TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

Nanoparticles in natural gas engine exhaust

Topi Rönkkö[1], Jenni Alanen[1], Sanna Saarikoski[3], Panu Karjalainen[1], Pauli Simonen[1], Kati Lehtoranta[2], Erkka Saukko[1], Timo Murtonen[2], Hilkka Timonen[3], Kimmo Teinilä[3], Heino Kuuluvainen[1], Risto Hillamo[3], Jorma Keskinen[1]

[1]Aerosol Physics, Faculty of Natural Sciences, Tampere University of Technology, P.O. Box 692, 33101 Tampere, Finland
[2] VTT Technical Research Centre of Finland Ltd., P.O. Box 1000, 02044 VTT, Espoo, Finland
[3]Atmospheric Composition Research, Finnish Meteorological Institute, P.O. Box 503, 00101 Helsinki, Finland

Introduction

Particulate emissions from natural-gas-fueled (NG) engines are typically relatively low if compared to gasoline engines or diesel engines without a DPF. Some previous studies indicate, however, that NG-fueled engines can emit substantial numbers of nanoparticles, frequently called as nucleation mode particles (e.g. Jayaratne et al. 2010, Hajbabaei et al. 2013, Alanen et al. 2015). In diesel and gasoline engine exhaust the initial exhaust nanoparticle formation takes place already in high temperature conditions or, alternatively, when the exhaust is cooled and diluted in the atmosphere (Lähde et al. 2009; Rönkkö et al. 2013). The amount as well as the physical and chemical characteristics of these nanoparticles significantly depend on their formation processes and, on the other hand, on the technologies used in vehicles and engines. This study investigates the characteristics and formation of nanoparticles in the exhaust of natural gas fueled engine.

Materials and methods

Experiment 1:

Particle emissions of a retrofitted natural gas engine (max power ca. 100 kW) at engine test bench were measured without exhaust after-treatment. Four modes for engine loading were tested. In modes 3 and 4, hydrocarbons were added in the exhaust to imitate the emissions of a large-bore NG engine power plant.

Particle emission measurements:

- Partial flow exhaust sampling with cooling primary dilution
- Particle number and size distribution measurements done with ELPI+ (Dekati), Particle Size Magnifier (PSM; Airmodus) combined with a CPC (TSI), EEPS (TSI) and a Nano-SMPS (TSI)
- Measurement for the electrical charging state of the exhaust particles with Ion-SMPS and volatility studies with a thermodenuder

Experiment 2:

The same NG engine as in Experiment 1, now with and without exhaust after-treatment (oxidative+reductive). The exhaust temperature was varied in the range 350-500 ºC.

Particle emission measurements:

- Similar setup as in Experiment 1
- Addition: A Soot Particle Aerosol Mass Spectrometer (SP-AMS; Aerodyne)

Experiment 3:

The experiment was conducted with aerosol laboratory facilities by feeding a mixture of heated SO2 (6 ppm), N_2 (50%) and air (50%) through a heated catalytic converter.

- Similar dilution as in Experiments 1 and 2.
- Instruments: Nano-SMPS, Long-SMPS (TSI), SP-AMS, ELPI+, SO_2 (Environnement), CO_2 (Sick Maihak)

Results

Experiment 1:

- Exhaust particle number were dominated by sub-5 nm particles (Fig.1)
- Engine out particles had a non-volatile fraction and elevated electrical charge (Alanen et al. 2015)
  → Formation at high temperature conditions (engine cylinder) and growth and nucleation during dilution

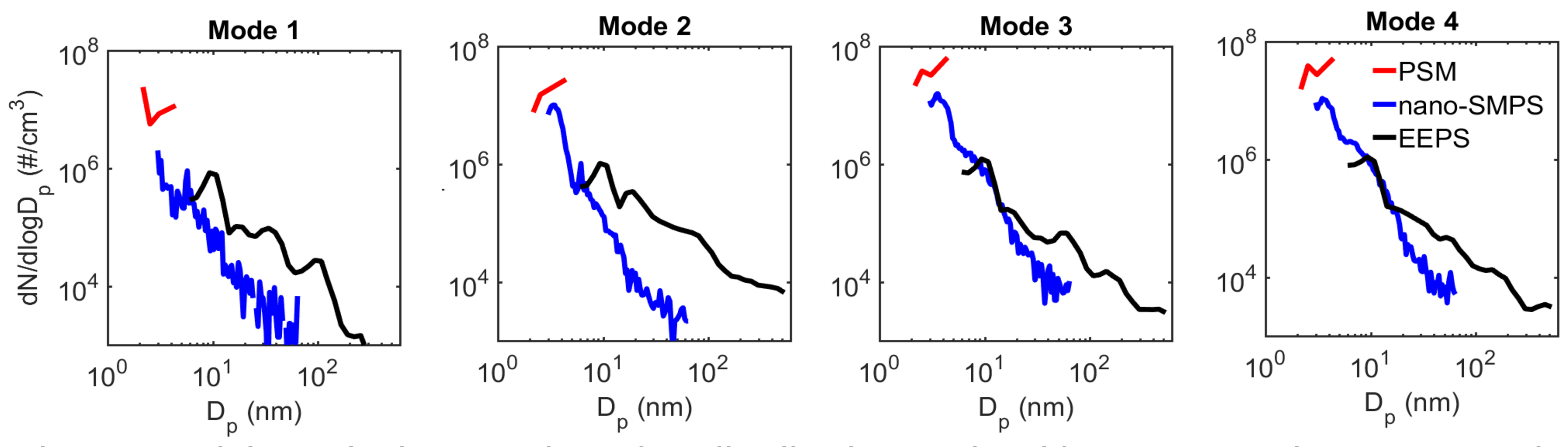

Fig. 1. Particle emission number size distribution emitted by a NG engine measured with three aerosol instruments at four engine operation modes. Figures in Alanen et al. (2015).

