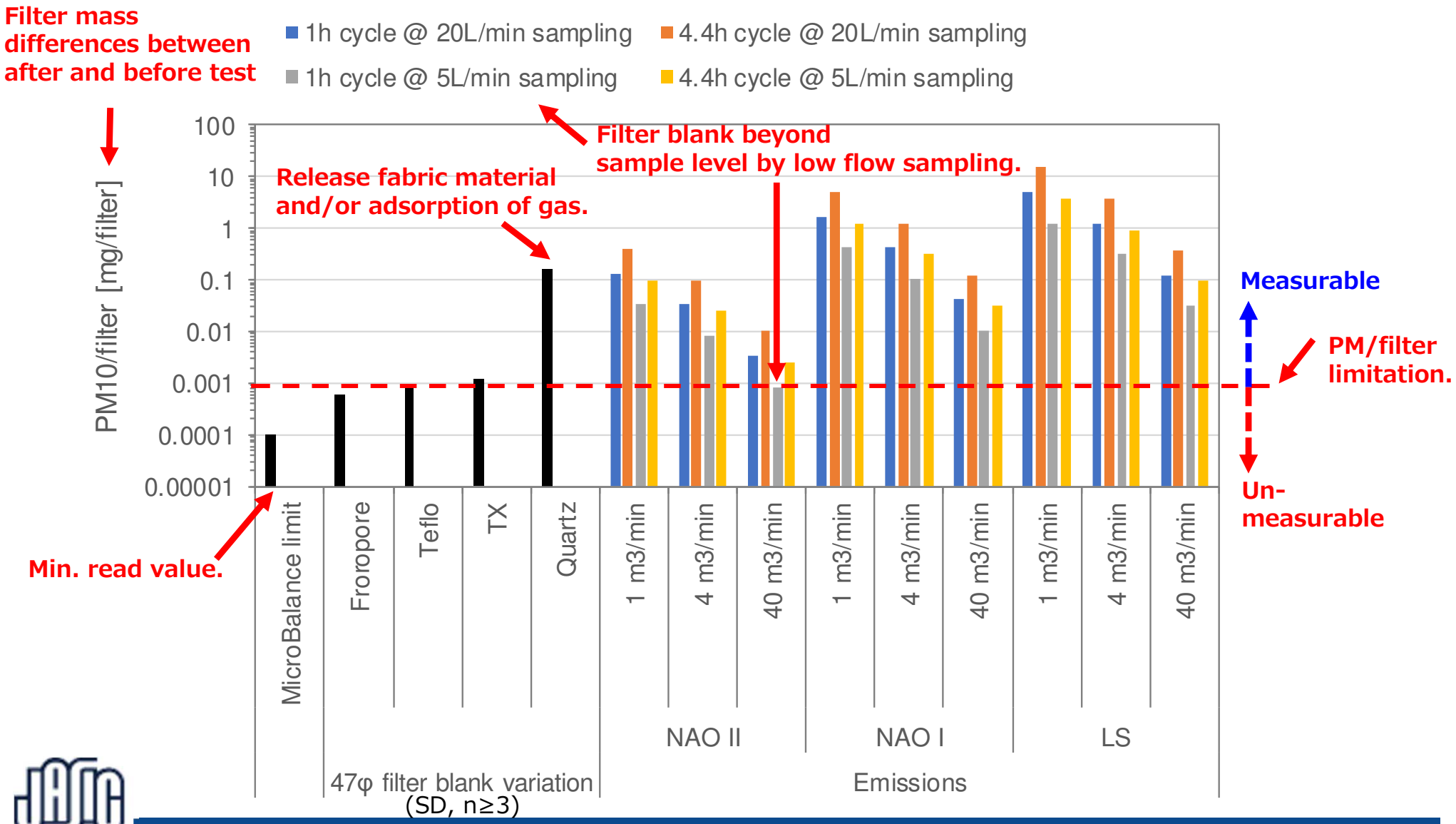
【Eg. Sampling efficiency from Tunnel】



What we need:
- ・Minimization of potential impaction losses in sample lines at low flow sampling.
- ・High sensitivity under high tunnel flow for brake cooling and high sampling flow.

Off-line filter measurement (2/2)

- Teflon filters are suitable for mass measurement due to lower blank level.
- Filter sampling (aspiration from tunnel) flow must be high to maintain sensitivity under higher tunnel flow rate.
- 1-h cycle can be measured using 20 L/min sampling methodology.

