16th ETH-Conference on Combustion Generated Nanoparticles

Influence Factors of NaCl Particle Generated by Atomization Method and Particle Concentration Reduction Factor on Calibration of Solid Particle Counting System

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The European Union has announced the next term emission regulations for light-duty vehicles, Euro 5 and 6, which include particle number (PN) emission standards. The PN counting method for the regulation is described in UNECE Regulation No.83.The required PN counting system consists of a Volatile Particle Remover (VPR) and a Condensation Particle Counter (CPC). The regulations also require calibrating the Particle Concentration Reduction Factor (PCRF) in VPR periodically. Since PCRF is directly used in calculation of total amount of PN emission, the improper calibration of the factor can cause a large uncertainty of PN emission measurement. This paper investigates propriety to use NaCl particles generated by atomizing method in PCRF calibration as reference particles.

Figure 3 shows the principle of atomizing method with heating treatment. The NaCl solution in a bottle is atomized by an atomizer, and generated mist passes through the heated sample line controlled at 100 degC. Then, the sample mist is cooled down by cooling air during going through a heated exchanger. As a result, surplus water vapor comparing dew point at room temperature is condensed and removed by a water droplet trap. Finally, the sample gas is introduced into a tube with silica gel as a dryer to absorb remained vapor in the gas, so that sample gas including dry NaCl particle can be supplied form the generator outlet.

Figure 7 shows the size distribution of the NaCl particles with heating treatment. In this case, the size distribution was not changed between at inlet and outlet as expected. From the stability of the size distribution in Figure 7, NaCl particles generated with heating treatment are considered not to contain excess water fraction which will cause large particle loss and inaccurate PCRF calibration.

In this paper, the reliability and stability of NaCl particles generated by atomizing method as reference particle for PCRF calibration, has been evaluated, as one of the important influencing factors on accuracy of PN emission. The following conclusion can be obtained through the investigation:

- From the comparison of obtained PCRF by atomizing method, combustion method and spark method, it is shown that the PCRF dependency on the particle species used in calibration process can be minimized by adding heating treatment for generators.
- It is confirmed that the NaCl particles by atomizing method shows sufficient stability, being compared with the other methods.
- The mean PCRF calibrated by NaCl particle for almost 196 units of VPR calculated has been sufficiently stable. This result suggests that PCRF calibration with NaCl particle can achieve sufficient reproducibility.

As a result, it is shown that the NaCl particles by atomizing method can be used in PCRF calibration as reference particles because of sufficient stability and reliability.

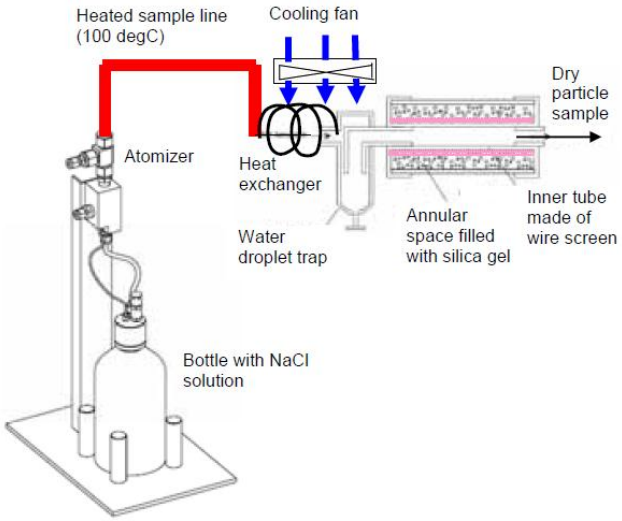

Fig. 3 Schematic diagram of LCU

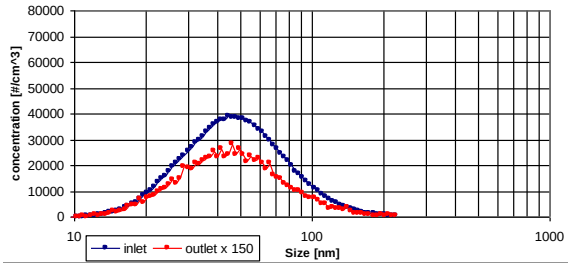

Fig.7 Size distributions at inlet and outlet of VPR (LCU with heating)

