Crosscheck of Particle Number Counting Systems and Influence of Particle Species on Particle Concentration Reduction Factor

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1. Introduction

Currently, particle number counting method for the regulation is investigated in the PMP informal meeting. Regulation for particle number for type approval is planned to introduce in Euro 5b. Therefore, particle number counting systems (PNCS) are on the market from several instrument companies. All of PNCS on the market are suitable to Regulation 83 annex 4a, but these instruments have some structural difference, such as dilution method, setting of temperature, and so on. Because these differences may effect to particle loss in volatile particle removers (VPR) on each instruments, particle concentration reduction factor (PCRF) is contrived as correction method for particle number emission. But, test procedure is not strictly established for particle species, generation method for particle, setup for calibrations, and so on. Therefore instrument companies construct their calibration methods for measurement of PCRF from independent standpoints. So, not only differences of systematic structures but also differences of calibration methods are important key points which effect to measurement results with each instrument. As mentions above, it is necessary to investigate differences of measurement results with several systems calibrated based on PCRF. It is also important to understand the difference of calibration method which affect to measurement results.

Therefore, in this study, simultaneous measurements for particle number emissions from several vehicles and engines were investigated with four types of particle number counting system from some companies. Calibration for PNCS was also investigated to reveal influence on PCRF measurement.

2. Simultaneous measurement of particle emission with four types of PNCS

Particle number emissions from vehicles and engines were simultaneously measured with four types of PNCS manufactured by Matter Engineering AG, Horiba, Tsukasa Sokken and AVL. Experimental setup for measurement of particle number emission was shown in Figure 1.

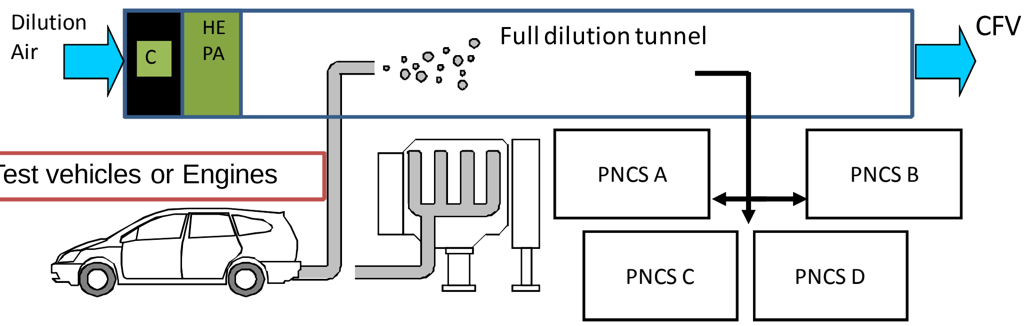

Figure 1 Experimental setup for simultaneous measurement of PNCS

Test vehicles or test engines were settled on chassis dynamometer systems or engine dynamometer systems. There exhaust lines were connected to full dilution systems. Four types of PNCS were connected to full dilution tunnels via each sampling prove.

In the test of vehicles, 3 types of SIDI vehicle, 2 types of MPI vehicle, 1 type of diesel vehicles equipped with DPF on the market in Japan were used in the test. Particle number emission from vehicles were measured with 5 types of driving cycles, such as NEDC, 11, 10-15, JC08 Cold and Hot. PN emissions were calculated based on Regulation 83 annex 4a used with PCRF supplied from manufactures or measured by our calibration system. Relationships of measurement results with 4 types of PNCS were shown in Figure 2. As shown in the figure, correlation of PN emissions with each instrument to that with PNCS A were very good, because the square of the Pearson product moment correlation coefficients (R_2) of the each instrument and PNCS A were greater than 0.99. Gradients from a linear regression of the data with each instrument and the data with PNCS A were not constant. Gradient means ratio of measurement values with each to the measurement value with PNCS A. Therefore, in the vehicle test, over 15 % of different was confirmed by different types of PNCS. These differences of measurement results should be caused by the differences of measurement procedures of each instrument, since all data were calculated with PCRF.

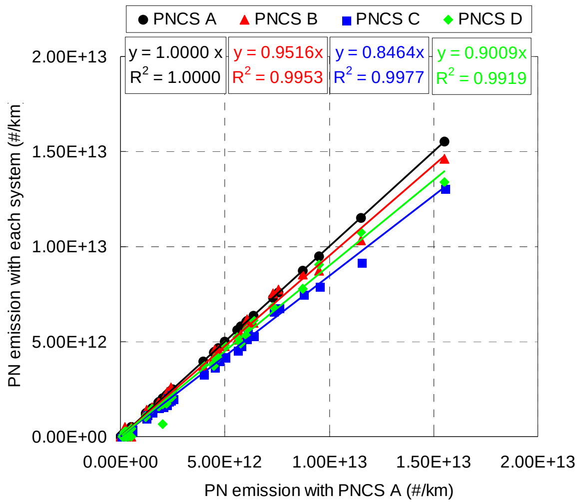

Figure 2 Particle number emissions from vehicles with four types of PNCS

For the test of engines, we used 2 types of diesel engines equipped with DPF: a Mercedes OM501 used with PMP round-robin exercise and a Hino J08E-TP used with Japanese round-robin exercise. Driving cycles in PMP round-robin exercise were WHTC-cold, WHTC-Hot, WHSC, ETC and ESC. Driving cycles in Japanese round-robin exercise were WHTC-cold, WHTC-Hot, WHSC and JE05. PN emissions were calculated based on Regulation 83 annex 4a used with PCRF supplied from manufactures or measured by our calibration system. Relationships of measurement results with 4 types of PNCS were shown in Figure 3. With an experiment with OM501, correlation of PN emissions with each instrument to that with PNCS A were also very good, because the square of the Pearson product moment correlation coefficients (R_2) of the each instrument and PNCS A were greater than 0.96. Gradients from a linear regression of the data with each instrument and the data with PNCS A were not constant, and were almost same level with an experiment for vehicles except for PNCS D.

PCRF of PNCS D was not changed in the period from vehicle tests to engine test. Therefore, the difference of gradients with two test periods should be caused from another factor.

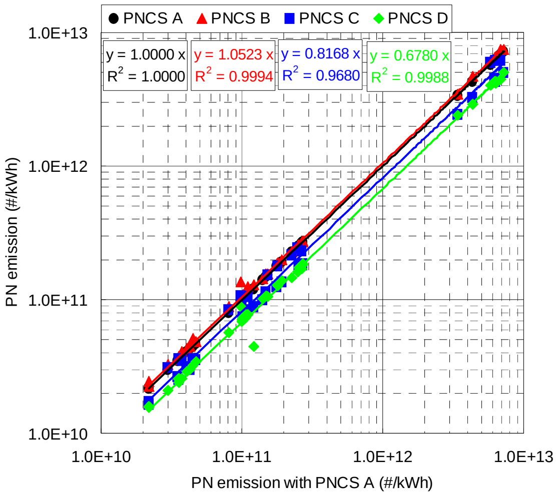

Figure 3 Particle number emissions from OM501 with four types of PNCS

With an experiment with J08E-TP, correlation of PN emissions with PNCS B to that with PNCS A was also very good. Gradient of PNCS B to PNCS A was not same level with previous two experiments for vehicles and engine. This difference should come from the individual difference, because PNCS B used in this experiment was another one with previous experiment. As mentioned above, 20% of difference of PN emission was confirmed in this test.

