The effect of a thermal denuder on the measurement of black carbon generated in a diesel engine

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Introduction

- Black carbon(BC) is contained in atmospheric aerosol due to the soot generated in diesel engines, and is known to act as a positive radiative forcing.
- Some volatile compounds produced during combustion process in diesel engines can cause bias for a filter-based measurement of optical properties.
- A thermal denuder is known to remove volatile compounds included in aerosol by passing the aerosol through a pipe maintained at a temperature nominally higher than 200 ℃.
- This research attempts to show that the BC measurement can be affected by the installation of a thermal denuder at an inlet of measurement instruments.
- In this study, mass concentrations and number concentrations measured with the thermal denuder in operation were compared to those measured without the thermal denuder.

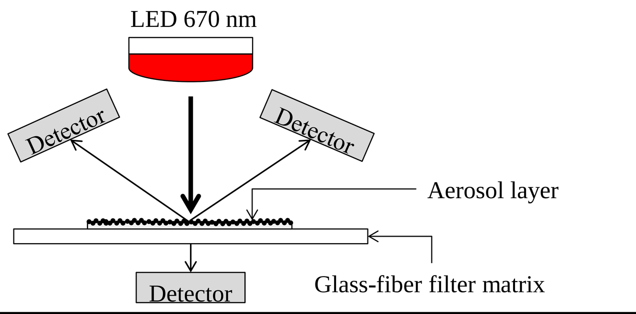
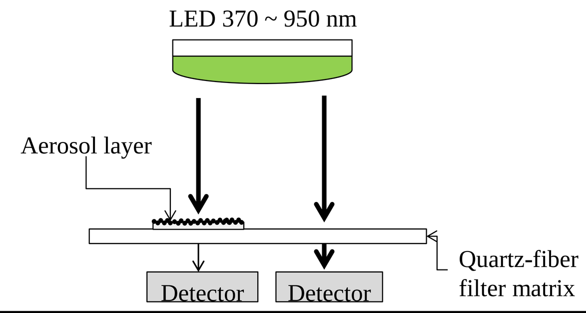
Literature Survey

Previous research on a thermal denuder

Temperature(℃)	Measurement	Source & Size distribution	Research group
150/200/250	▪ Size distribution	▪ Nebulized NaCl	Burtscher's group (Fierz et al., 2007)
150/250/300	▪ Size distribution ▪ Penetration eff.	▪ Dry carbon black ▪ Polydisperse	Hwang's group (Park et al., 2008)
200	▪ Mass ▪ Number conc. ▪ Effective density	▪ McKenna burner ▪ Inverted burner ▪ Polydisperse	Olfert's group (Ghazi et al., 2013)
100/200	▪ Light absorp. coeff. ▪ Number conc.	▪ Diesel engine ▪ Monodisperse (50~150 nm)	Present study

- This study investigates the effect of thermal denuder (TD) on mass concentrations for monodispersed BC particles generated in a commercial diesel engine for the first time as far as the authors know.

MAAP vs. Aethalometer

		Multi angle absorption photometer(MAAP)	Aethalometer
Principle		➢ Monitors both the light transmission through the glass-fiber filter and the light scattering caused by aerosol layer. ➢ Then, compensates the transmittance using scattering calculated by a radiative transfer model (Petzold & Schönlinner, 2004).	➢ Monitors the light attenuation through the quartz-fiber filter. ➢ Then, converts the light attenuation to BC mass concentration (Hansen et al., 1984).
Features	Flow rate (L/min)	➢ 16.7	➢ 6.7
	Collection time (min)	➢ 1 ~ 60	➢ 1 ~ 60
	Wavelength (nm)	➢ 670	➢ 370, 470, 520, 590, 660, 880, 930
Schematic			

- Filter-based methods are sensitive to particle-related back scattering effects caused by filter fibers.
- MAAP signals at three detection angles resolve the influence of light-scattering aerosol components of the angular distribution of the back scattered radiation.
- We used MAAP to measure the mass concentration compensated for the scattering effect.