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Background

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- The PMP (Particle Measurement Program) was organized under the UNECE WP29/GRPE

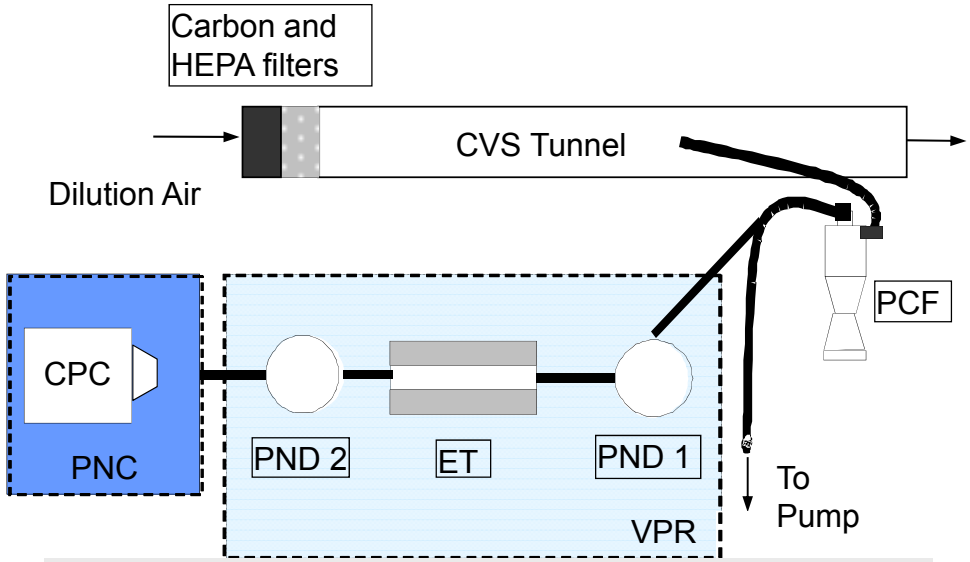
  Aim was to develop a new system of PM measurement (instrument, sampling and procedures) to complement or replace the existing gravimetric method

⇒ New particle number counting method by PMP has been incorporated in UN/ECE Regulation No.83

- EU introduces particle number (PN) emission limit at:
  - Euro 5b and Euro 6 for LDV
    - Euro 5b (2011/9): Vehicles with C.I. engine
    - Euro 6 (2014/9): Additional for vehicles with P.I. engine
  - Euro VI (2013) for HDE

PN counting system

PN counting system and calculation of PN emission



Configuration of PN counting system
(Solid particle only)

$$N = \frac{V \times k \times \overline{C_s} \times \overline{f_r} \times 10^3}{d}$$

N : particle number emission [km^{-1}]
V : Total Volume for diluted exhaust gas [L/test]
k : calibration coefficient for PNC
$\overline{C_s}$: Average particle counting conc. [cm^{-3}]
$\overline{f_r}$: Mean PCRF
d : distance [km/test]
(UNECE regulation R83)

Two coefficients, i.e. k (calibration coefficient for PNC) and $\overline{f_r}$ (mean PCRF) directly affect on the result of total PN emission

Purpose of this study

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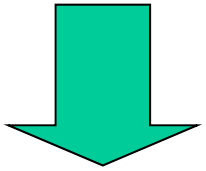
■ *Particles generation method for PCRF calibration* is one of key factors on measurement accuracy

It has been reported that:

- Influences of thermal treatments on soot particles generated by CAST and NaCl particles by evaporation and condensation, and
- Necessity of thermal treatment for generated particles



Influence of thermal treatment on NaCl particle generated by atomizing method was still unclear

Evaluation of NaCl particles generated by atomizing method for accurate PCRF calibration

- Influences from thermal treatment
- Stability of generated particle concentration
- PCRF reproducibility with different VPRs