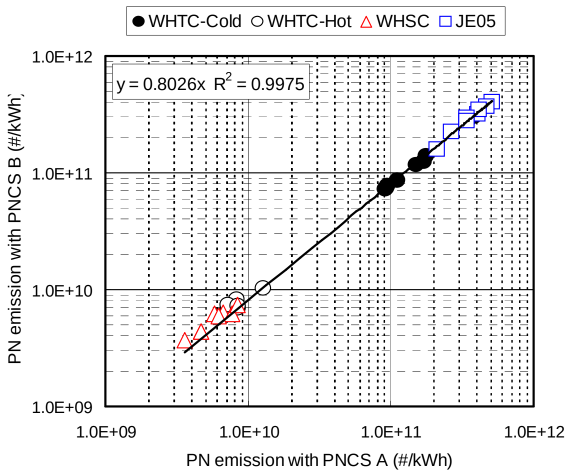

Figure 4 Particle number emissions from J08E-TP with two types of PNCS

3. Influences of difference on measurement procedures for PCRF

Schematic of the experimental setup for measurement of PCRF was shown in Figure 5. PNCS manufactured by Matter Engineering was used for evaluation. For the calibration of PNCS, 4 types of particle species generated by different methods were used. Particles of NaCl were generated by vaporization and condensation method, and atomizing. Carbon particles were generated from CAST manufactured by Matter engineering and GFG-1000 by Palas. Evaporation tube was settled between generator and neutralizer to investigate the effect of thermal treatment to generated particles. Particles classified by DMA were measured by the particle number counter (TSI 3010D) at upstream and downstream of the VPR to measure PCRF. Additional counter (TSI 3022A) was used for monitoring the concentration at upstream of the VPR.

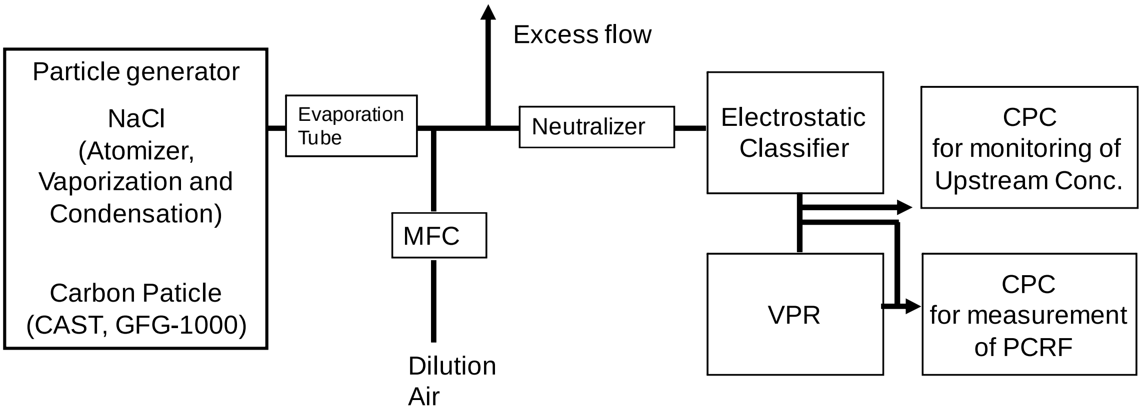

Figure 5 Experimental setup for measurement of Particle Concentration Reduction Factor

3.1. Thermal treatment for generated particles

We investigated influence of thermal treatment for Soot particles generated by CAST and NaCl particle generated by vaporization and condensation method. Figure 6 shows PCRF measured with or without thermal treatment of VPR. In the case of 50nm of CAST particle, PCRF without thermal treatment was larger than that with thermal treatment. This result means soot particle without thermal treatment before VPR should be vaporized at evaporation tube (ET) in the VPR. When particles with volatile component are introduced to ET in the VPR, size of particles should be changed to smaller particle or number of particle should be reduced by vaporization of volatile component. In the case of NaCl particle, PCRF without thermal treatment was twice larger than that with thermal treatment. NaCl particle generated with vaporization and condensation method may be agglomerated from smaller NaCl particle. NaCl particle without thermal treatment may by divide into smaller particle in the VPR. Therefore, NaCl particle generated by vaporization and condensation method need to be re-melting over than melting point of NaCl in order to stabilize generated particle. In both case, thermal treatment of generated particle is indispensable to measure PCRF exactly.

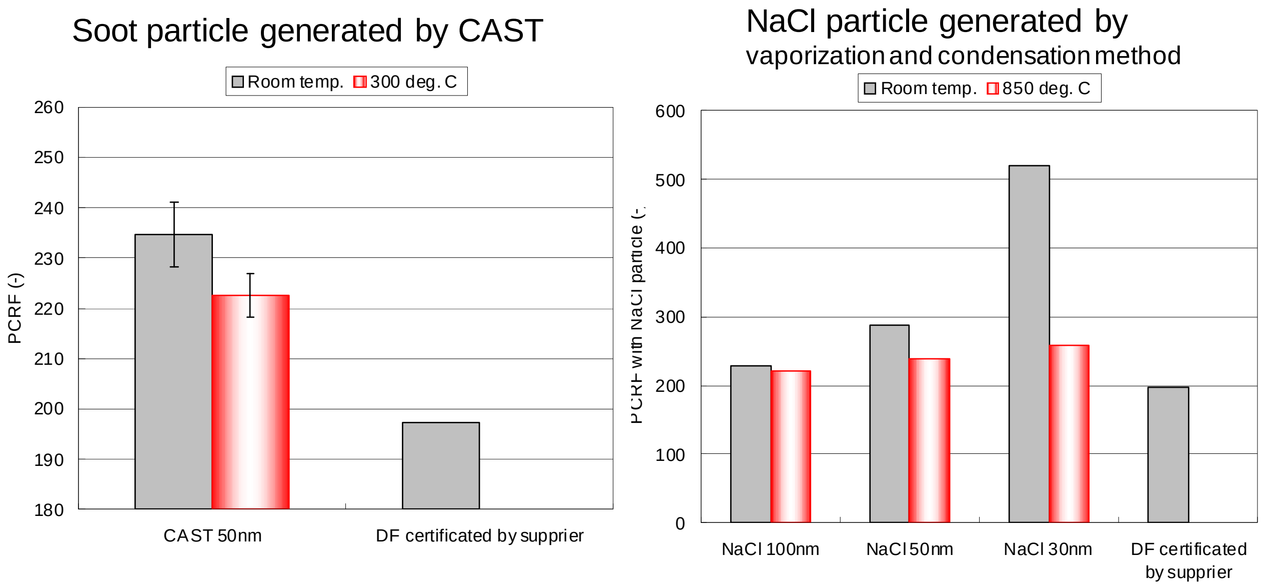

Figure 6 Influence of thermal treatment of generated particle on PCRF measurement

3.2. Influence of particle concentration at upstream of the VPR

We investigated influence of particle concentration at upstream of the VPR with carbon particles generated by CAST and GFG-1000. In both case, PCRF was decreased with a decrease in particle concentration at upstream of the VPR, when PCRF was calculated from particle concentration at upstream and downstream of the VPR used with single CPC. With monitoring by second counter, particle number concentration at upstream of the VPR was increased when sampling line was exchanged to measure particle concentration at downstream, although flow rate of split line was set to simulate flow rate of PNC. This phenomenon may be caused from the balance of DMA flow. Slight difference of flow rate, between PNC and mass flow controller, should make influence of particle classification by DMA. When particle concentration at upstream of the VPR was higher than 5,000 /cm3, PCRF with one CPC method and two CPC method are almost same.

