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TAMPERE UNIVERSITY OF TECHNOLOGY

Number and Characteristics of Particles Emitted from a Marine Engine Using Different Fuels

N. Kuittinen[1], P. Karjalainen[1], P. Aakko-Saksa[2], H. Timonen[3], P. Simonen[1], F. Mylläri[1], H. Wihersaari[1], J. Keskinen[1], T. Rönkkö[1]

[1] Aerosol Physics, Faculty of Natural Sciences, Tampere University of Technology [2] VTT, Technical Research Centre of Finland [3] Finnish Meteorological Institute

Introduction

Particles emitted from ship engines worsen the air quality in port cities and are estimated to cause 60 000 premature deaths annually (Corbett *et al*., 2007). The particles emitted from marine traffic may participate in cloud formation and be a source of black carbon in close vicinity of the arctic glaciers (eg. Eyring *et al*., 2010; Winther *et al*., 2014). Due to tightening regulation of fuel sulfur content (MARPOL Annex VI), new fuels with lower sulfur contents are emerging. In this study, number emissions and the characteristics of primary particles emitted from a 1.6 MW marine diesel engine were investigated when using four marine fuels with different properties.

Methods

Particle emissions were studied from a medium-speed diesel engine at two loads:

- **75%** (corresponding to cruise at sea)
- **25%** (corresponding to typical operation near harbour)

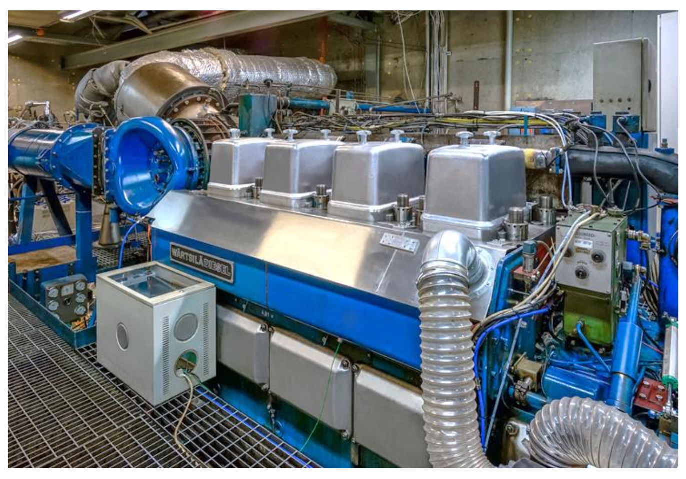

Figure 1. Wärtsilä Vasa 4L32 test-bed engine used in the measurements.

Particle number and size distributions were measured with CPC (Airmodus), Nano-SMPS (TSI) and SMPS (TSI).

Particle volatility was studied using a thermodenuder or catalytic stripper (Amanatidis *et al.*, 2013)