Calibration of PCRF

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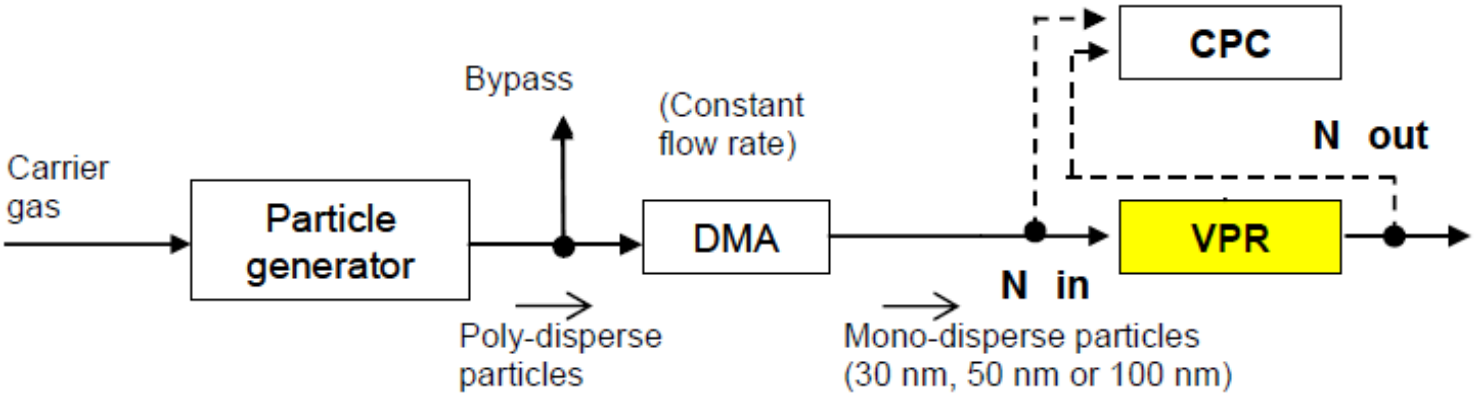
Outline of PCRF calibration



- Calculation of PCRF and mean PCRF

$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)}$$

$fr(di)$: PCRF for particles of diameter di

$Nin(di)$: upstream particle concentration for particles of diameter di

$Nout(di)$: downstream particle concentration for particles of diameter di

$$\overline{f_r} = \frac{f_r(d_{30nm}) + f_r(d_{50nm}) + f_r(d_{100nm})}{3}$$

$\overline{f_r}$: mean PCRF

Experimental set up

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Particle generators used in evaluation

Generator	**LCU**	CAST	mini CAST	GFG
Principle	**Atomizing**	Combustion	Combustion	Spark
Particle species	**NaCl**	Soot	Soot	Carbon
Particle size	5 nm to 400 nm	30 nm to 200 nm	20 nm to 200 nm	20 nm to 150 nm
Manufacturer	HORIBA	Matter Engineering	Jing	PALAS