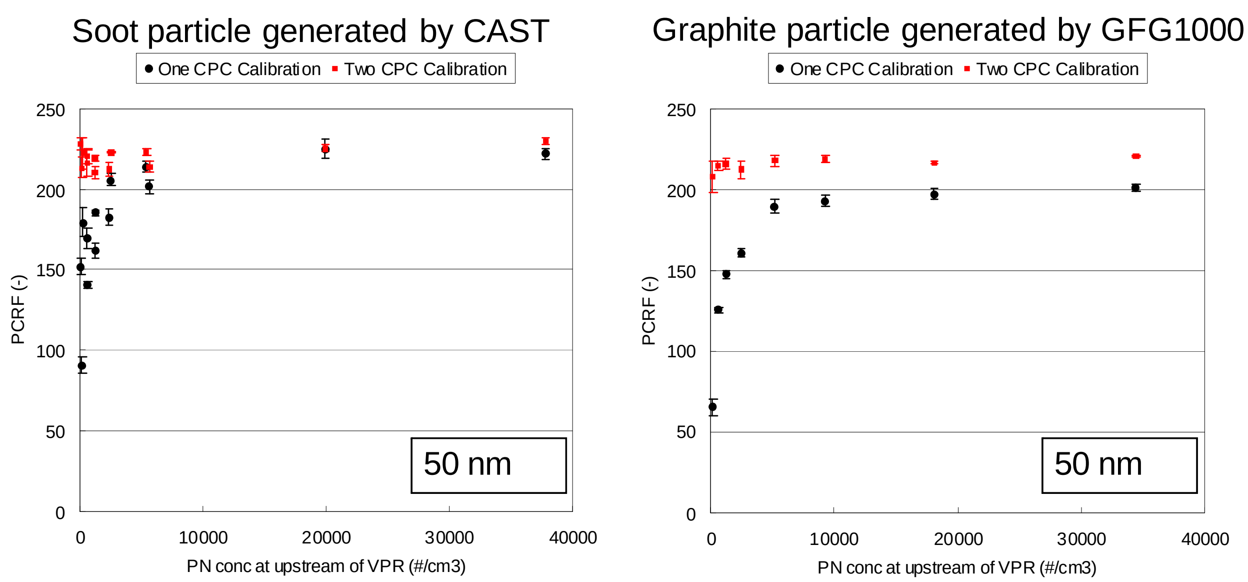

Figure 7 Relationships between PCRF and particle concentration at upstream of the VPR

3.3. Influence of particle species generated by several method

Particle concentration reduction factors were measured with 4 types of particle. Particle size distributions of several particles used in this investigation are shown in Figure 8. Measurement result of PCRF with these particle species are shown in Figure 9. As shown in the Figure 9, measurement results of PCRF used with each particle species generated by different method were different. The reason is uncertain though Values of PCRF generated from GFG-1000 were lower than dilution factors calibrated by supplier in Japan. PCRFs for 100nm were almost same values as for other particles. The difference of PCRF values was large, when particle diameter was smaller, as shown in figure. In especially 30 nm, PCRF of NaCl generated by atomizing without thermal treatment is larger than that of other particle species. Means of PCRF were almost same values except for GFG-1000.

Ratio of PCRF with several particle normalized with PCRF with GFG-1000 were calculated in Figure 10 from the data of means of PCRF. As shown in the figure, PCRF could be the twice or more different depending on particle species and generation methods. Therefore, it is important that calibration method and procedure should be unified.

