Particle Emission Reduction in a SI-DI Vehicle by an Open Channel Filter

Panu Karjalainen[1], Juha Heikkilä[1], Topi Rönkkö[1], Matti Happonen[1], Sampo Saari[1], Aleksi Malinen[2], Tero Lähde[2], Liisa Pirjola[2], Pekka Matilainen[3], Toni Kinnunen[3] and Jorma Keskinen[1]

[1]Aerosol Physics Laboratory, Department of Physics, Tampere University of Technology, Tampere, FI-33101, Finland

[2]Department of Technology, Metropolia University of Applied Sciences, FI-00180 Helsinki, Finland

[3]Ecocat Oy, FI-41331, Vihtavuori, Finland

e-mails of contact persons: panu.karjalainen@tut.fi, topi.ronkko@tut.fi (presenter)

Introduction

The new legislation development in Europe will limit also the PM (particulate mass) and PN (particle number) emissions of spark-ignition direct injection (SI-DI) vehicles. In Euro 6 regulations (applied 09/2014) the PM limit for SI-DI vehicles will be 0.005 g/km, and PN $6.0 \cdot 10^{12}$ 1/km for the first three years [1]. After that, in 2017 the PN is lowered to $6.0 \cdot 10^{11}$ 1/km which is the same as Euro 6 PN limit for diesel vehicles.

Open channel particle filters are used to reduce diesel exhaust PM and PN emissions. These devices cause typically only low back-pressure increases and do not require an active regeneration system, which are clear benefits when the operation of open channel filter is compared to wall-flow filters. In addition, due to the development and new structures, the particle emission reduction efficiencies have increased even up to 80%, slightly depending on the solution and e.g. the engine out particle size distribution. Especially the smallest solid exhaust particles can be reduced efficiently by these devices. In addition to diesel applications, open channel filters offers one approach to reduce the emissions of SI-DI vehicles. In this study, we conducted exhaust particle measurements for SI-DI vehicle with and without open channel filter (Particle Oxidation Catalyst, POC), in order to clarify its effect on exhaust solid particle size distribution and solid particle number.

Experimental

The vehicle in the study was a modern SI-DI passenger car (model year 2011, displacement 1.8 dm^3, TFSI, maximum power 88 kW). The particle reduction efficiency was studied during a New European Driving Cycle (NEDC) and at three driving modes (speed 80 km/h, gear 5, wheel power: 5, 10 and 20 kW). The test vehicle was mounted on chassis dynamometer.

Two different partial flow exhaust sampling and dilution systems were used. First, the exhaust sampling was conducted with a porous tube dilution system which is able to mimic the real-world dilution and cooling process and thus enables e.g. the studies related to nucleation mode formation. After this dilution system, particle number and size distributions were studied using ELPI, CPC (Dp > 3 nm) and two SMPS with different size ranges. SMPSs were used only during steady state points and when needed, exhaust sample was treated by thermodenuder. The other sampling system consisted of heated ejector type diluter using heated dilution air and of the secondary dilution, also conducted by ejector but with cool dilution air. After that double ejector system the particle concentration was measured by CPC 3075 (TSI Inc.) tuned to measure the concentration of particles larger than 23 nm. From the viewpoint of POC function, focus was in solid particles and in the effect of open channel filter on those.

Results and discussion

According to the particle size distribution measurements during steady state driving modes, solid particles in the SI-DI exhaust were in the same size range like in typical diesel exhaust without diesel particle filter. However, the particle concentration and number emission were significantly lower when compared to diesel exhaust. When measured over the NEDC, total emission of solid particles larger than 23 nm was ~$8 \cdot 10^{11}$ #/km. Thus, the number emission was above the upcoming PN limits.

The particle reduction efficiency of POC-F depended strongly on particle size; more than 95 % of particles smaller than 10 nm were removed, while for 50 nm solid particles the reduction efficiency was 50-60 %, depending on engine load. Thus the smallest particles were collected most efficiently. The engine load had only a minor effect on the particle reduction indicating that the filter operates at wide temperature and flow velocity range. Like in diesel applications, the effects of engine load may to be caused by changes in temperature and flow rate. The reduction efficiency as a function of solid particle size was very similar with those observed previously in a light-duty and heavy-duty diesel applications.

Due to the use of POC-F, the reduction of the emissions of non-volatile particles larger than 23 nm was 50 % over the NEDC test cycle. For particle larger than 3 nm in size the reduction efficiency was 60 %, due to the high reduction efficiency of smallest particles. The use of POC-F decreased the PN emission to values below the upcoming PN limit. Thus the results indicate that an open channel filter can be a one solution to reduce SI-DI vehicle exhaust particle emissions.

