Exhaust particle characteristics and particle emission factors from a marine diesel engine with different fuels

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Annual primary particulate matter (PM) emissions of 1.7 Tg from international shipping are comparable to the PM emissions from road traffic (Eyring et al., 2005). It has been shown that 70 % of ship emissions occur closer than 400 km from shore, forming a significant source of pollution in coastal areas. (Corbett et al., 2007) PM emissions from shipping are not directly regulated but limits on sulphur (MARPOL Annex VI) are expected to have a reducing effect. Limits require ships to use low sulphur level fuels or abatement technologies such as scrubbers.

Diesel engines typically emit particles that can be seen in particle size distribution as one, two or three separate modes. Soot mode particles consist of agglomerates that can have volatile condensates on them. Nucleation mode particles usually include volatile components such as water, sulphur compounds and hydrocarbons. In some heavy duty diesel engine applications the exhaust can contain sub-10 nm solid particles forming so called core particle mode. Marine engines have been observed to produce a pronounced nucleation mode with particle diameters less than 50 nm. (Kasper et al., 2007)

In this study, marine engine particle number concentration and number size distributions were studied. Tested fuels included Marine Diesel Oil (MDO, 0.1% S), Intermediate Fuel Oil (IFO, 0.5% S), High Sulphur Fuel Oil (HS, 2.5% S) and a blend of biofuel (30%) and MDO (70%). The measurements were conducted using a 1.6 MW medium-speed test-bed engine equipped with mechanical injection system. Load conditions of 75% and 25% were used, corresponding to the operating conditions at open sea and near harbour, respectively.

The partial flow exhaust sampling system used in this study included a porous tube diluter (dilution ratio 12) followed by a residence time chamber. The sample was further diluted using an ejector dilutor with a dilution ratio of around 8. In part of the measurements the sample was directed through thermodenuder or catalytic stripper (Amanatidis et al., 2013) to study the volatility of the particles. Particle number and size distributions were measured using CPC (Airmodus A20), SMPS (TSI Inc.) and Nano-SMPS (TSI Inc.), together operating in size range of 2-414 nm. TUT-HTDMA system described by Happonen et al. (2013) was used to study the hygroscopicity of the particles.

The size distributions showed distinct nucleation modes with concentrations two to three orders of magnitude higher than for soot mode. For the high sulphur fuel, a clear three mode distribution was observed when running the engine on 25 % load. Emission factors were calculated for each mode by fitting lognormal distributions into the measured data and using the data on operating parameters of the engine. In general, fuel seems to have only a relatively small effect on the total emission factors; those were all in the order of magnitude of 10^{15} #/kWh. Lower load condition seems to slightly increase the emission factors; greatest effect was noticed for the soot mode emission factor. The fuel type had an effect on the hygroscopic growth factors calculated for particles treated with relative humidity of 80 %.

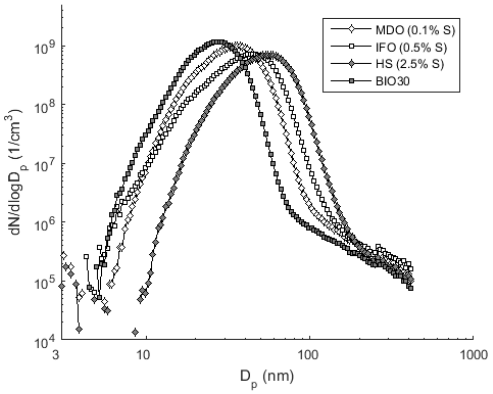

Figure1. Comparison of particle size distributions measured with four different fuel types at 75 % load.

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