Effective Density Calculation

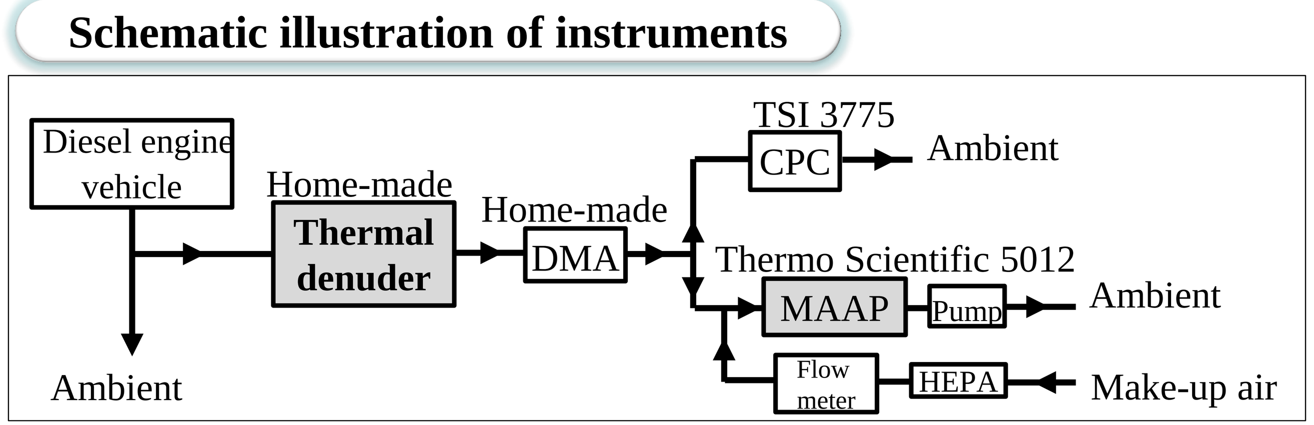
$$m_{BC} = \frac{C_{BC}}{N} \Rightarrow \rho_{eff} = \frac{m_{BC}}{V_{eff}}$$

C_{BC} : BC mass concentration , ρ_{eff} : effective density
V_{eff} : volume calculated from mobility diameter
m_{BC} : equivalent single particle mass,, N: number concentration,

- Effective density can be calculated from the equivalent mass and the equivalent volume assuming spherical BC.
- The equivalent mass is easily obtained from the mass concentration and the number concentration.
- The equivalent volume is also can be obtained from the mobility diameter.

Experimental method (1/2)

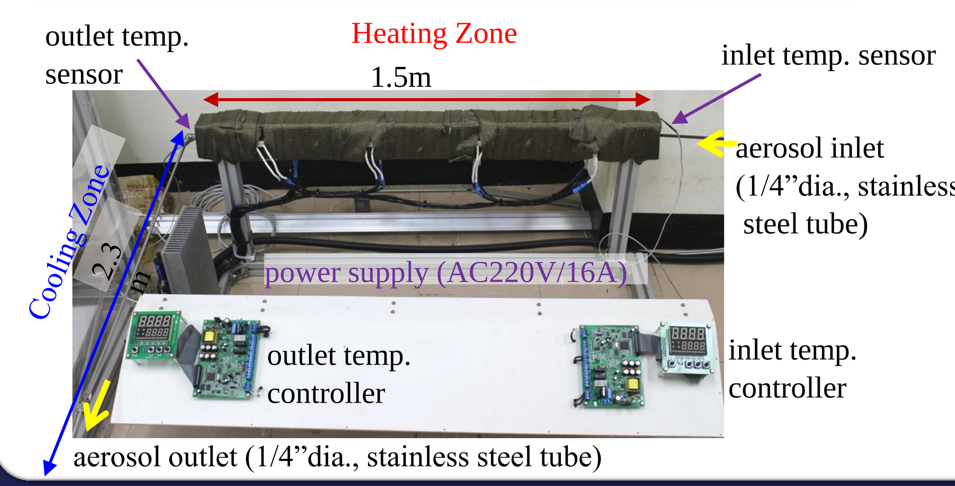
Schematic illustration of instruments



- The diesel BC was produced from a commercially available 2.0L waste-gate turbocharger (WGT) diesel vehicle.
- A home-made differential mobility analyzer (DMA) selected 50, 100, 150, 200, 250 nm BC particles.
- Condensation particle counter (CPC, TSI 3775) was used to measure number concentrations every 1 second and multi angle absorption photometer (MAAP, Thermo Scientific 5012) was used to measure mass concentrations every 1 minute.
- Make-up air was introduced into MAAP to satisfy the flow requirement, 16.7 lpm.