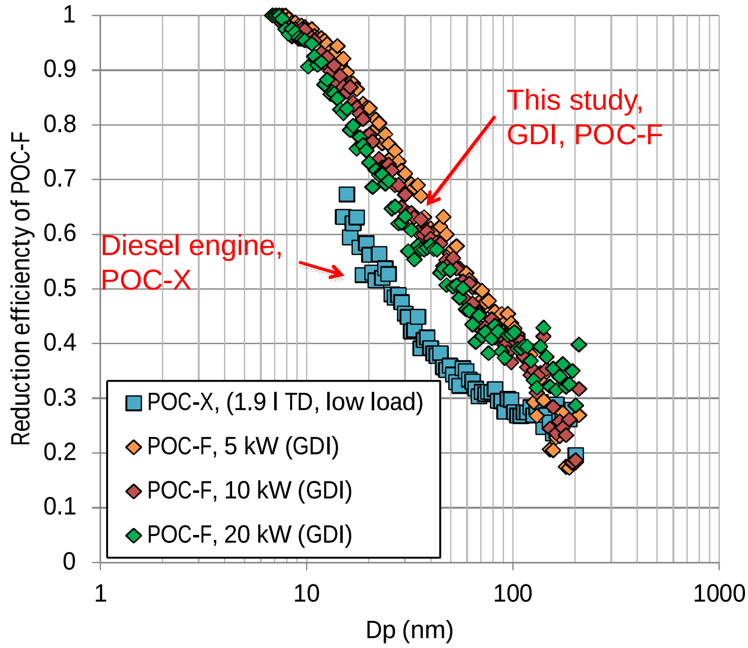


Figure 1. Dry particle reduction efficiencies of two kinds of open channel filters POC-F (this study) and POC-X ([2], LD diesel application).

References

[1] Dieselnet website, http://dieselnet.com/standards/eu/ld.php, information retrieved 20.6.2012.
[2] Bielaczyc, P. et al., Performance of Particle Oxidation Catalyst and Particle Formation Studies with Sulphur Containing Fuels, SAE Int. J. Fuels Lubr. 2012, 5(2).

Reduction of Particle Emissions of SI-DI Vehicle by Open Channel Filter

Panu Karjalainen[1], Juha Heikkilä[1], Topi Rönkkö[1], Matti Happonen[1], Sampo Saari[1], Aleksi Malinen[2], Tero Lähde[2], Liisa Pirjola[2], Pekka Matilainen[3], Toni Kinnunen[3] and Jorma Keskinen[1]

[1]Aerosol Physics Laboratory, Department of Physics, Tampere University of Technology, Tampere, Finland

[2]Department of Technology, Metropolia University of Applied Sciences, Helsinki, Finland

[3]Ecocat Oy, Vihtavuori, Finland

Motivation

- Characteristics of SI-DI vehicle exhaust particles?
- Particle emissions vs. upcoming emission limits?
  (PN emission $6 \cdot 10^{11}$ #/km in 2017)
- Open channel filters to reduce emissions of SI-DI vehicles?

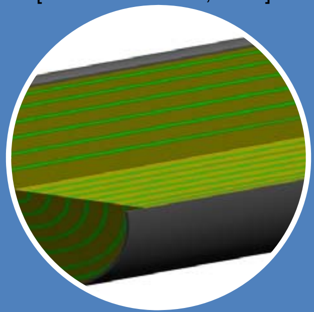
Experimental: vehicle

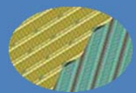
- Vehicle
  - Passenger car, 1.8 dm^3 TFSI 88 kW, model year 2011
  - three way catalyst
- Fuel: Gasoline, ethanol content of 10 %
- Lubricant oil: Fresh SAE 5W-30 longlife

- Driving conditions:
  - New European Driving Cycle (NEDC)
  - Three steady driving modes (speed 80 km/h, wheel power 5 kW, 10 kW and 20 kW)
- With and without open channel particle filter (POC-F), installed after three way catalyst

Studied POC-F: new product of family for particle trapping, developed and manufactured by Ecocat Oy

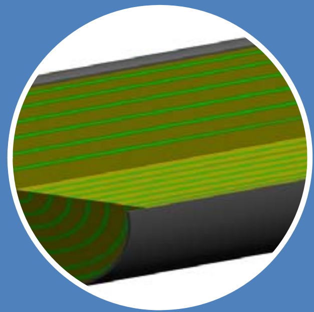
[EP 1 230 978 B1, 2002].

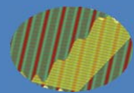




POC-X

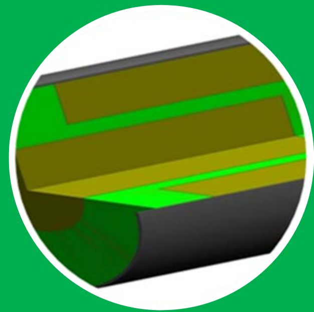
Substrate channels are designed with several corrugated layers





