Size-resolved particle emission factors for individual ships

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Introduction

More than 80 % of world trade is transported by ships and shipping is projected to increase further in the future (Buhaug et al., 2009). Emissions from shipping are today poorly regulated in legislation. Shipping has therefore become a more and more important source for urban air quality in coastal and harbour cities. Shipping also contributes globally to climate effects. E.g. the global contribution of particles from shipping is almost as large as from road traffic, 1.7 compared to 2.1 Tgy^{-1} (Eyring et al., 2005). For emission inventories both laboratory and field measurements are needed to complement each other. Measurements for large fleets on individual ship basis for nanoparticles are today very scarce.

Experimental method

A method previously used for vehicle emission measurements where particle emissions were related to CO_2 as a tracer of combustion e.g. (Hak et al., 2009, Hallquist et al., 2012) was in this study used for ship emissions. The measurements were conducted on a small island located in the entrance to the port of Gothenburg. A sample was extracted from passing exhaust ship plumes and characterized using an EEPS (Engine Exhaust Particle Sizer, model 3090, TSI Inc.), a CPC (Condensation Particle Counter, 3775, TSI Inc.) and a non-dispersive infrared gas analyser (LI-840, LI-COR Inc.) for CO_2. A thermodenuder was used in front of the EEPS to measure the volatile to non-volatile ratio of selected plumes. Emission factors (EFs) were calculated using the following formula:

$$EF_{PN/PM} = \frac{\Delta part}{\Delta gas} \times EF_{gas}$$

where $\Delta part$ and Δgas are changes in particle number/mass and CO_2 during ship passages and EF_{gas} is the EF for CO_2.

Results and Discussion

In these measurements particle emissions from individual ships have been characterized, both regarding number, mass and size distribution (Part 1) but also for volatility (Part 2) (Jonsson et al., 2011). The measurements were conducted in the entrance to the port of Gothenburg which is an emission control area (ECA) where the fuel sulphur content may not exceed 1 % by weight. In total 734 EFs (Fig. 1) were determined. In addition, for 92 of the measured EFs also the EF for the non-volatile fraction was determined (Part 2).

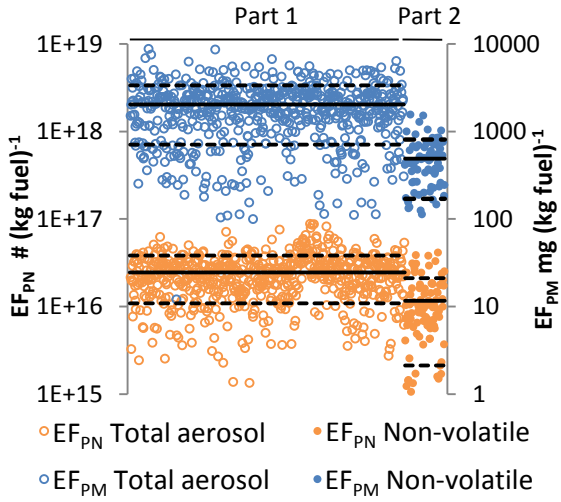

Figure 1: EF for 734 ship passages for number (EF_{PN}) and mass (EF_{PM}). The total aerosol was measured in Part 1 and the non-volatile fraction in Part 2. Solid lines represent averages and dashed lines represent 1 standard deviation.

The average emission factor for particle number, $\overline{\overline{EF_{PN}}}$ was 2.55±0.11×10^{16} (kg fuel)$^{-1,}$ and the average emission factor for particle mass, $\overline{\overline{EF_{PM}}}$ was 2050±110 mg (kg fuel)$^{-1}$. Compared to diesel buses without particle filter, the EFs in this study were a factor of 10 higher regarding number and a factor of 2 higher regarding mass (Hallquist et al., 2012).

Size-resolved EFs typically showed unimodal size distributions with average peak modes ~40 nm (Fig.2).

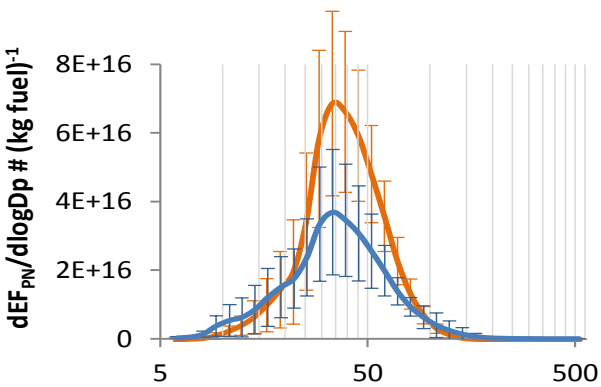

Figure 2: Size-resolved EFs for particle number for two cargo ships with multiple passages. Errors are at the statistical 95% confidence interval.

Conclusion

Using a stationary measurement platform for ship emissions proved to be very successful both regarding reproducibility, cost and number of ships studied. The average EF_{PN} and EF_{PM} for this SECA harbour area were found to be 2.55±0.11×10^{16} (kg fuel)$^{-1}$ and 2050±110 mg (kg fuel)$^{-1}$ respectively. The number size distributions were typically unimodal with average peak sizes at around 40 nm.

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