Experimental set up

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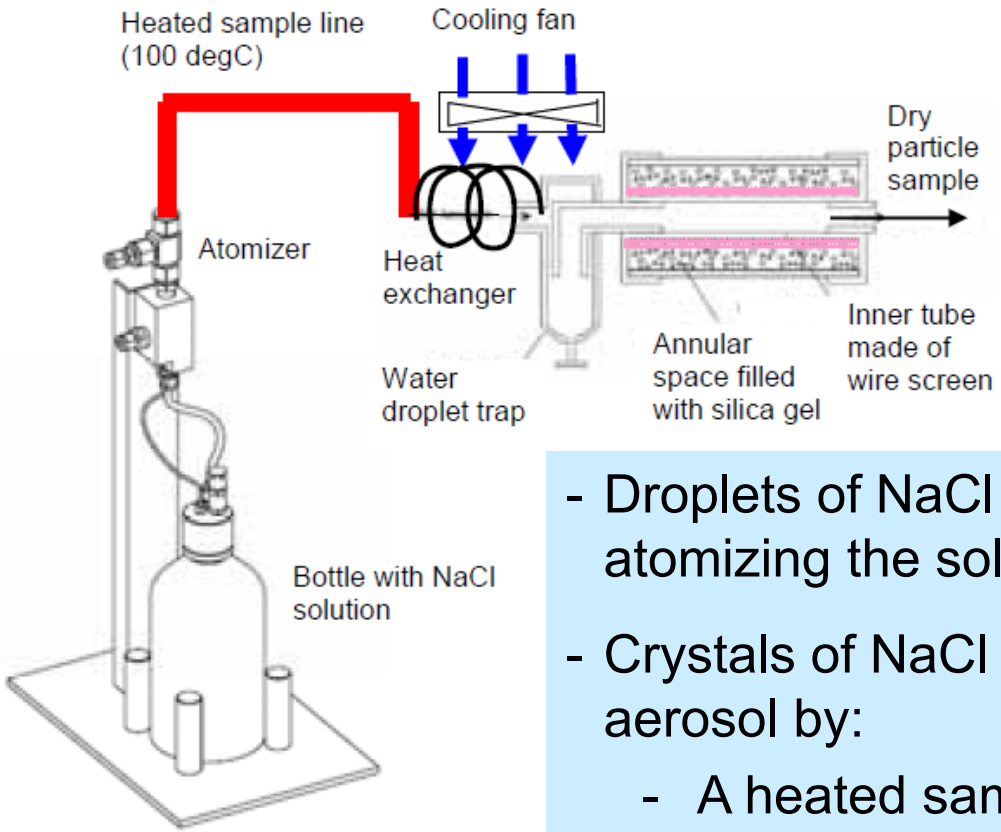
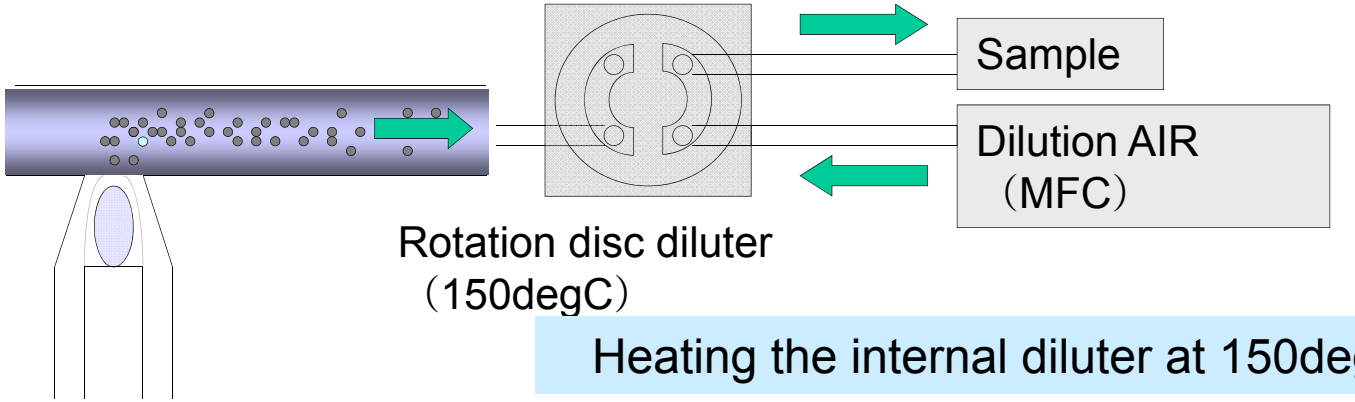
- Thermal treatment for NaCl particles generated by LCU



- Droplets of NaCl solution are generated by atomizing the solution.
- Crystals of NaCl are formed by removing water from aerosol by:
  - A heated sample line controlled at 100 degC,
  - A heat exchanger with cooling fan, and
  - A silica gel dryer