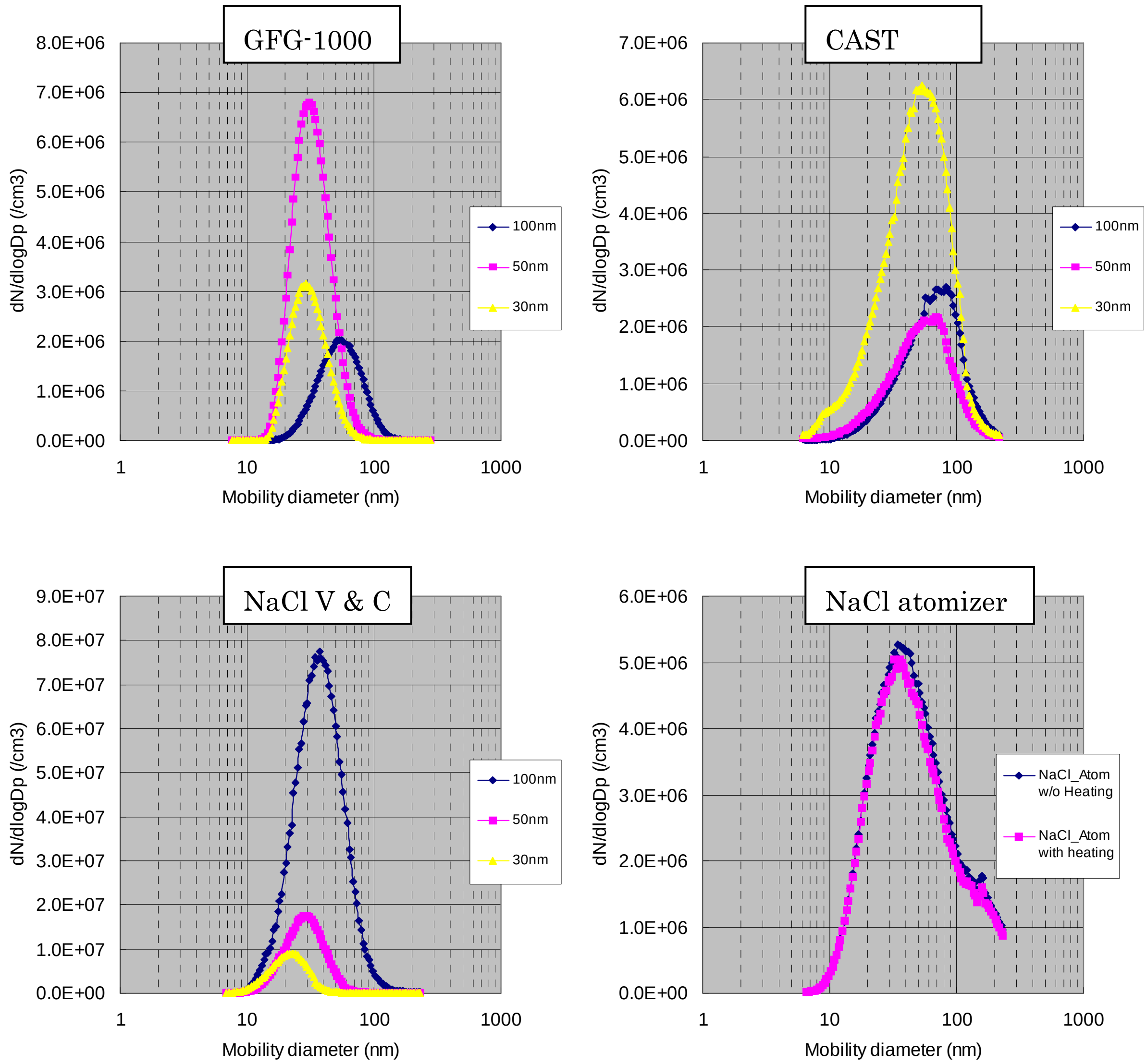

Figure 8 Particle size distributions generated from several method

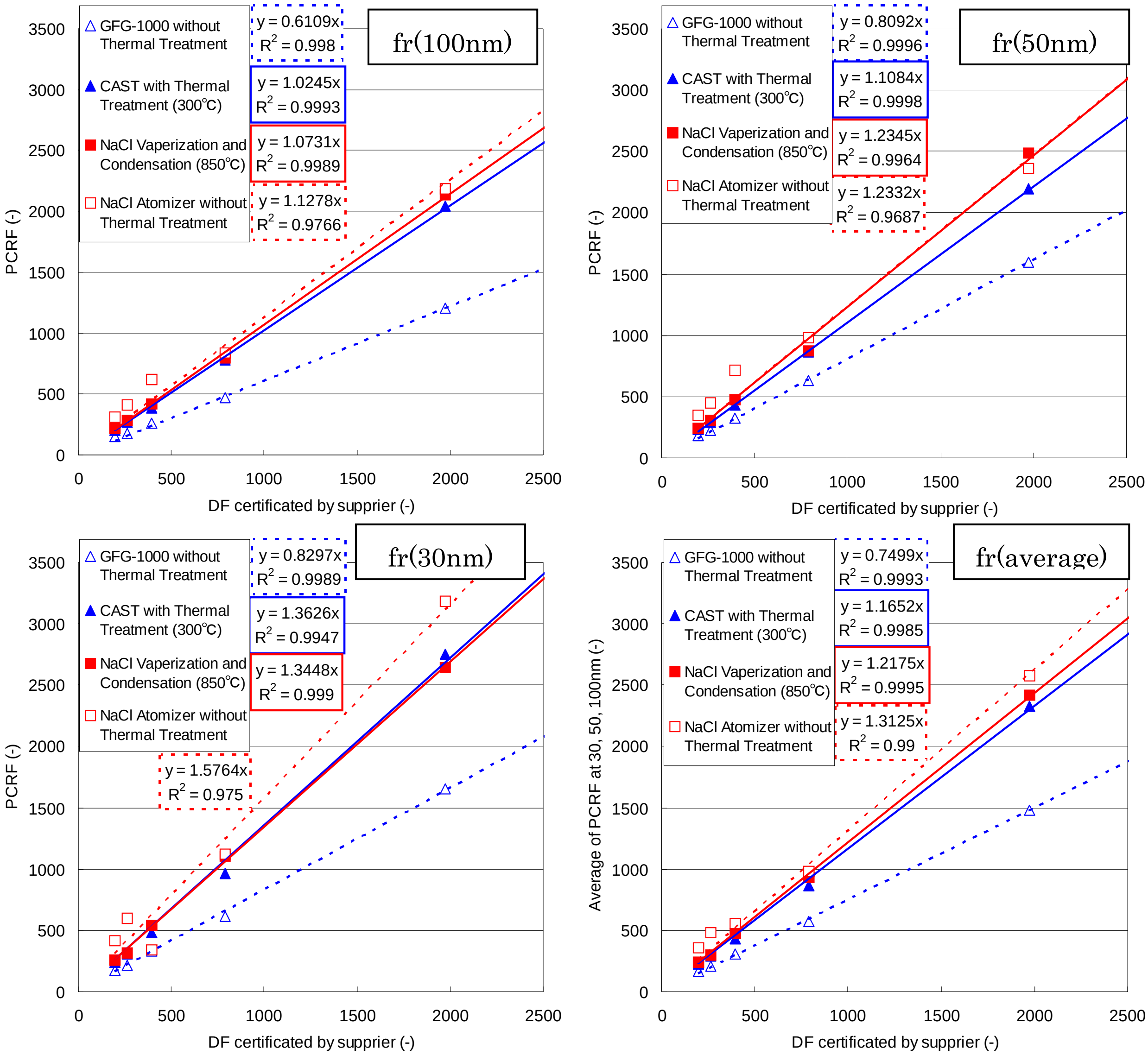

Figure 9 Influence of particle species on the measurement of PCRF

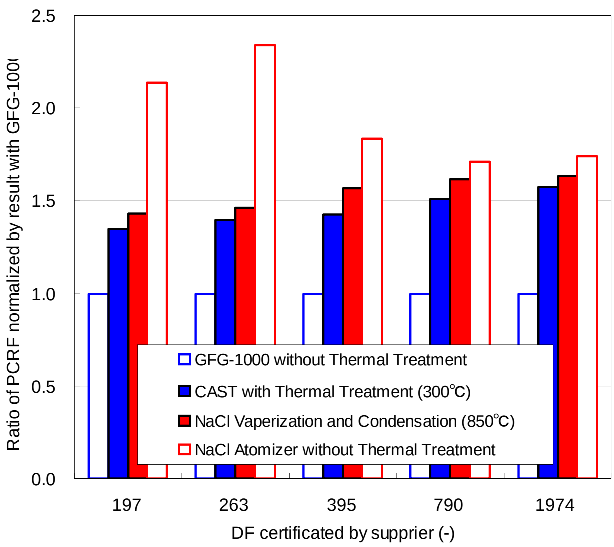

Figure 10 Ratio of PCRF with several particles to that with GFG-1000

4. Summary

We simultaneously measured particle emissions with several number counting systems, and investigated influences of particle species and generation methods on calibration of number counting system. Results obtained from our research are as follows.

- Correlations of measurement results were very good through all experiment. But gradients of measurement results were different with PNCS of each manufactures.
- 5 ~ 20% of difference of measurement results were confirmed. Differences of result should be caused by difference of calibration methods used in each instrument companies
- Thermal treatment is necessary to measure PCRF in order to stabilize particle condition.
- Simultaneous measurement at upstream and downstream of VPR is essential to reduce effect of changing of particle concentration.
- Values of PCRF had a possibility the twice or more different by the difference of particle species and generation method.

From the result mentioned above, calibration methods and procedures should be unified and made strict further for a good accuracy of measurement.

Crosscheck of Particle Number Counting Systems and Influence of Particle Species on Particle Concentration Reduction Factor

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Contents

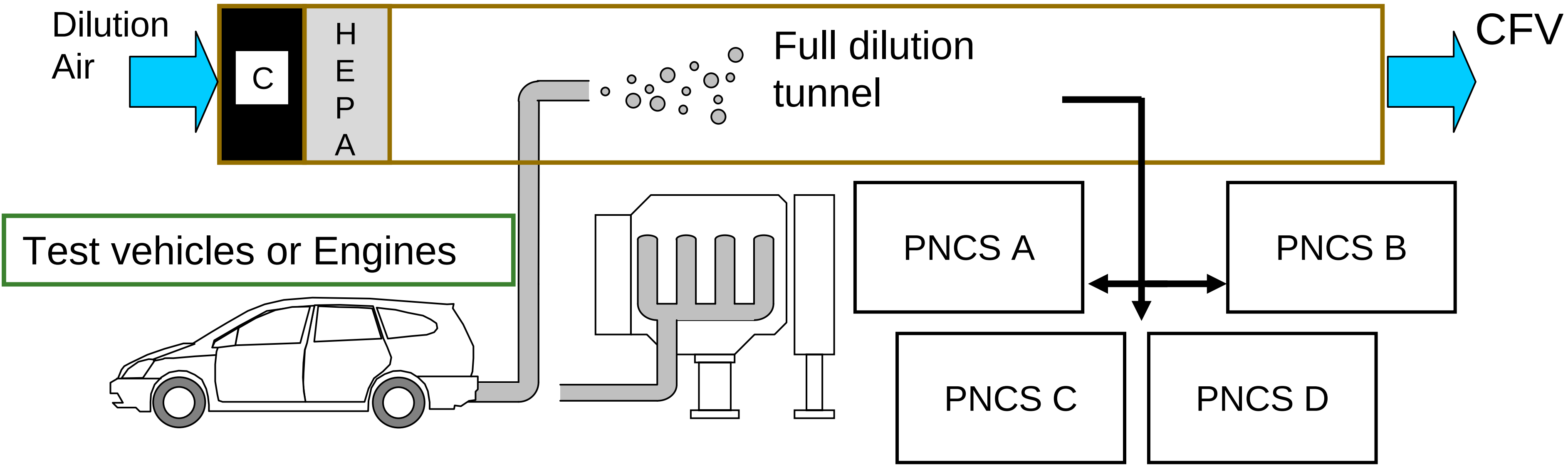
Background

- Introduction of particle number regulation for vehicle and engine in Europe
  - Necessary to clear rules for calibration of VPR
  - Clarify differences of measurement results with different type of PNCSs
- Imperfection of calibration procedures
  - Vague rules for calibration
    - Type of particle species
    - Generation method of particles
    - Measurement methods and so on
  - These vagueness may occur influence for measurement result.
- Therefore, we should make these problem clear.