POC-L

Placing additional straight mesh between corrugated wire meshes



POC-F

NEW DEVELOPMENT

Up to 55%

Up to 65%

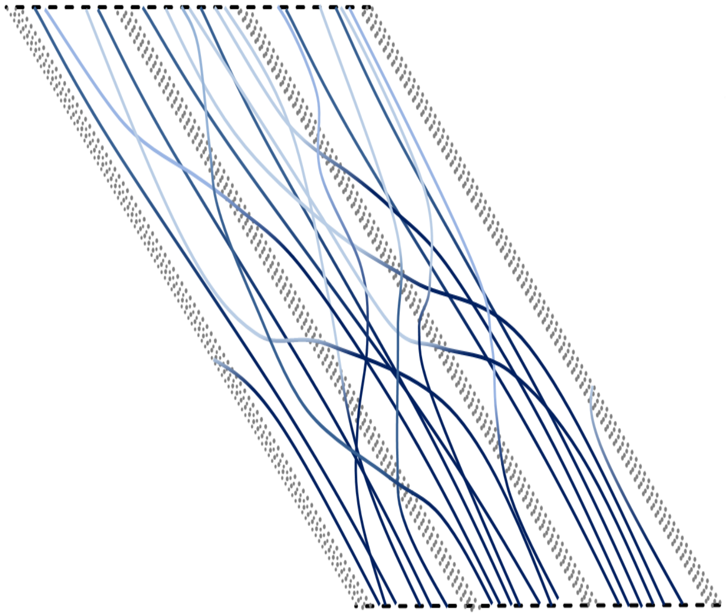
Up to 80%

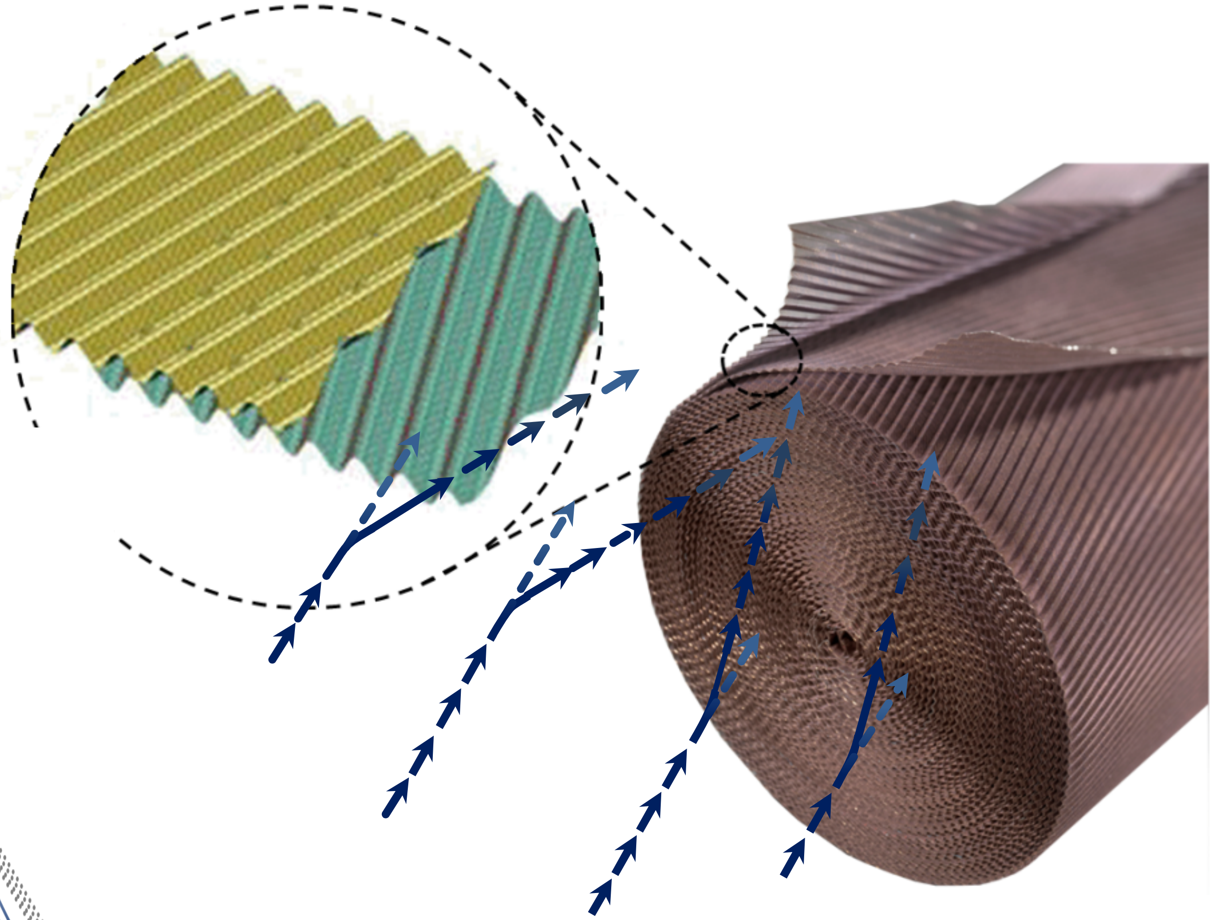
PM reduction efficiency

POC Catalysts

Filter Mechanisms:

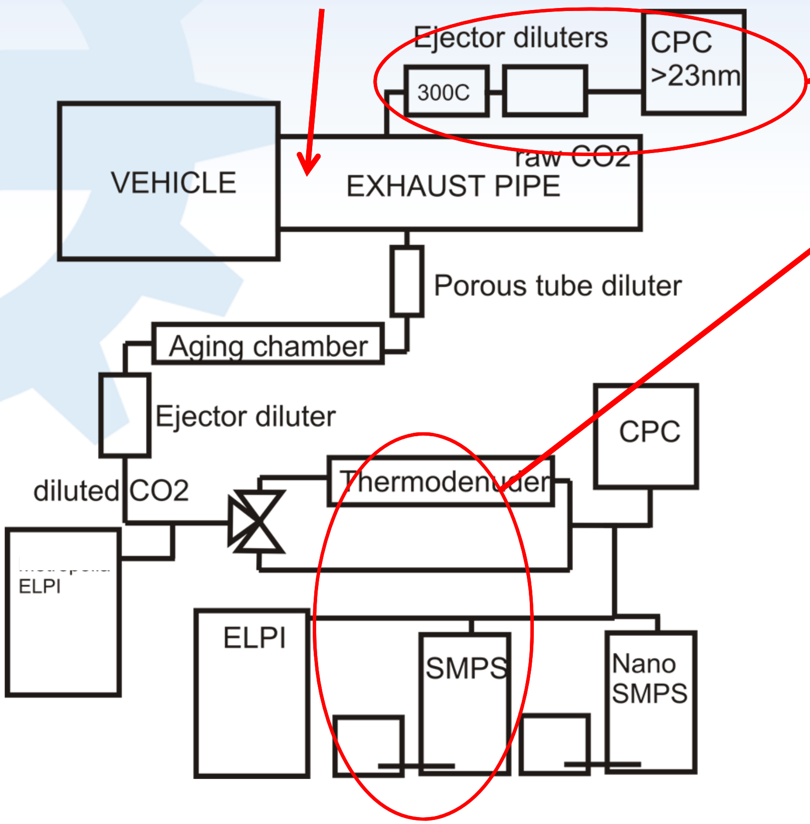
- Impaction: Large particles
- Diffusion, interception: Small particles





Experimental: particle instruments

With and without open channel filter (POC-F)



Only the results related to solid particles reported here

Gas components: CO, SO_2, No_x

Exhaust particles from SI-DI vehicle (without open channel filter)

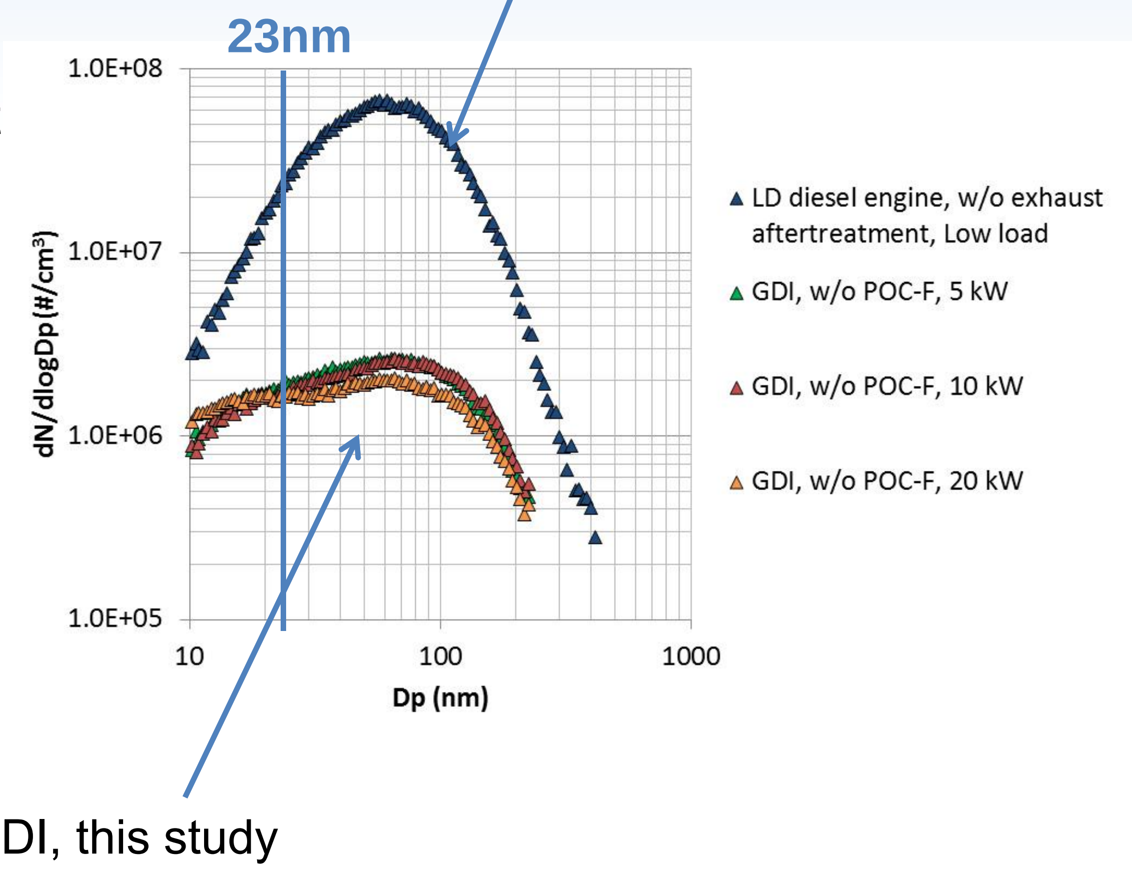
Compared to LD diesel exhaust without exhaust aftertr.