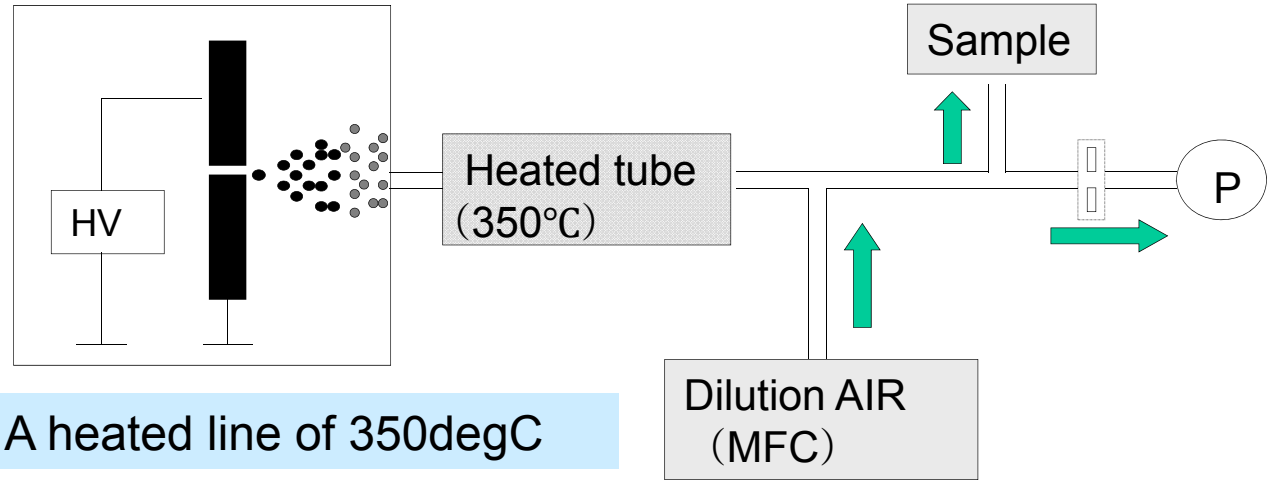
Experimental set up

- Thermal treatment for soot particles generated by CAST



Heating the internal diluter at 150degC

- Thermal treatment for carbon particles generated by GFG and soot particles generated by mini-CAST



A heated line of 350degC

Influences from thermal treatments

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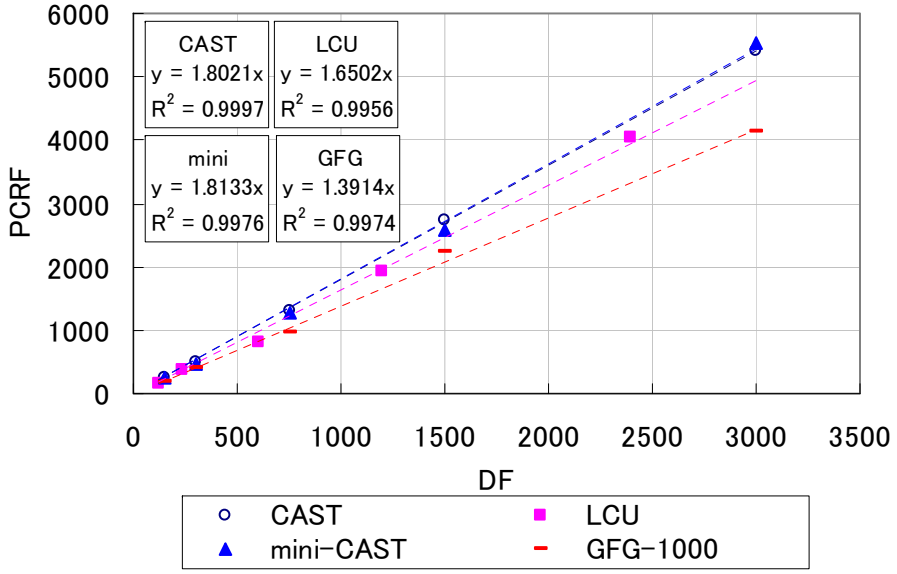
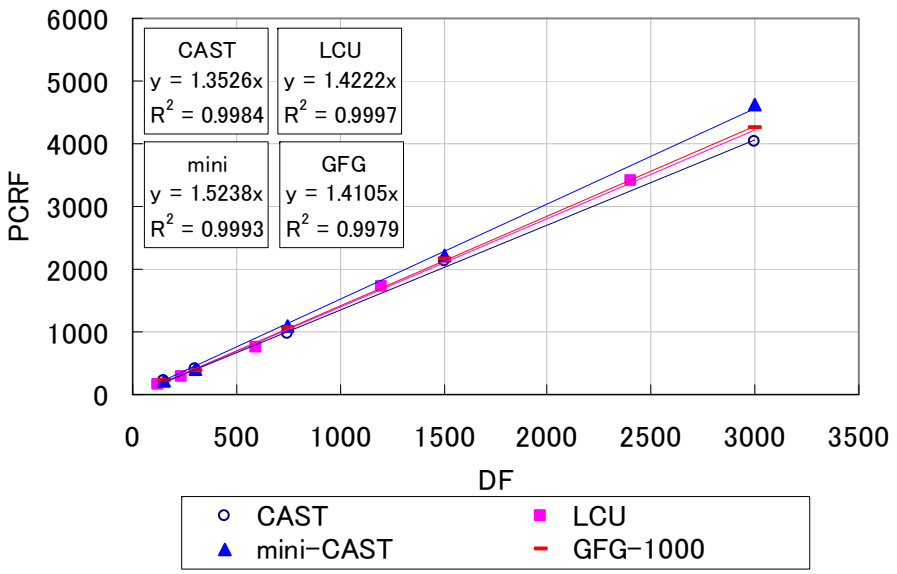
Without thermal treatment