Objectives

- In this study,
  - Simultaneous measurements with 4 types of PNCS were investigated for vehicle and engine test.
  - Measurements of PCRF were investigated to clear these influence on calibration.
    - Thermal treatment for calibration particles
    - Particle concentration at upstream of VPR
    - Types of particle species

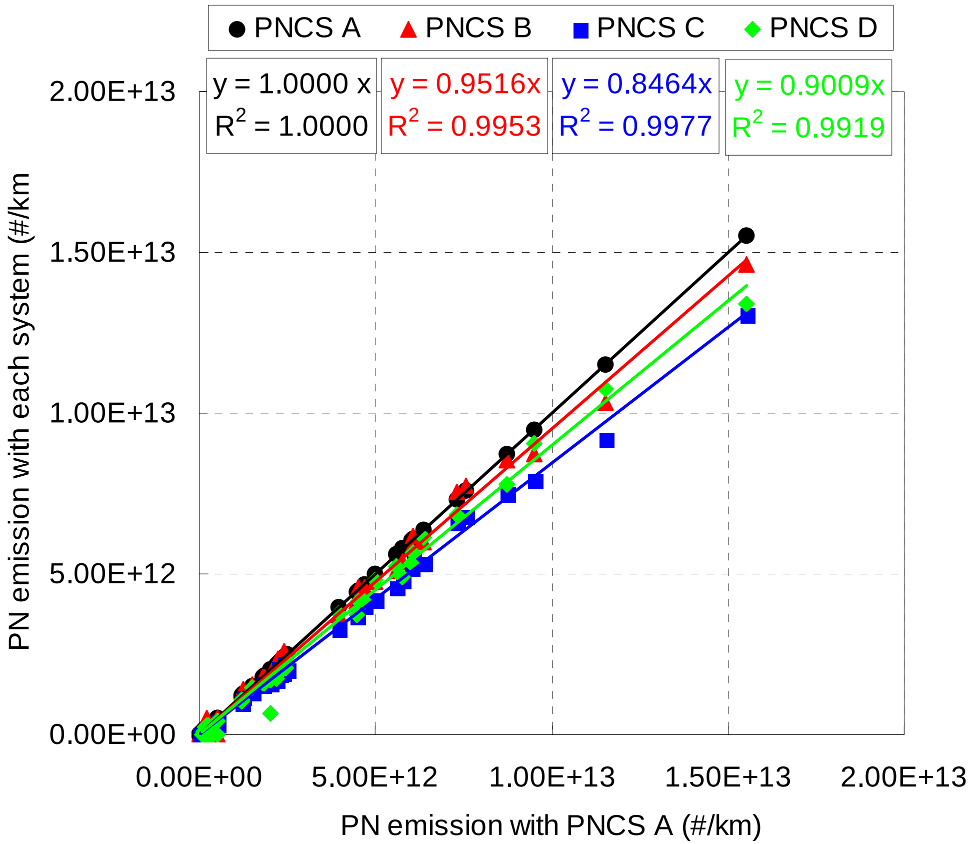
Crosschecks of Particle Number Counting Systems –Experimental Setup –



4 types of instruments (PNCS) were used for comparison of Number Counting.

2 engines and 6 vehicles were used for crosscheck of PNCS.

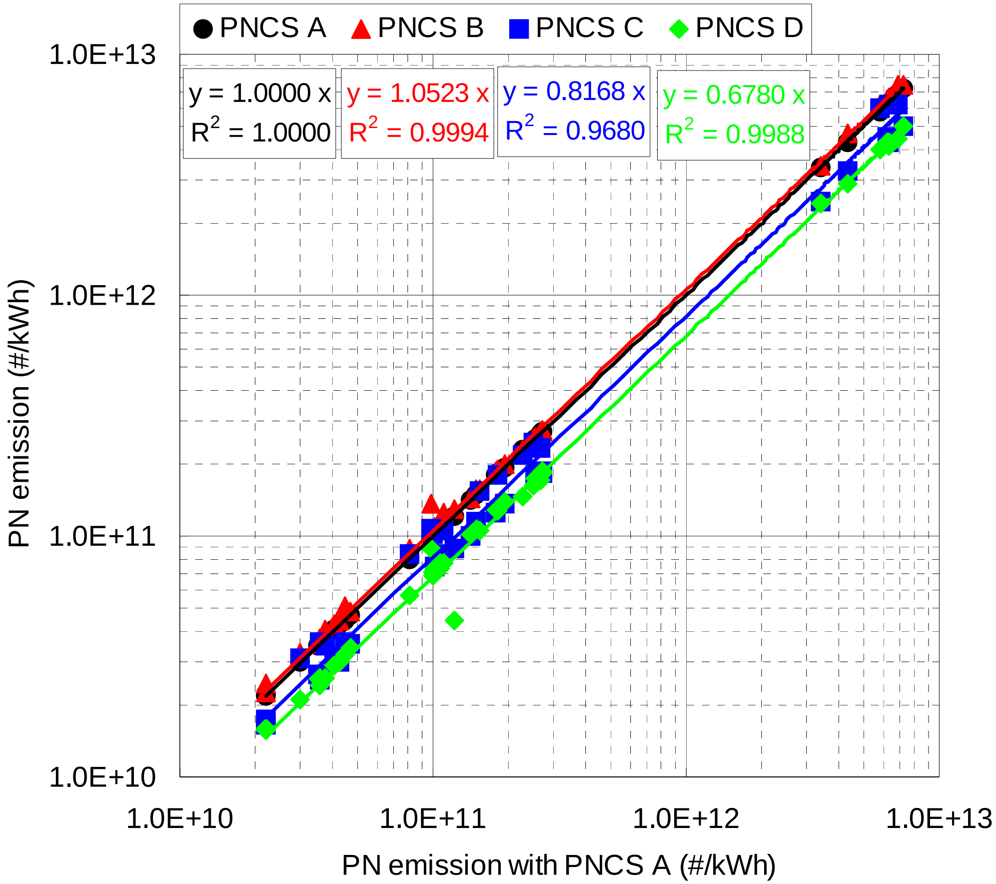
Crosschecks of Particle Number Counting Systems —Results of vehicle test—



PNCS A: PND1_DF=ca. 20, PND2_DF=10
PNCS B: PND1_DF=10 or 50, PND2_DF=15
PNCS C: PND1_DF=10 or 20, PND2_DF=10
PNCS D: PND1_DF=25 or 100, PND2_DF=10

- PN from 6 type of vehicles were measured with 4 types of PNCS.
  - Vehicle: 3 of SIDI, 2 of MPI and 1 of DPF-diesel
  - PNCS: 4 types of PNCS
- Correlations of results of each PNCS were very good.
- Gradients of emission were different for each instrument.
  - PNCS A>PNCS B>PNCS C>PNCS D
- These difference are caused by difference of PCRF measurement by each instrument companies.