Experiment 2:

- Catalytic converter decreased the particle number at a low exhaust temperature, which can be explained by losses of core particles formed in the engine cylinders
- Higher exhaust temperatures increased the particle emission:
  - Increase in volatile particle number and mass (Fig. 2)
  - Increase in particulate sulfate measured with SP-AMS

  → Nucleation in the cooling dilution process

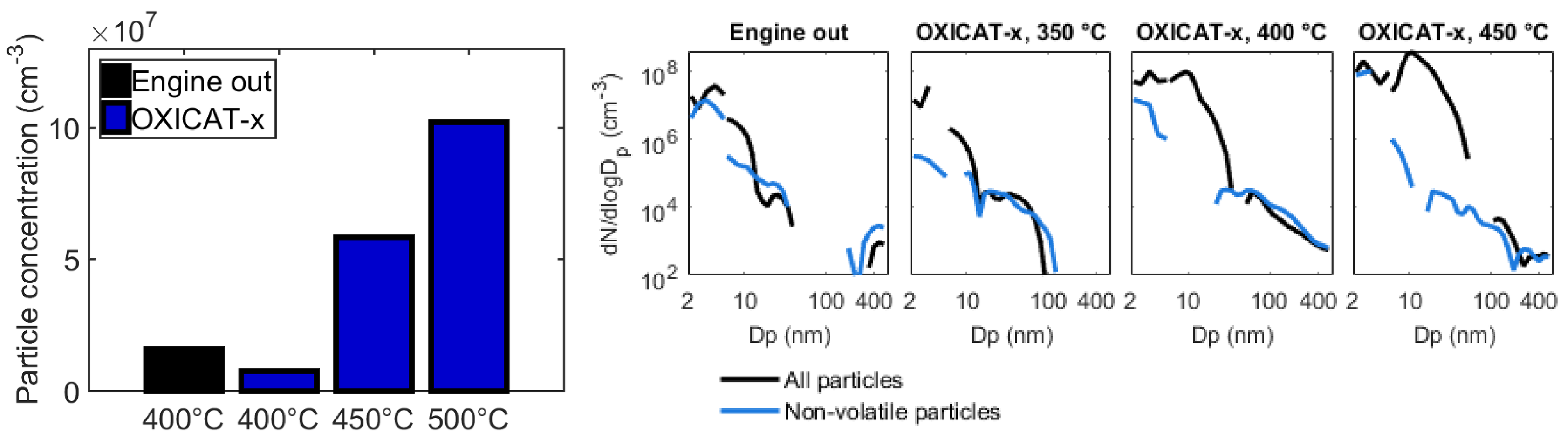

Fig. 2. Particle emission number concentration and size distribution from a NG engine was influenced by exhaust after-treatment and exhaust temperature. The number concentrations and the size distributions were measured with PSM and EEPS. Figures in Lehtoranta et al. (2017).

Experiment 3:

- Increase in the temperature of catalytic converter (Oxicat):
  - Increase in particle number and mass (Fig. 3)
  - increase in particulate sulfate

  → Nucleation in the cooling dilution process

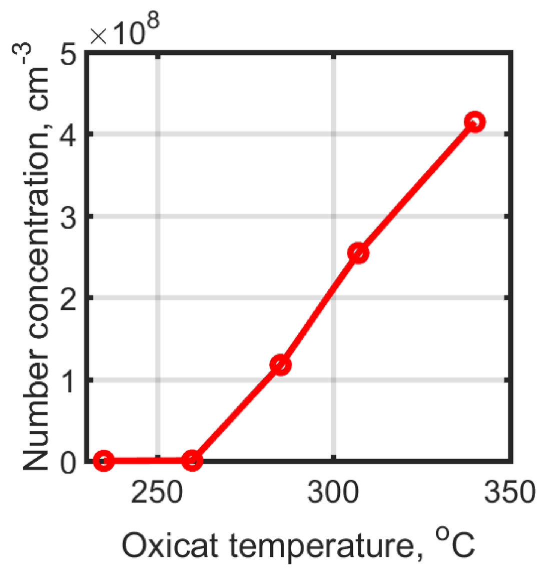

Fig. 3. The effect of oxidation catalyst temperature on particle number concentration formed from artificial exhaust and measured with Nano- and Long-SMPS

References

Jayaratne et al. 2010. *Environ. Sci. Technol.,* 44(10), 3724–3731
Hajbabaei et al. 2013. *Energy*, 62, 425–434
Alanen et al. 2015. *Fuel,* 162, 155–161
Lähde et al. 2009. *Environ. Sci. Technol*., 43(1), 163–168
Rönkkö et al. 2013. *Environ. Sci. Technol., 47(20),* 11882–11889
Lehtoranta et al. 2017. *Emiss. Control Sci. Technol.,* 3(2), 142–152

Contact information

Topi Rönkkö
topi.ronkko@tut.fi

Jenni Alanen
jenni.e.alanen@tut.fi

Acknowledgements

This work was conducted in CENGE and NewGas projects, funded by Tekes, the Finnish Funding Agency for Innovation, Neste Oil, AGCO Power, Wärtsilä, Dinex Ecocat, Dekati, Suomi Analytics, Viking Line, Airmodus and Oilon.