With thermal treatment



- PCRF dependency on the particle species in calibration process can be minimized by applying the appropriate thermal treatments to the generated particles.

Influences from thermal treatment

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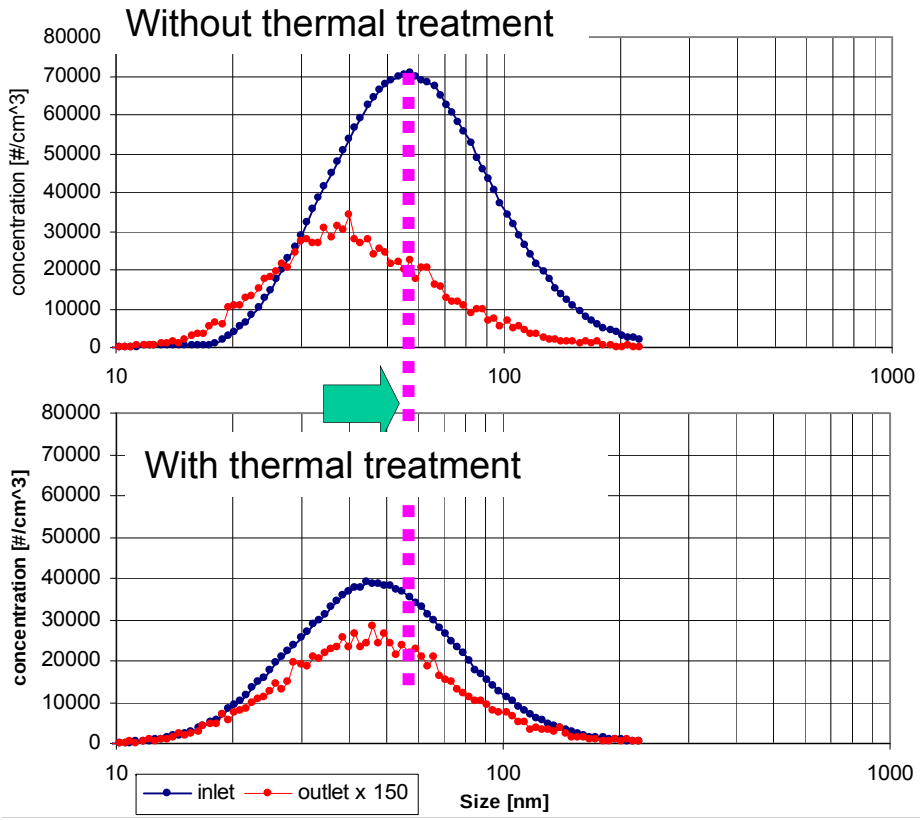
Stability of particle size distribution for NaCl particles