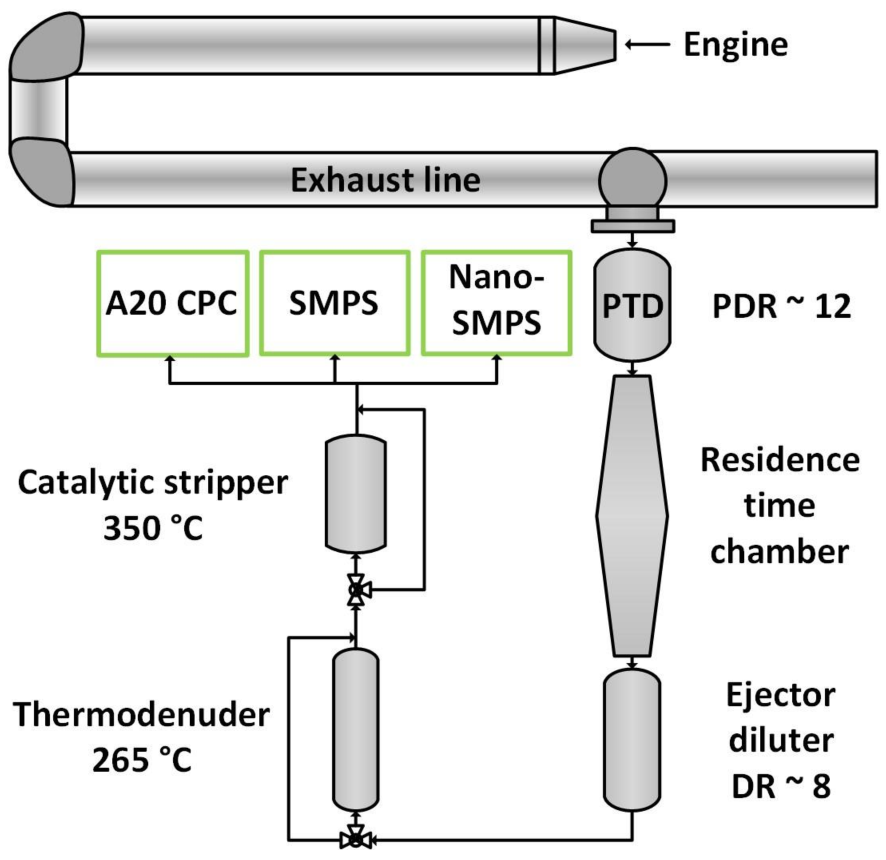

Figure 2. Dilution setup and the particle instruments used. Primary dilution included a porous tube diluter combined with a residence time chamber.

Four fuels were tested, including

- Marine diesel oil (MDO)
- Intermediate fuel oil (IFO)
- High sulfur heavy fuel oil (HFO)
- Biofuel blend (BIO30): 30% bio-component and 70% distillate oil

Table1. *Studied fuels and their properties.*

	MDO	IFO	HFO	BIO30
Density (kg/m^3)	870 (15°C)	906 (50°C)	979 (50°C)	866 (50°C)
Heating value (kJ/kg)	42.5	42.1	40.3	40.7
Sulfur content (m-%)	0.08	0.38	2.2	< 5ppm
Oxygen content (m-%)	< 0.5	< 0.5	< 0.5	3.9
Ash (m-%, 775°C)	< 0.005	0.038	0.094	<0.005

Results

The particle number size distributions were generally **bi-modal, except tri-modal for HFO.**

Increase in fuel sulfur and ash content, as well as decrease in engine load, lead to larger mean particle sizes.

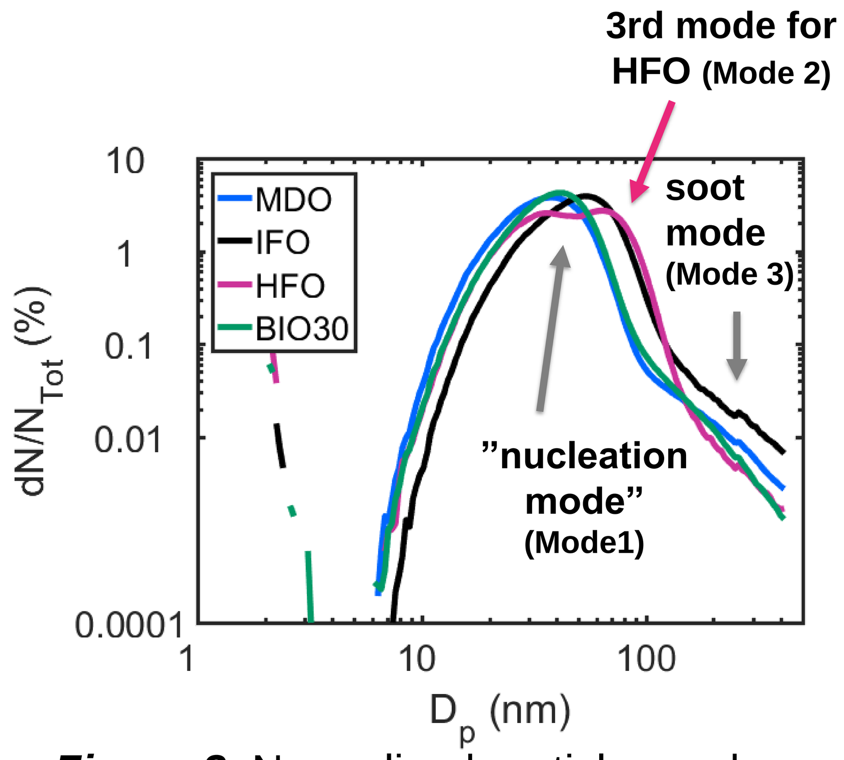

Figure 3. Normalised particle number size distributions at 25% load.

Depending on the fuel and load point, **up to 70 to 90%** of particle volume contained **volatile compounds.**

Nonvolatile core particles and soot mode particles were observed with all fuels.