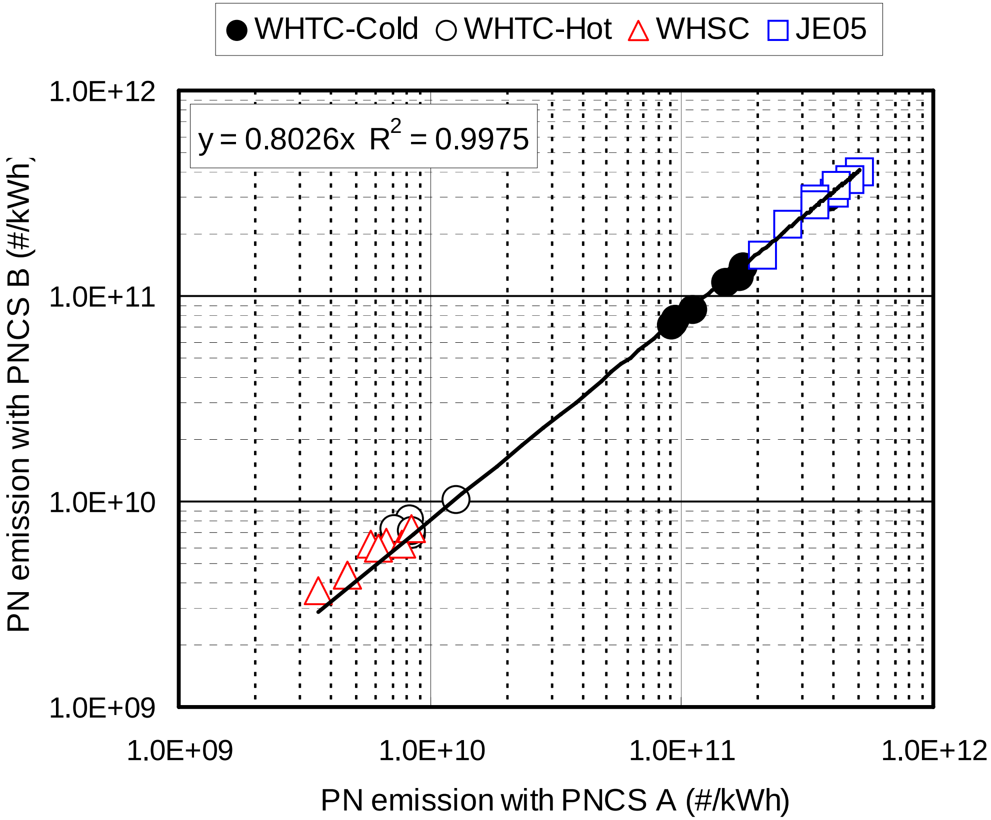
Crosschecks of Particle Number Counting Systems —Results of engine test1—



PNCS A: PND1_DF=ca. 20, PND2_DF=10
PNCS B: PND1_DF=10, PND2_DF=15
PNCS C: PND1_DF=10, PND2_DF=10
PNCS D: PND1_DF=10, PND2_DF=10

- PN from 1 type of engine was measured with 4 types of PNCS.
  - Engine: OM501 LA
  - PNCS: 4 types of PNCS
- Correlations of results of each PNCS were very good.
- Gradients of emission were different for each instrument.
  - PNCS B>PNCS A>PNCS C>PNCS D
- Gradient of emissions with each instruments were almost constant in previous slide, except for PNCS D.

Crosschecks of Particle Number Counting Systems —Results of engine test2—



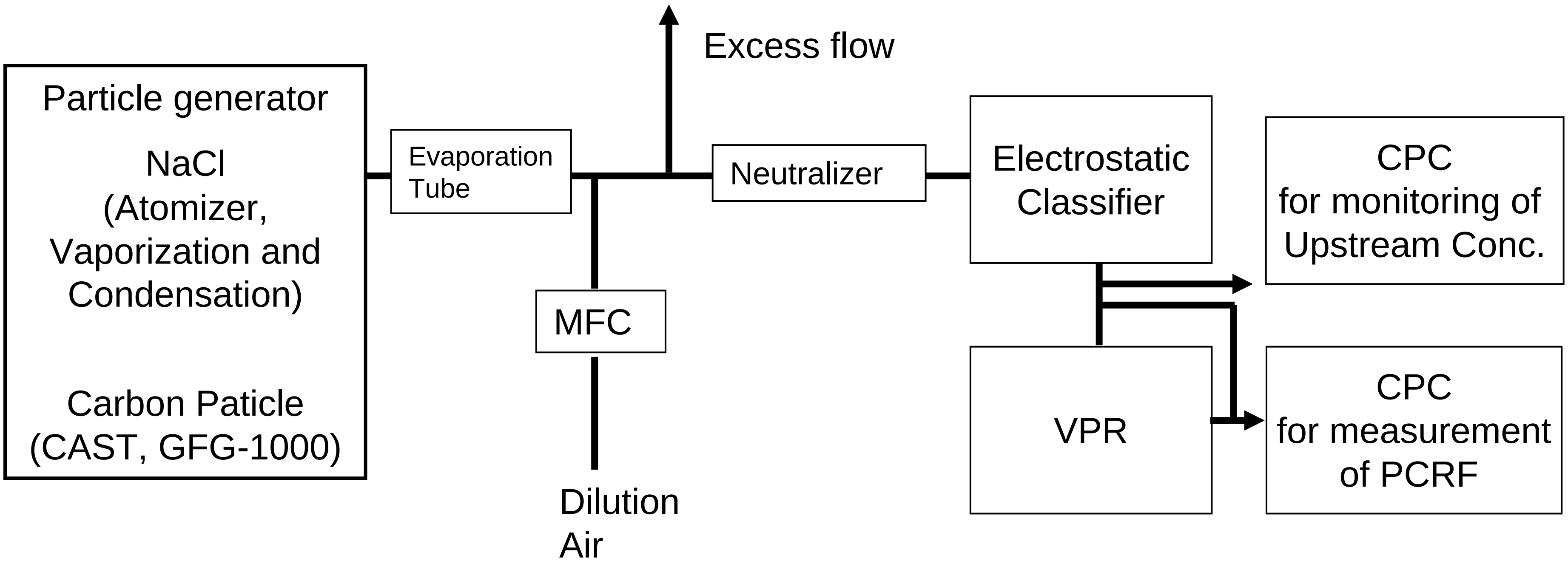
PNCS A: PND1_DF=ca. 20, PND2_DF=10
PNCS B: PND1_DF=10, PND2_DF=15

- PN from 1 type of engine was measured with 2 types of PNCS.
  - Engine: J08E-TP
  - PNCS: PNCS A and PNCS B
- Correlations of results of each PNCS were very good.
- Gradient of emission was different.
  - PNCS A>PNCS B
- ca. 20% of difference of measurement results were confirmed by crosscheck.
  (Differences of slope with previous slide should come from the **individual difference**.)

Summary of Crosscheck for PNCS

- Correlations of measurement results were very good through all experiment.
- Gradients of measurement results were different with PNCS of each manufactures.
  - 5 ~ 20% of difference of measurement results were confirmed.
  - We think differences of result are caused by difference of calibration methods used in each instrument companies.
- Therefore, It is important to grasp the influence of calibration methods, such as particle species, methods of particle generation and procedures.

Measurement of Particle Concentration Reduction Factors –Experimental Setup –



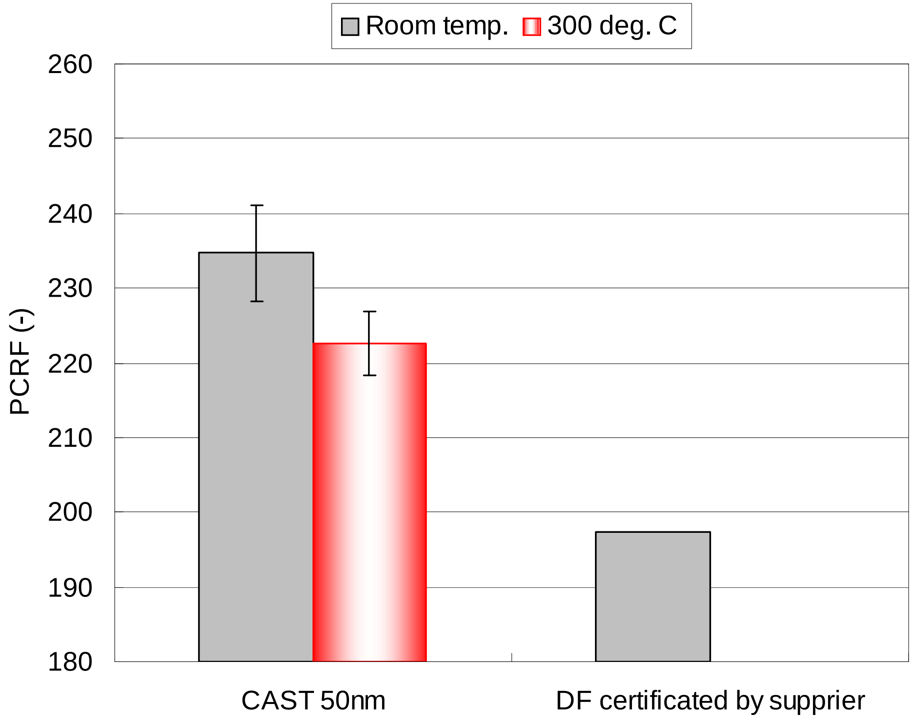
4 types of particle species were used for measurement of Particle Concentration Reduction Factor.