Experimental method (2/2)

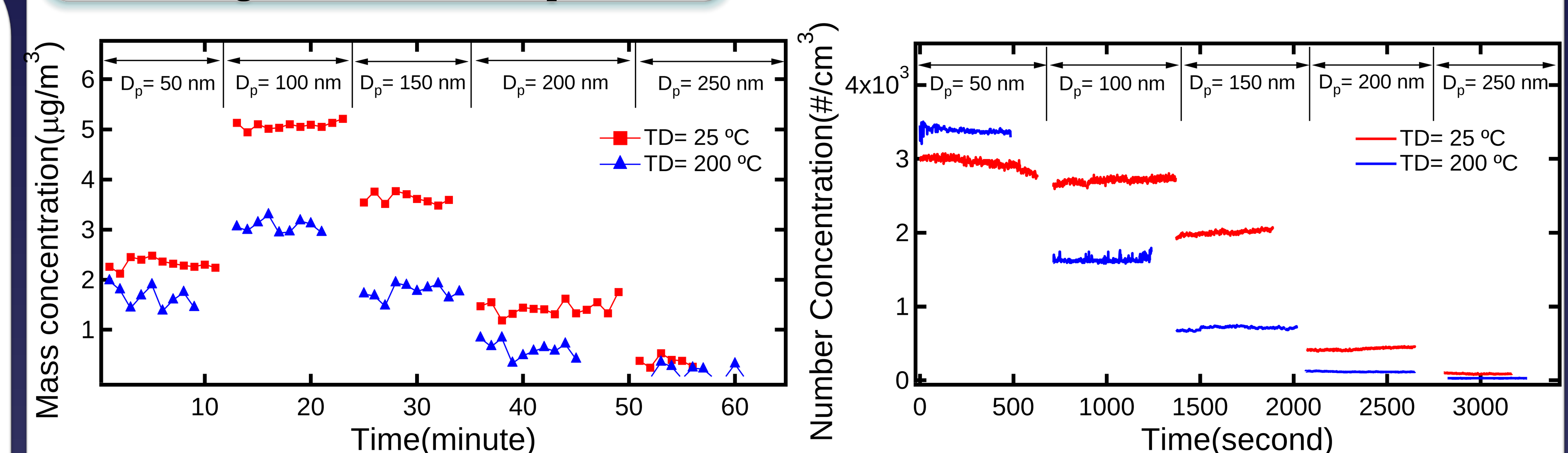
Description of our thermal denuder



- A home-made thermal denuder was installed at the inlet of measurement instruments. The temperature of the thermal denuder was maintained at approximately both 100 and 200 ℃, where the volatile compounds and humidity included in the diesel exhaust are supposed to be removed.
- A pre-heater can help to effectively remove moisture at aerosol inlet.