- Similar particle sizes
- Lower particle number concentration/emission but,

Number emission of >23nm particles ~8·10[11] #/km

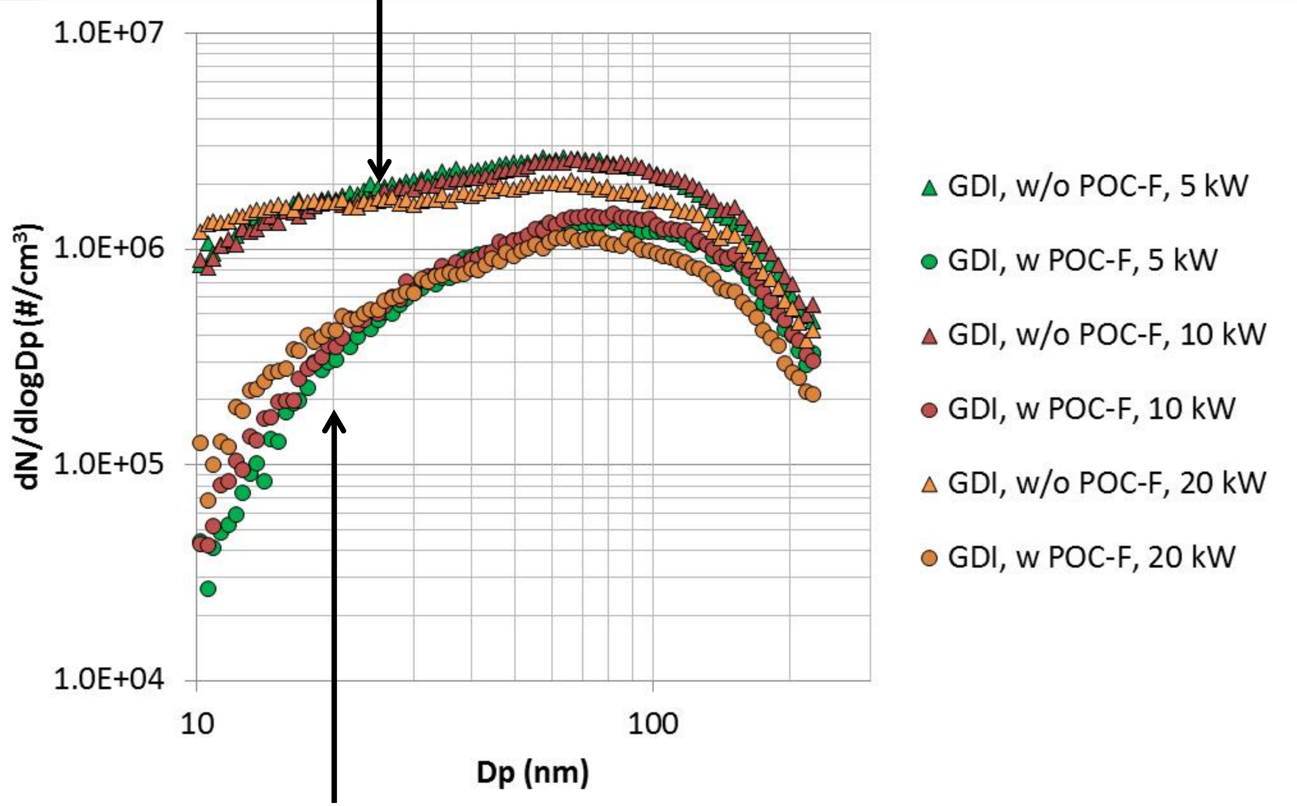
(NEDC with warm start)