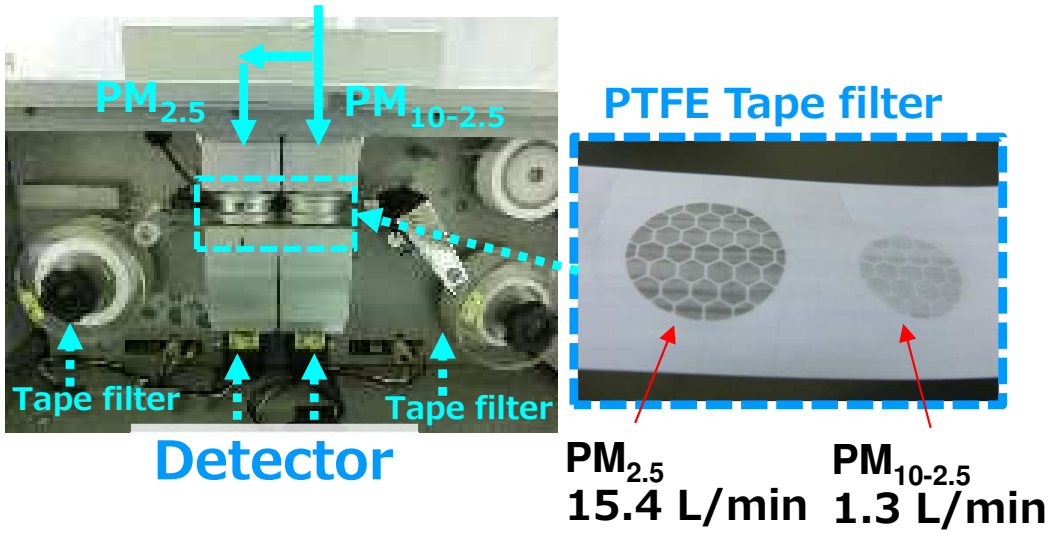


On-line filter measurement

- **On-line filter measurement using an automated filter monitor was also demonstrated to minimize handling and transportation losses.**

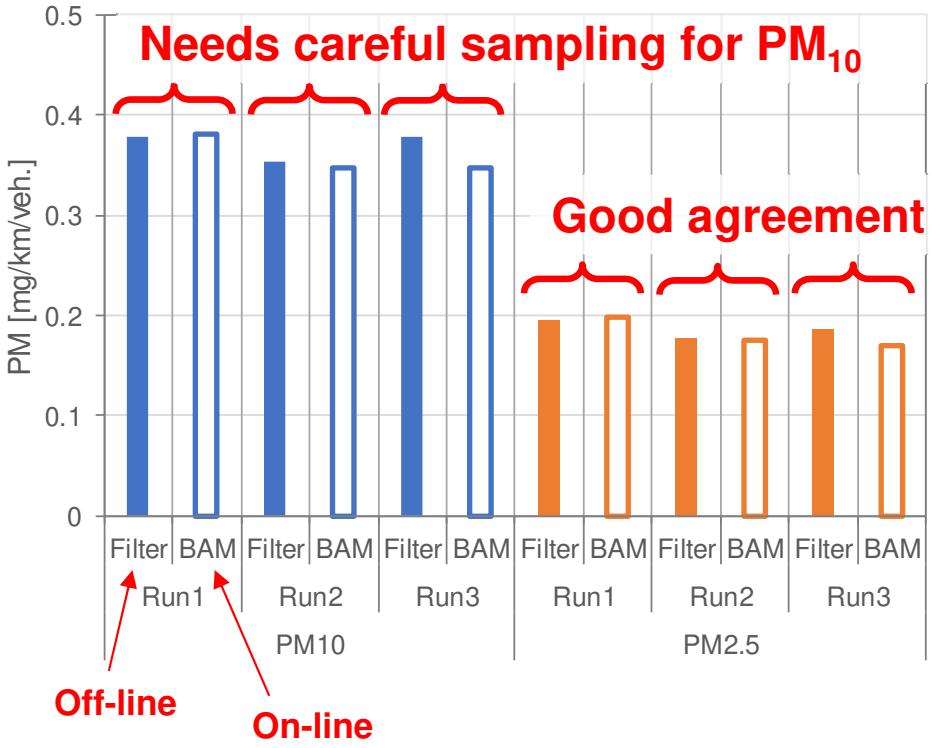
【Eg. On-line filter sampling】

What we need:
Minimize handling and transportation losses.
Simultaneous measurement of PM_{10}/$PM_{2.5}$



Bata Attenuation Monitor (BAM)
(PM-712, Kimoto electrics)
https://www.kimoto-electric.co.jp/english/product/pdf/pm712.pdf

【Filter vs Online Filter】



Test Condition:
1h cycle, NAO II pad, 1m³/min

Conclusions & Next Steps

Conclusions:

- **Robust fine-PN measurements require the use of partial-flow CPCs.**
- **There is no significant difference in emission levels from 0.3 to 40 kph under 1—4 m^3/min.**
- **High sensitivity of PM and PN measurements is achieved at lower flow rates.**
- **Solid PN measurement decreased due to thermophoresis.**
- **On-line filter measurement using an automated filter monitor minimises handling and transportation losses.**

Next Steps:

- **Further investigation will be performed to evaluate emission levels using different sampling inertia, brake size, and friction materials.**