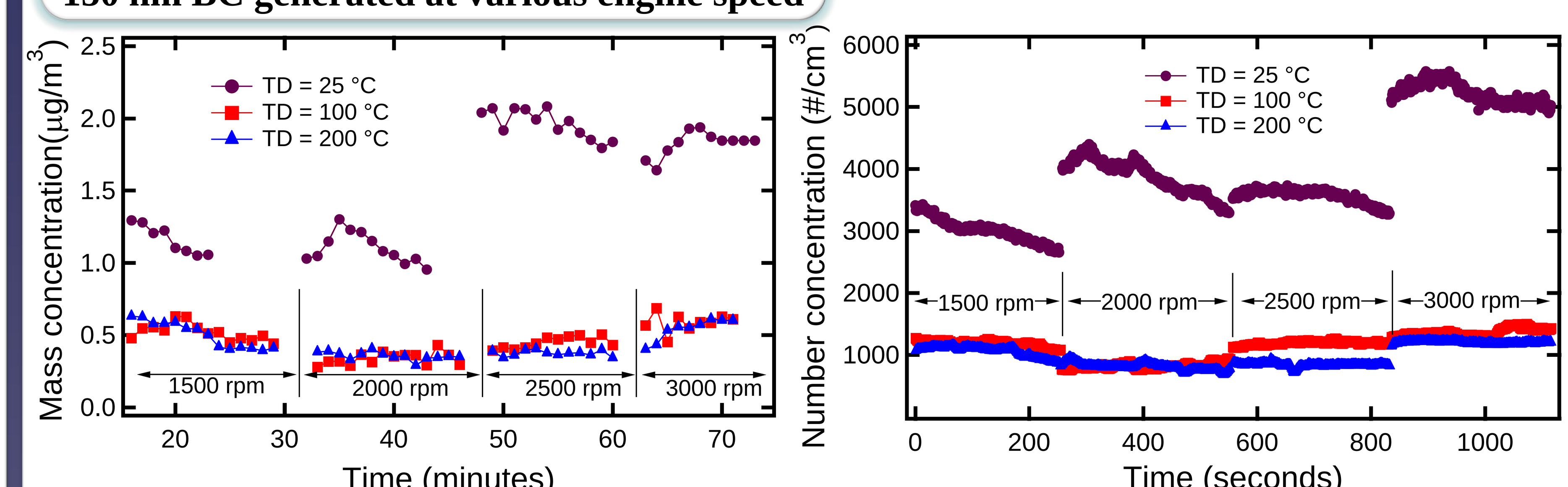
Results & Discussion

BC generated at 1500 rpm



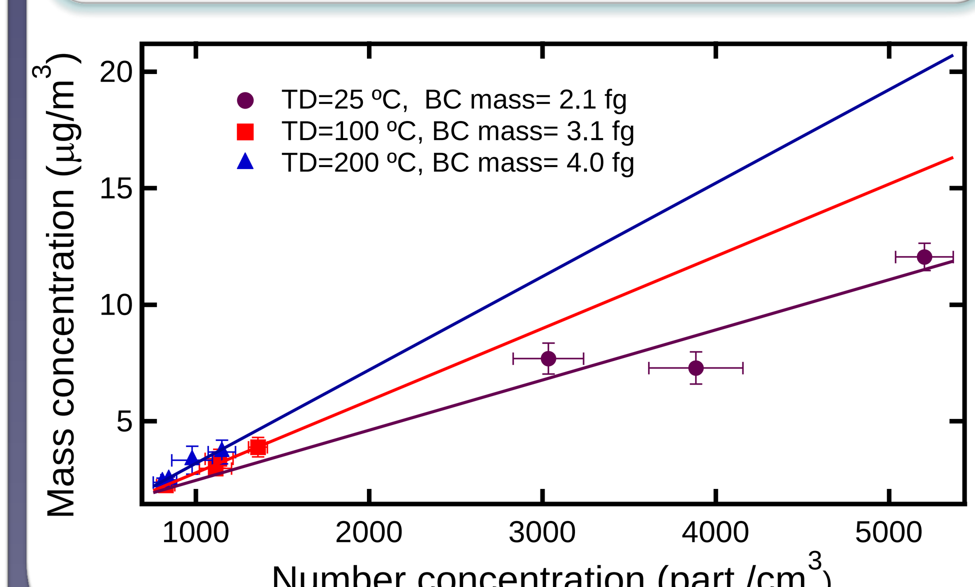
- Mass concentrations and number concentrations were measured for various particles generated 1500 rpm. Results show that mass concentrations decreased when TD was in operation.
- When TD was in operation, number concentrations decreased for all cases except D_p=50 nm.

150 nm BC generated at various engine speed



- Mass concentrations and number concentrations were measured for 150 nm BC generated at various engine speed . They decreased when TD was in operation for all cases.

150 nm BC Mass & Effective Density



TD(℃)	BC mass(fg)	ρ_{eff} (g/cm³)
25	2.1	1.19
100	3.1	1.76
200	4.0	2.26

- Graphs of mass concentrations versus number concentrations give us the equivalent mass from the slope of linear fit.
- When TD was operated at 200 ℃, the effective density of black carbon was obtained to be very similar to the effective density of graphite (2.09 ~ 2.23 g/cm³, John et al., 1990).

Conclusion

- When a thermal denuder was in operation, mass concentrations and number concentrations of black carbon generated in diesel engine decreased. The effective density of 150 nm BC, when the thermal denuder was operated at 200 ℃, was similar to the effective density of graphite.
- It seems that the mass concentrations and the number concentrations decreased with TD in operation because of the removal of volatile compounds presumably coated on top of the core BC. However, there is another possibility that BC could be lost on the inner wall of cooling zone due to thermophoresis.
- The measurements of mass concentration and number concentration are on going for the particles which do not have volatility, for example, carbon particles generated in a spark discharger.

References

Fierz et al., 2007, JAS; Ghazi et al., 2013, AST; Park et al., 2008, JAS; Petzold & Schönlinner, 2004, JAS; Hansen et al., 1984, JAS; Chow et al., 2009, AR; John et al., 1990, MSA;

Acknowledgements

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