→ higher than upcoming PN emission limit



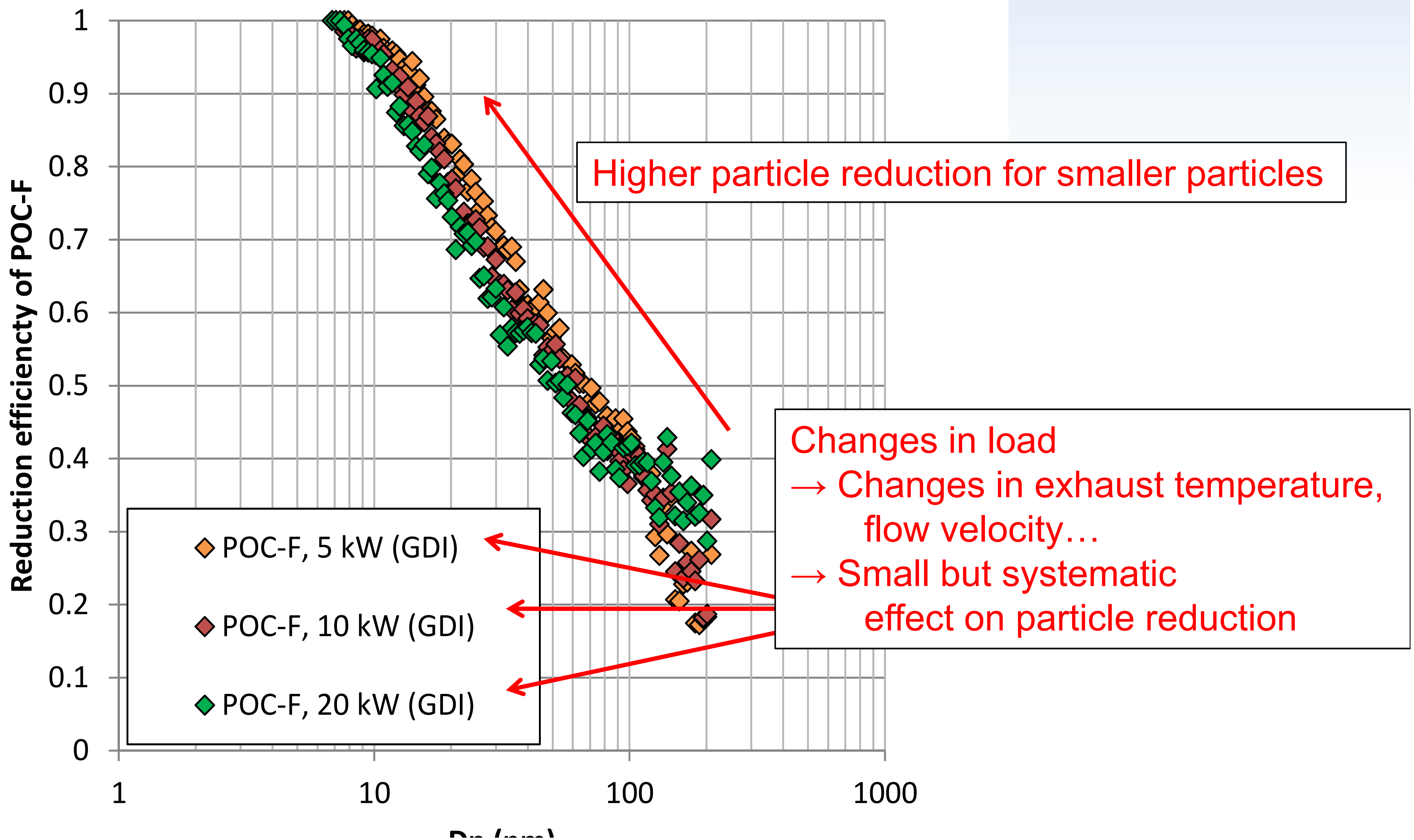
Effect of POC-F on solid particle number size distributions

