

## PARTICLE EMISSIONS FROM SHIP ENGINES

A. PETZOLD<sup>1</sup>, Ph. FELDPAUSCH<sup>1</sup>, L. FRITZSCHE<sup>1</sup>, A. MINIKIN<sup>1</sup>, P. LAUER<sup>2</sup>, and H. BAUER<sup>3</sup>

<sup>1</sup> Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft- und Raumfahrt Oberpfaffenhofen, 82234 Wessling, Germany

<sup>2</sup> MAN B&W Diesel AG, Stadtbachstr. 1, 86135 Augsburg, Germany

<sup>3</sup> Institute for Chemical Technologies and Analytics, Vienna University of Technology, Getreitemarkt9/164/AC, 1060 Vienna, Austria

Keywords: MARINE POLLUTION, SHIP EMISSIONS, COMBUSTION AEROSOL.

### INTRODUCTION

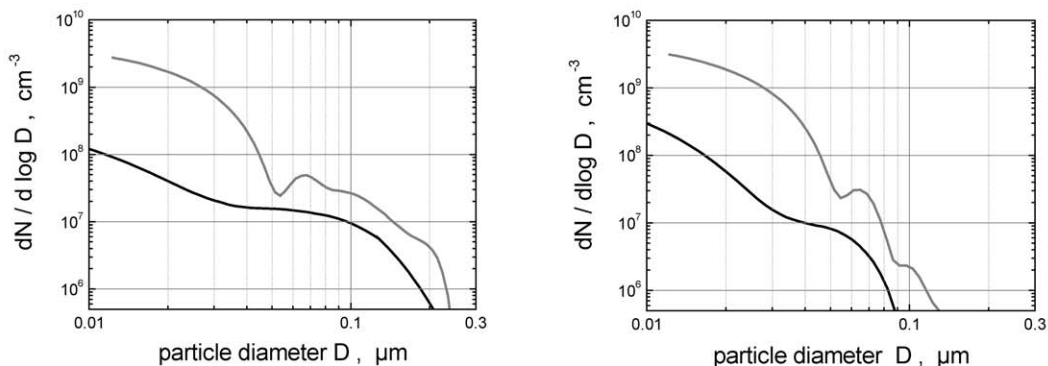
Emissions from the internationally operating marine transport sector are considered as one of the major contributions to anthropogenic emissions on a global scale of growing importance. First results are published on emissions of trace gases and particles from ships during cruise (Sinha et al., 2003) and at berth (Cooper, 2003). Model studies have examined the environmental impact of NO<sub>x</sub> emissions (Endresen et al., 2003) and the role of sulphur chemistry in ship plumes (Song et al., 2003). In particular the emission of particles and their fate in the marine environment are however widely unknown. From observations so far mainly bulk aerosol properties like mass concentrations are reported, while detailed chemical analyses and aerosol microphysical data are missing. In a first attempt, detailed aerosol microphysics and chemistry was measured in the exhaust gas of a single-cylinder test bed engine, which was operated at various load conditions, running on fuel with a sulphur content of 3.45 wt.-%.

### METHODS

Investigated properties were aerosol number and size distribution for total exhaust aerosol and nonvolatile combustion particles from on-line measurements and chemical composition from bulk filter samples. The aerosol microphysics instrumentation consisted of a TSI 3071 DMA operated in a closed-loop set-up, and a multiple-channel Condensation Particle Counter for resolving the sub- 20 nm size fraction (Stein et al., 2001). A heated thermodenuder was used for separating volatile and nonvolatile compounds. The on-line operating instruments required a dilution of 1:10<sup>4</sup> which was determined from parallel measurements of the CO<sub>2</sub> level in diluted and undiluted gas samples. Analytical methods deployed on bulk filter samples were multi-step combustion methods for organic/elemental carbon and ion chromatography for inorganic compounds, i.e. mainly sulphate.

### RESULTS AND DISCUSSION

Number densities of particles > 15 nm in diameter of the total aerosol exceeded 10<sup>9</sup> cm<sup>-3</sup> STP in the exhaust of the ship engines. The fraction of nonvolatile particles varied from 2.5 to 4%. However, as is shown in Figure 1, a clear size dependence of the fraction of volatile particles is observed. The vast majority of externally mixed volatile particles by number is centred in the Aitken and Nucleation mode regimes. In the accumulation mode regime, the observations indicate an internally mixed aerosol with a considerable fraction of sulphate-water coating. The increase of the size distribution of nonvolatile particles towards the 10 nm size threshold indicates the presence of a large number of sub-10 nm particles also for the nonvolatile aerosol fraction. Because of the large contribution of volatile sulphuric acid to the particle mass, it cannot be excluded, that part of the 10 nm sized particles detected downstream the thermodenuder result from incomplete volatilisation of sulphuric acid-water particles instead of being composed of carbonaceous material.



**Figure 1.** Particle size distributions in the exhaust of ship engines at 25% load (left) and 100% load (right); size distributions are plotted for total (grey) and nonvolatile (black) particles.

Compound	Mass Fraction in % of total particle mass	
	25% load	100% load
Black carbon	7	2
Organic matter	18	8
Sulphate	38	47
Sulphate-bound water	30	37
Ash	7	6

**Table 1.** Mass fractions of chemical constituents in the exhaust of ship engines.

The fractional chemical composition of exhaust particles emitted from the ship engine is summarised in Table 1 for two load conditions. Particles emitted by ships are mainly composed of sulphate and sulphate-bound water, while black carbon contributes less than 10% by mass. Emission properties of ship engines will be presented for different load conditions. First conclusions concerning CCN activation of ship exhaust particles will be drawn based on the measured chemical composition and particle size distribution, using the experience of CCN activation of aircraft engine exhaust particles as gained during the PartEmis experiment for aircraft engine exhaust particles (Petzold et al., 2003).

#### REFERENCES

- Cooper, D.A. (2003). Exhaust emissions from ships at berth, *Atmos. Environ.*, 37, 3817-3830.
- Endresen, Ø., et al. (2003). Emission from international sea transportation and environmental impact, *J. Geophys. Res.*, 108, 4560, doi:10.1029/2002JD002898.
- Petzold, A. et al. (2003) Properties of jet engine combustion particles during the PartEmis experiment: Microphysics and chemistry. *Geophys. Res. Lett.*, 30, doi 10.1029/2003GL017283, 2003.
- Sinha, P. et al. (2003). Emission of trace gases and particles from two ships in the southern Atlantic Ocean, *Atmos. Environ.*, 37, 2139-2148.
- Song, C.H., Chen, G., & Davis, D.D. (2003) Chemical evolution and dispersion of ship plumes in the remote marine boundary layer: investigation of sulfur chemistry, *Atmos. Environ.*, 37, 2663-2679.
- Stein, C., Schröder, F. & Petzold, A. (2001), The Condensation Particle Size Analyzer: A new instrument for the measurement of ultrafine aerosol size distributions, *J. Aerosol Sci.*, 32, S381 – S382.