Matter system were only used for influence of calibration methods.

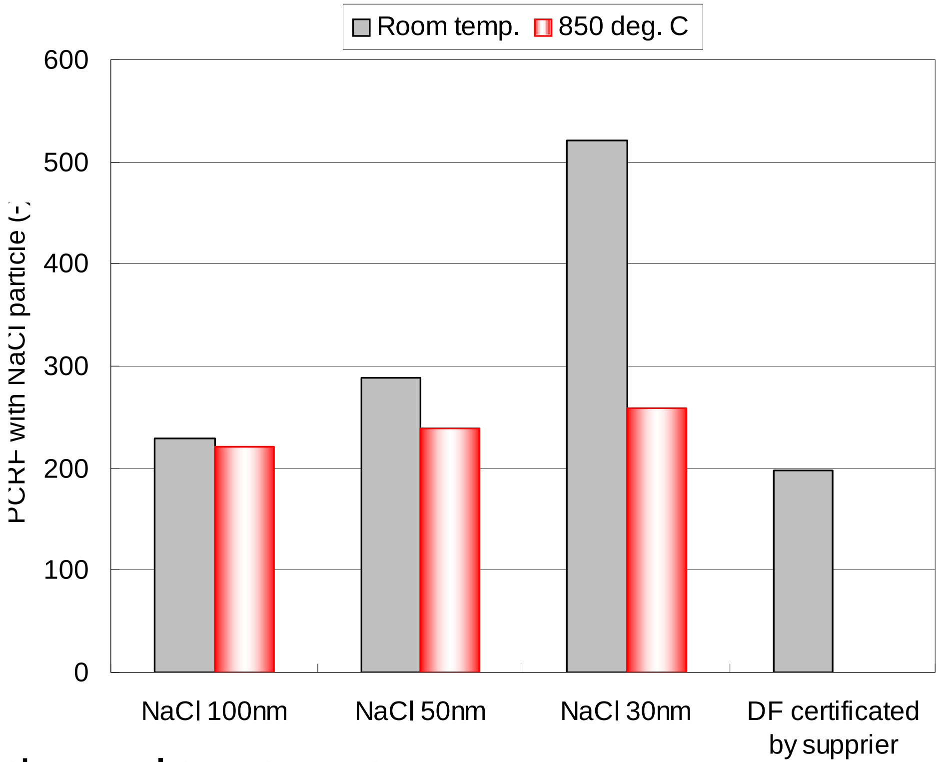
Evaporation tube was settled at upstream of particle classifier for stabilization of generated particle.

Influence of Thermal Treatment of Generated Particle for Calibration

Soot particle generated by CAST



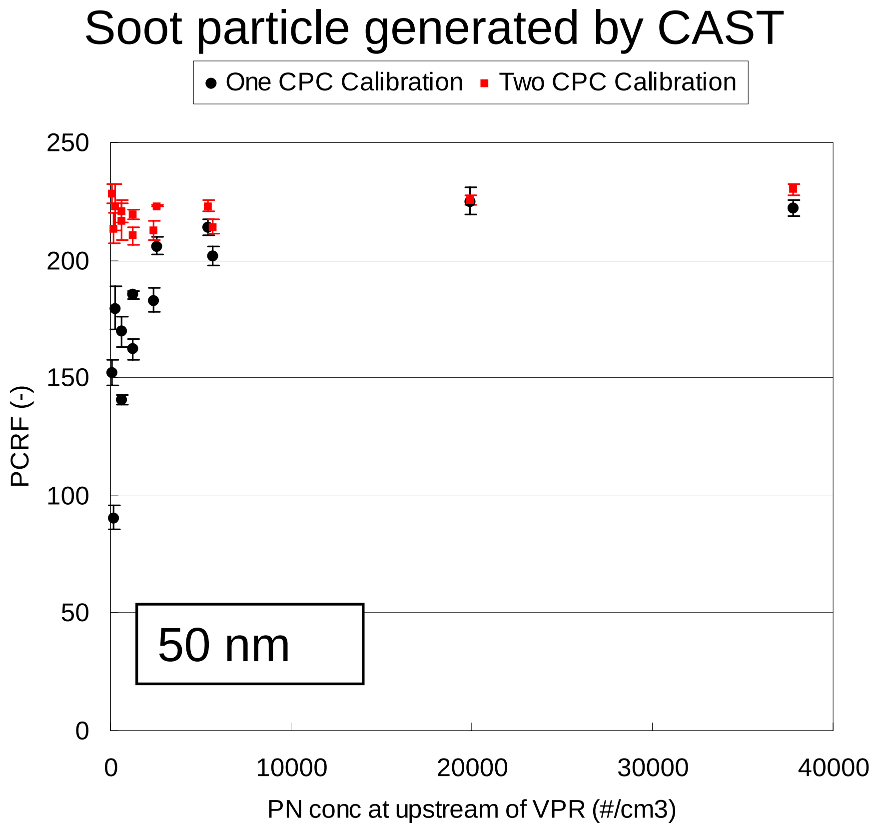
NaCl particle generated by vaporization and condensation method



PCRF measurements were influenced by thermal treatment.

These result shows vaporization or decomposition of particle were occurred at ET.

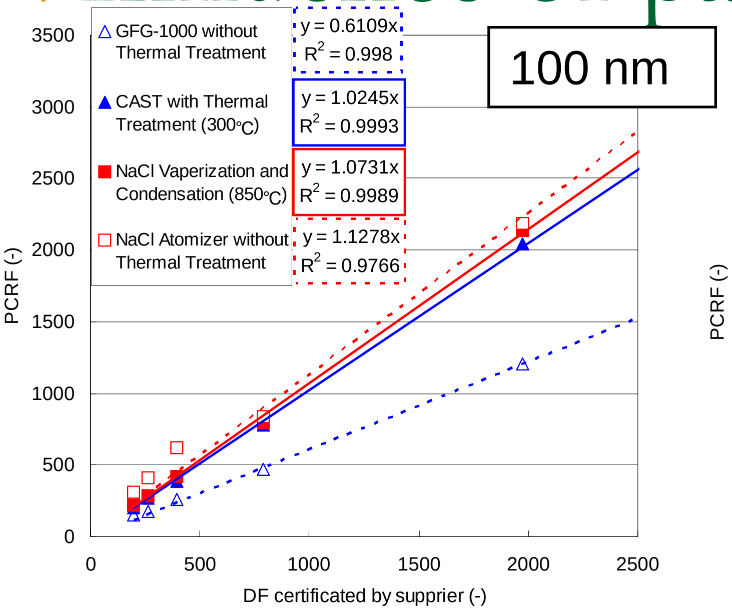
Influence of particle concentration at upstream of the VPR

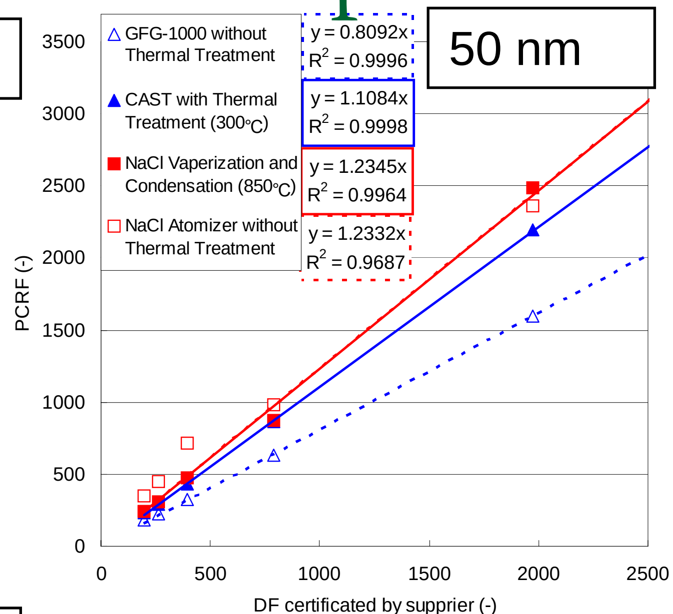


PCRF measurements were influenced by inlet conc. of VPR with one CPC calibration.