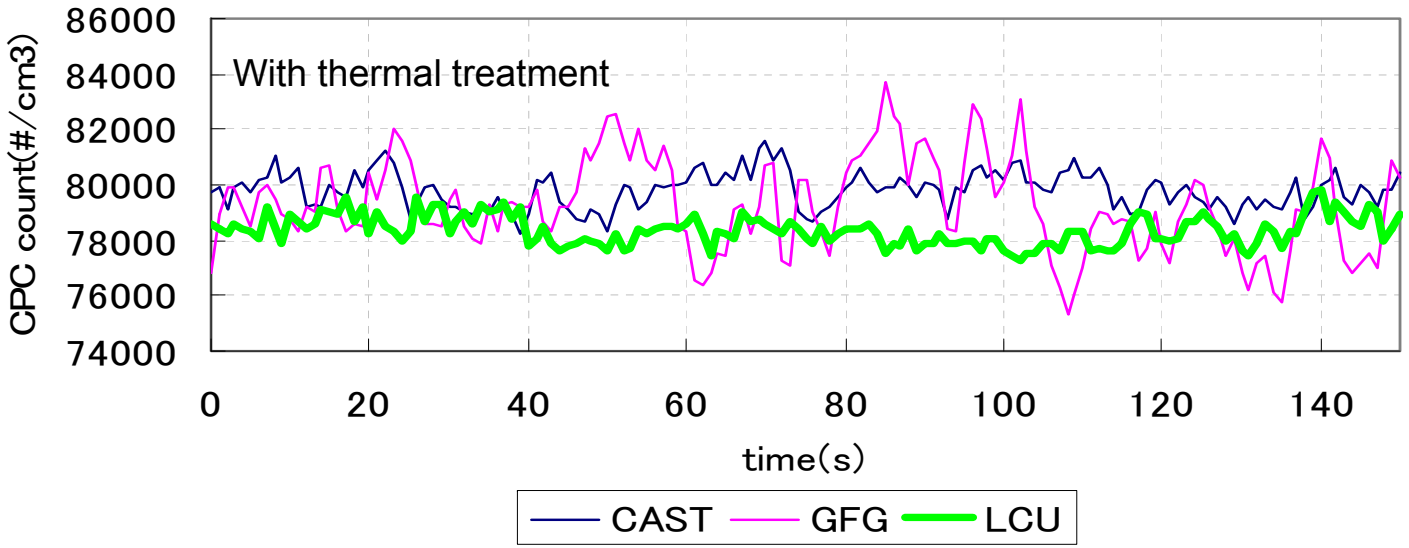
The size distribution of particles at downstream flow of VPR is clearly shifted to the smaller side compared to that at upstream flow.

The size distribution at upstream and downstream flow of VPR agrees with each other.

In the case of without thermal treatment, water may remain in the particle because it can not be removed perfectly.

Stability of particle concentration

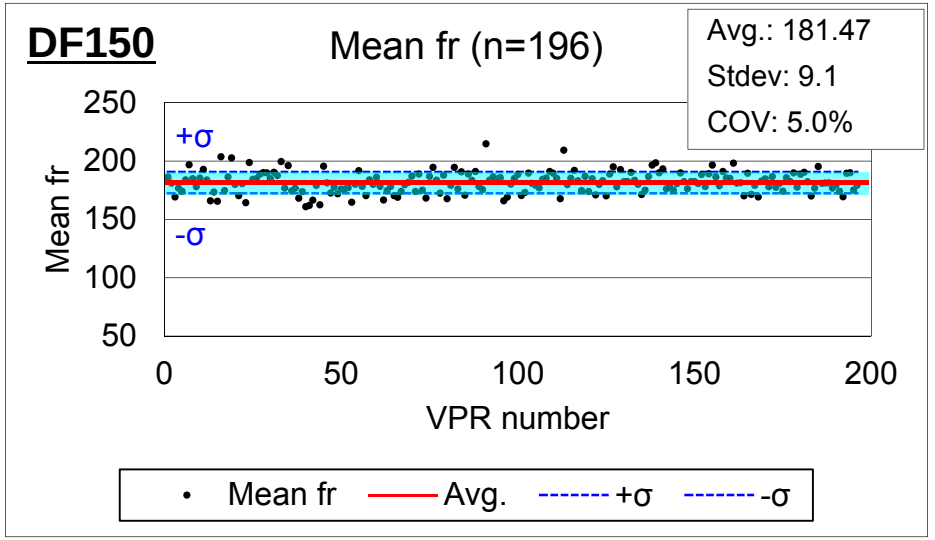
- The particles generated by CAST and LCU show almost equal good stability.

