Nanoparticle emissions from LNG and other low sulfur marine fuels

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Why consider particle emissions from ships?

• Emissions of primary particles from shipping (1.7 Tg) are within same magnitude as for road traffic (2.1 Tg) annually (Eyring, 2005, Journal of Geophysical Research, vol 110)

• 15-25% of global PM2.5 emissions are from shipping (EEA technical report, 4/2013)

• Cause approx. 60 000 deaths from lung cancer and cardiovascular diseases annually and globally (Corbett et al., 2007, Env. Sci. & Tech. vol 41)

• Not yet directly regulated

• Ongoing discussions within International Maritime Organization about regulation of emissions of black carbon

• Consist of black carbon, sulfate, organic carbon, elemental carbon, ash, particulate nitrate and inorganic substances and metals (Moldanová et al., 2009, Atm. Env. Vol 43; Lack et al., 2009, Journal of Geophysical Research, vol 114)
Indirectly regulation of particles

- Indirectly regulated through regulation of sulfur content in marine fuels (Regulation 14 in MARPOL Annex VI, International Maritime Organization (IMO))
- Reduction of particles was the driving force
- Global limits and limits in designated sulfur emission control areas (SECAs)
Limitations of fuel sulphur content

Note: The shipping sector still discuss % sulfur in the fuel
Limitations of fuel sulfur content

Force ship owners to use....
  • Abatement technologies (scrubbers)
  • Low sulfur marine fuels
  • Alternative fuels (for example liquefied natural gas (LNG), methanol)

To comply with the regulation of sulfur content in SECAs

Focus on particle emission from:
  • Low sulfur marine fuels
  • Alternative fuels, here LNG

Focus on number of particles emitted and the sizes and emissions from ship operations
Experimental

Two different studies

1. Measurements on test-bed engine, Chalmers*
   - Marine diesel engine with installed power of 81 kW
   - Heavy fuel oil (HFO) with 0.1% sulfur content
   - Marine diesel oil (MDO) with 0.5% sulfur content
   - Swedish environmental class 1 diesel (MK1) with <3 ppm sulfur content as reference fuel

2. Onboard measurements
   - Dual-fuel engine with installed power of 7600 kW/engine
     - Liquefied natural gas (LNG)
     - Marine gas oil (MGO) with 0.05% sulfur content as pilot fuel

* Anderson et al., 2015, Characterization of particles from a marine engine operating at low loads, Atmospheric Environment, vol. 101, pages 65-71
Experimental

Particle measurements

• Engine Exhaust Particle Sizer (EEPS, Model 3090 TSI Inc.)
  5.6-560 nm (number, mass and size distribution)
• Dust monitor (Grimm Model 1.108)
  300 nm to 20 µm (number and mass)
• Thermodenuder heated to 300°C
  Non-volatile (solid) fraction of the emission

• Dilution with Fine Particle Sampler (FPS)

Gaseous emissions

• CO₂, CO, O₂, NOₓ, SO₂ and Total hydrocarbons (THC)
Results: Sizes of particles

Nanoparticles (<50 nm after Hinds, 1999)
Dominate; 88-96% of total particle number.
Volatile and non-volatile character

Diameter >50 nm
Non-volatile character.

Origin of particles
Lubrication oil and pilot fuel (marine gas oil, MGO)

Note: logarithmic scales on x- and y-axis
Results: Sizes of particles

Nanoparticles
- Dominate;
- 94% for MDO, 85% for HFO of total particle number.
- Both of non-volatile (solid) and volatile character.

Diameter >50 nm
- HFO considerably higher than MDO.
- Non-volatile (solid) particles.

Origin of particles
- Fuel and lubrication oil

Sulfur

Fuel quality, (viscosity, ash etc)

Present marine fuels and MK1

Note: logarithmic scales on x- and y-axis

HFO: heavy fuel oil; MDO: marine diesel oil; MK1: Swedish environmental class 1 diesel
Results: Sizes of particles

Nanoparticles Dominate independently of fuel type.

Diameter >50 nm
HFO considerably higher than MDO and LNG.

Note: logarithmic scales on x- and y-axis
HFO: heavy fuel oil; MDO: marine diesel oil
Results: Number of particles

**Trend**
Emissions of non-volatile particles increase with reduced engine load.

**Why?**
Higher amount of pilot fuel used

**Important to consider when operating in ports and coastal areas**
Results: Number of particles

Highest emissions of particles related to number (PN) for HFO.

Significant reduction in emissions of particles for LNG, compared to present marine fuels

Note: logarithmic scales on x- and y-axis
HFO: heavy fuel oil; MDO: marine diesel oil
Concluding remarks

These studies show that
A change from low-quality fuels (heavy fuel oil) to high-quality fuels (marine diesel oil or marine gas oil) or alternative fuels (here LNG) is a step in the right direction towards more sustainable shipping in aspect of air quality

• But, there are still particle emissions to consider

Both sulfur content and fuel quality should be considered in evaluation and in future legislation of particle emissions from ships

• Sulfur content impact emissions of nanoparticles
• Fuel quality impact emissions of particles with Dp>50 nm
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Thank you for your attention!

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