PCRF were not influenced by inlet conc. With two CPC calibration method.

Influence of particle species on PCRF



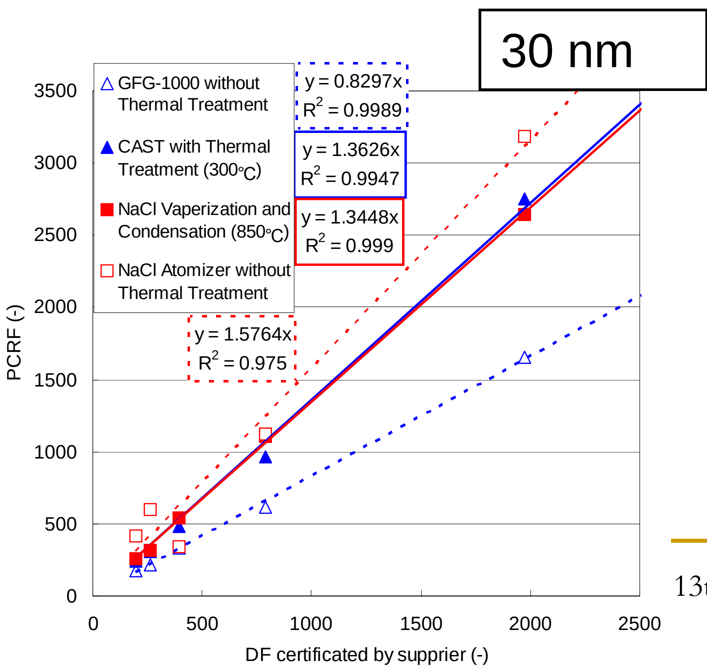


GFG-1000 without Thermal Treatment

CAST with Thermal Treatment (300 degC)

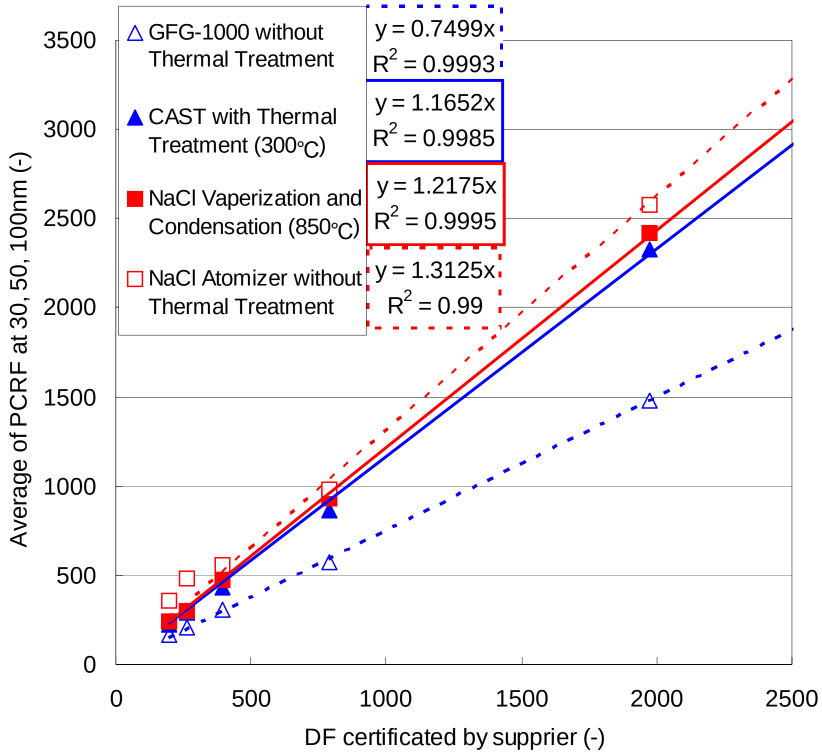
NaCl Vaperization and Condensation (850 degC)

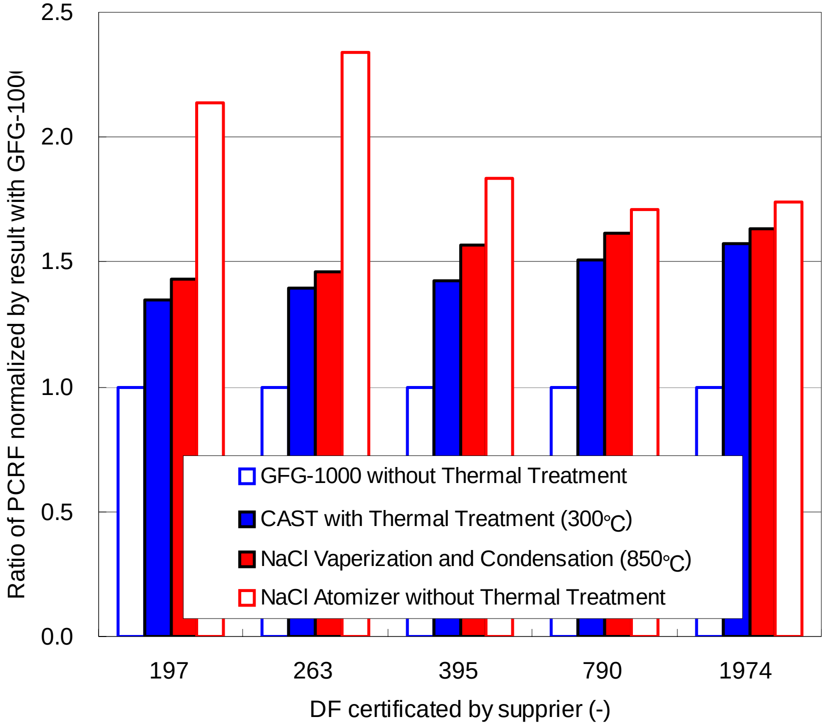
NaCl Atomizer without Thermal Treatment



- Measurement values of PCRF with each particle species were different.
- Especially, differences of PCRF were larger for smaller particle.

Influence of particle species on PCRF





- Measurement of PCRF were influenced by particle species and generation methods.
- PCRF could be the twice or more different depending on particle species and generation methods.
- Therefore, it is important that calibration method and procedure should be unified and strict more.

Summary of Particle Concentration Reduction Factor measurement

- Thermal treatment is necessary to measure accurate PCRF.
- Simultaneous measurement at upstream and downstream of VPR is essential to reduce effect of changing of particle concentration.
- Values of PCRF had a possibility the twice or more different by the difference of particle species, and generation method.

Conclusion

- Measurement result of PN emission was different by each PNCS.
- These difference of results should be caused from results of measurement of PCRF.
- PCRF measurement is influenced from particle species, generation method, thermal treatment, and so on.
- Therefore, calibration methods and procedures should be unified and strict more for a good accuracy of measurement.

Thank you for your kind attention.

Particle size distributions