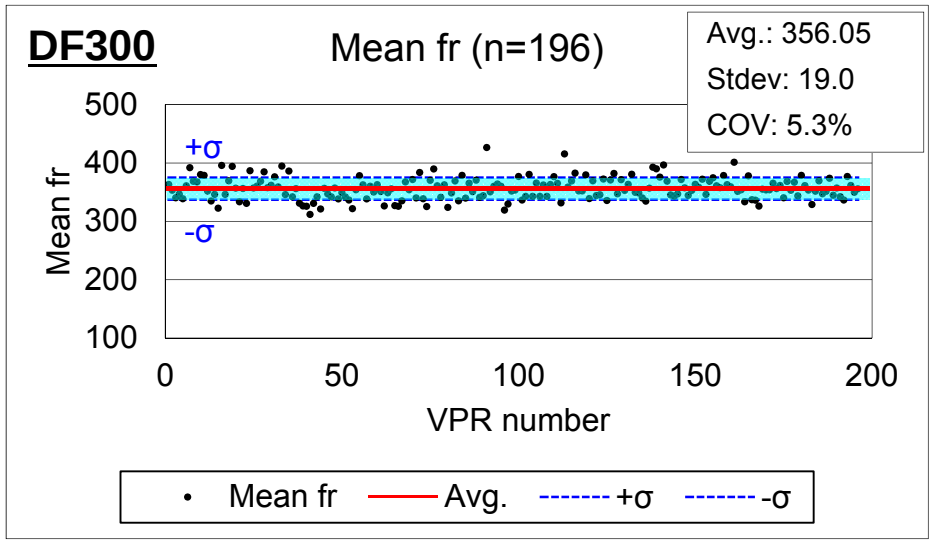


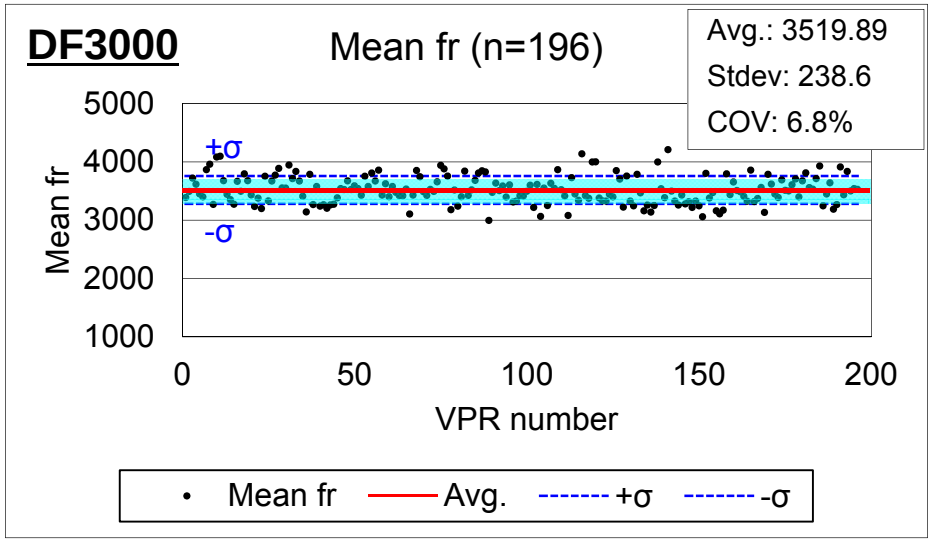
Generator	CAST	GFG-1000	LCU
Average	79807	79294	78357
Standard deviation	662	1694	539
Coefficient of variance (CV)	0.83%	2.14%	0.69%

PCRF reproducibility with VPRs

- CV of mean PCRF with 196 units of VPR is small enough, from 5.0% to 6.8%.
- This suggests that PCRF calibration with NaCl particles can be performed with sufficient reproducibility for long term.







Conclusion

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- PCRF dependency on the particle species used in calibration process can be minimized by applying the appropriate thermal treatment to the generated particles
- NaCl particles generated by atomizing method shows the sufficient stability compared to combustion aerosol generators and an aerosol generator using electrical spark method
- PCRF calibration with NaCl particles generated by atomizing method can be performed with sufficient stability and reliably

NaCl particles generated by atomizing method can be used in PCRF calibration as a reference

Thank you