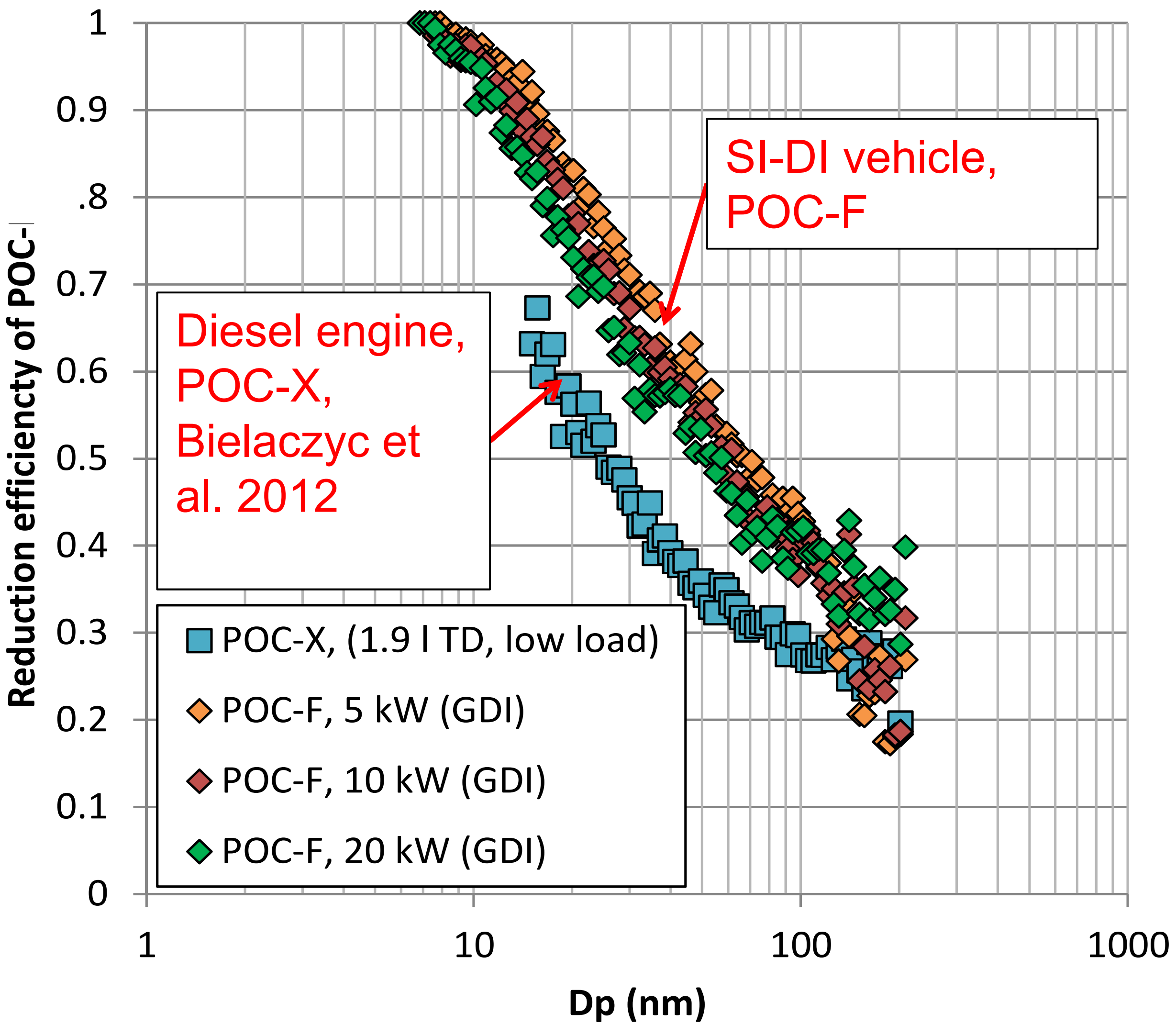
Without POC-F, three driving conditions



With POC-F, three driving conditions

Particle reduction efficiencies vs. particle size

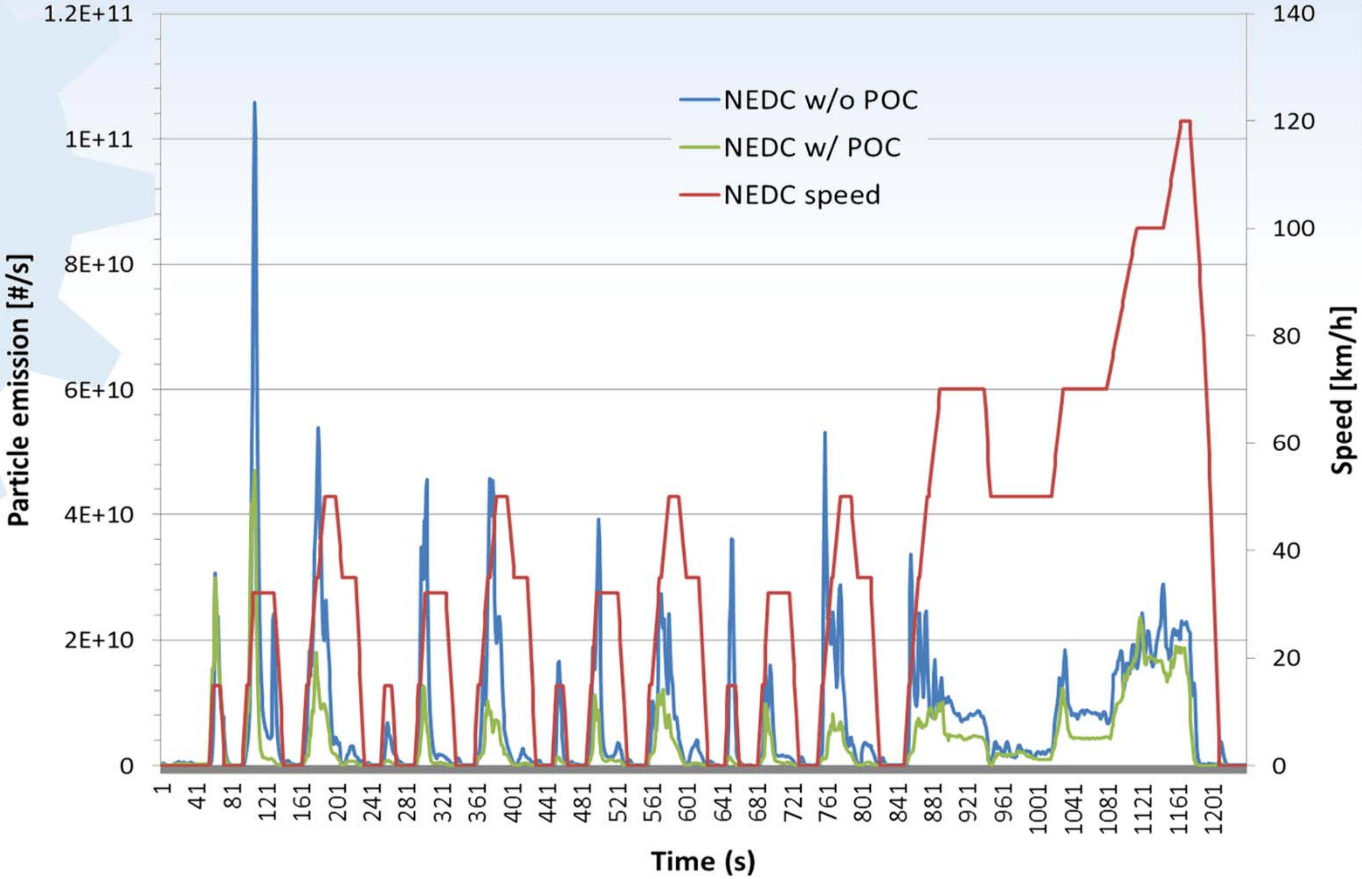




Higher particle reduction with improved POC structure

Types of curves similar

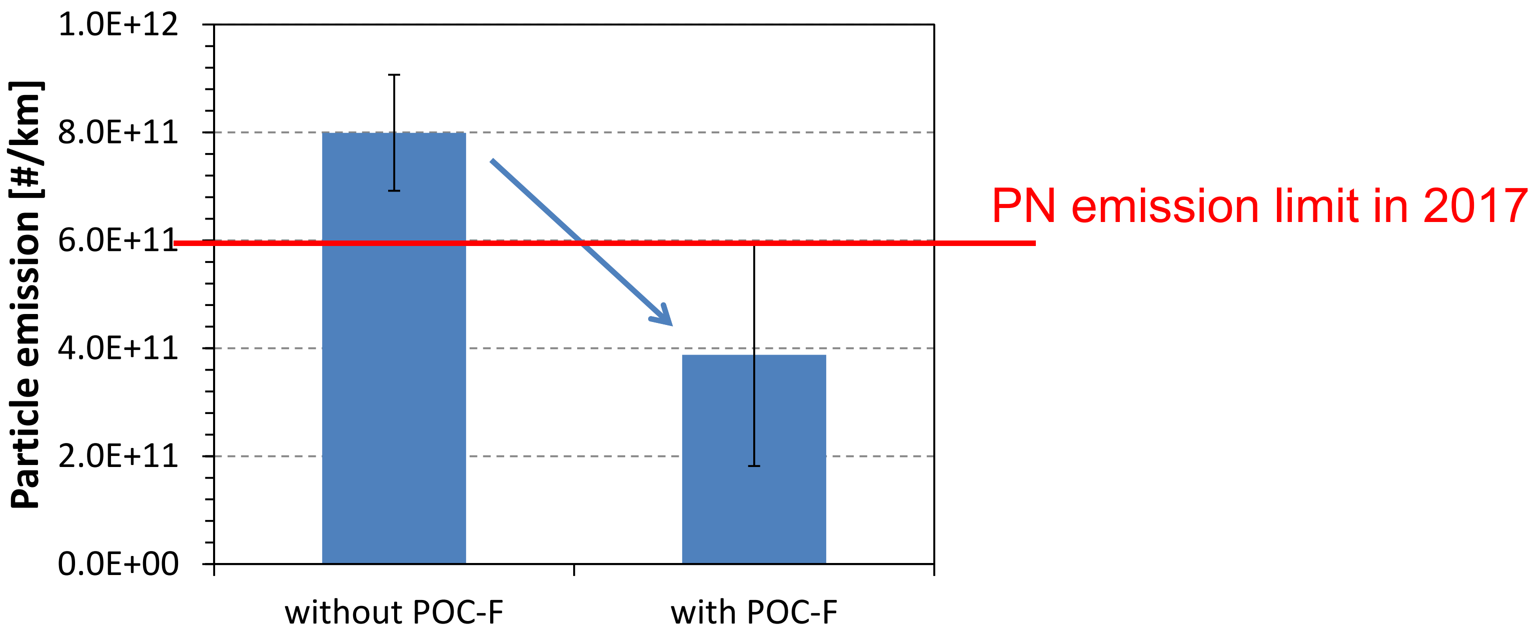
Particle emissions, NEDC



PN emission reduction over the NEDC

- 50% for >23nm solid particles
- 60% for > 3nm solid particles

Total number emissions of solid particles, D_p > 23 nm, NEDC,



Summary

Solid exhaust particle emissions of SI-DI vehicle

- Higher than upcoming PN emission limit for SI-DI vehicles (and diesel passenger cars)
- Mean particle size ~50nm

Solid particle number reduction efficiency of open channel filter (POC-F)

- Depended on particle size
  - o >95% for particles < 10 nm
  - o 50-60% for 50 nm particles
- Depends on engine out particle size distribution, but in this study
  - o 50% for particle > 23nm (PN emission below upcoming emission limits if POC-F was installed)
  - o 60% for particles > 3nm
- Not much affected by driving conditions

Acknowledgements

Measurements were part of the TREAM project funded by Tekes, Ecocat Oy, Neste Oil Oyj, AGCO Sisu Power and Oy Nanol Technologies Ab.

References

Bielaczyc, P. et al., Performance of Particle Oxidation Catalyst and Particle Formation Studies with Sulphur Containing Fuels, SAE Int. J. Fuels Lubr. 2012, 5(2).