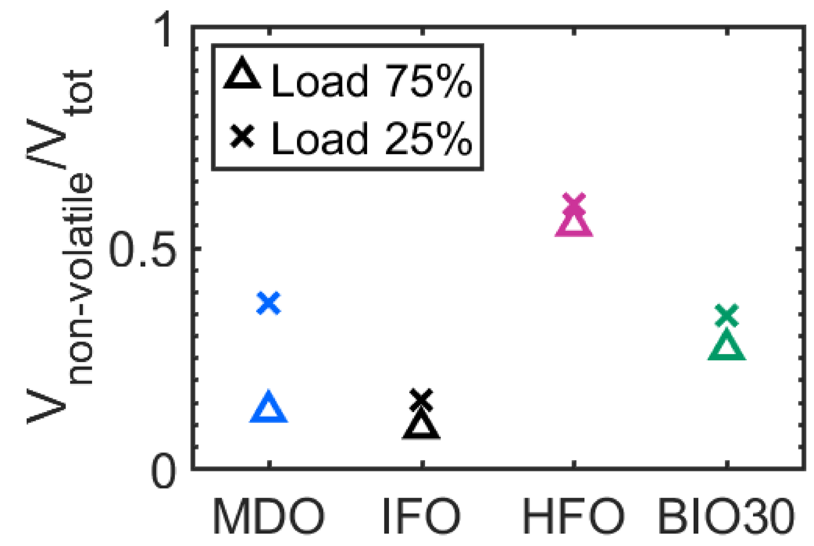

Figure 4. Share of non-volatile particle volume remaining after treatment with thermodenuder.

Modal particle number emission factors for nucleation mode particles exceeded the emission factors for soot mode particles by two to three orders of magnitude.

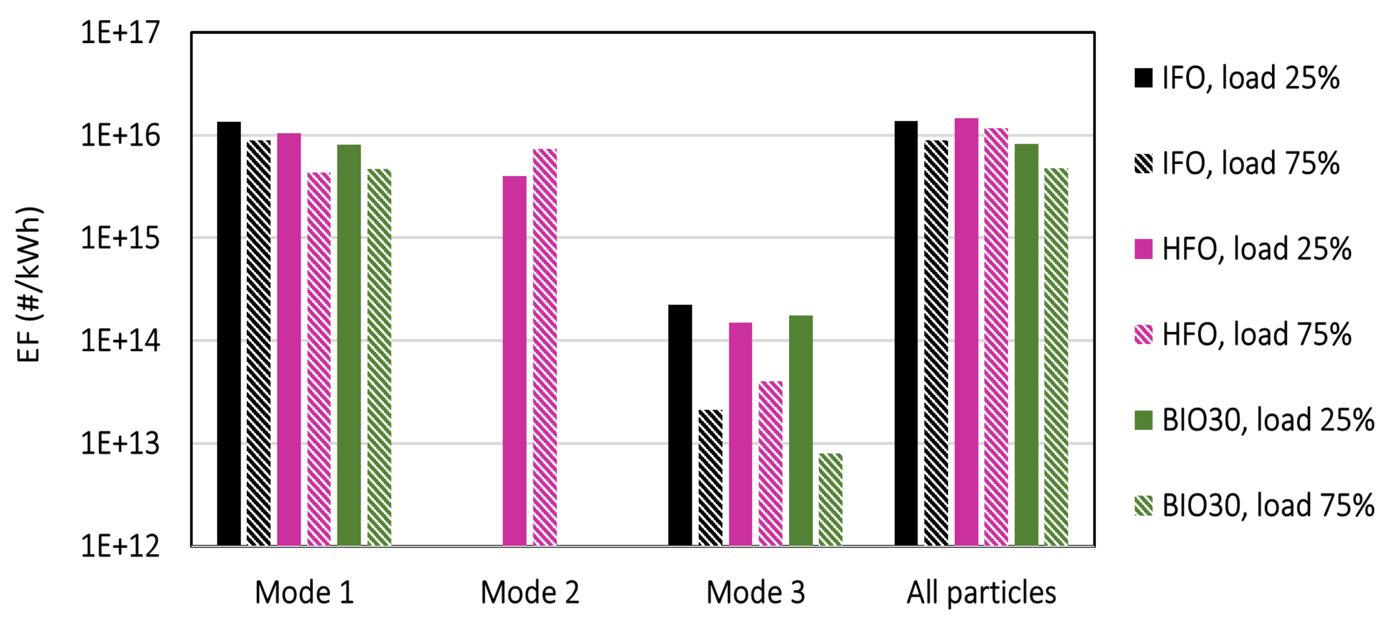

Figure 5. Modal number emission factors calculated by fitting lognormal distributions into SMPS data and using number concentrations from CPC (Kuittinen *et al.,* manuscript in prep.).

The emission factors for total particle number were only moderately affected by the choice of fuel.

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Contact

Niina Kuittinen
Tampere University of Technology
niina.kuittinen@tut.fi

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