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Real-world Exhaust Emissions in Congested Urban Areas

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Introduction

Exhaust emissions from internal combustion engines are one of the primary sources of fine particulate matter and nitrogen oxides in urban areas. Notably the ultra-fine particles, mostly with tens of nm diameters, pose a major threat to human health, a reason why increasingly stricter emissions standards are imposed on new vehicles. In EU, most manufacturers meet such standards by improvements in engines and by catalytic converters, reducing total particulate mass during certification tests, but without necessarily providing a comparable reduction in ultra-fine particles and also in particulate emissions during real-world operation.

For diesel engines, the most problematic is extended operation at idle or low load, where the efficiency of catalytic devices is reduced, and short bursts of acceleration, where high fuelling rates are used to deliver high performance and fast acceleration. The frequency of such operation increases with increasing congestion levels, a reality in most urban areas. In the Czech Republic, the fuelling rates are also often further increased by aftermarket "chip-tuning", and vehicles with closed particle filters are rare as their installation is not necessary to meet EU emissions limits.

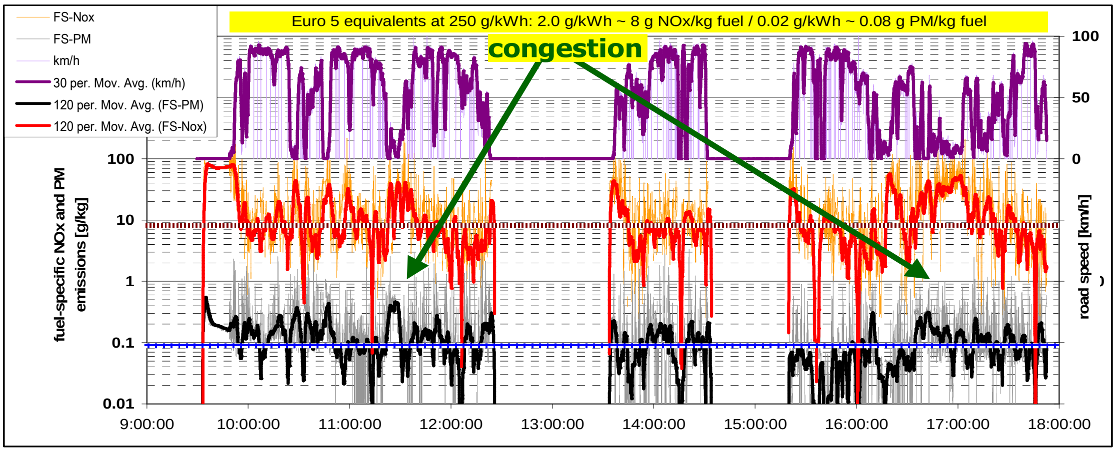
The above concerns are also to some extent applicable to gasoline (spark ignition) engines, which historically had relatively low particle emissions compared to diesel engines and have not been the subject to particle emissions limits.

Experimental

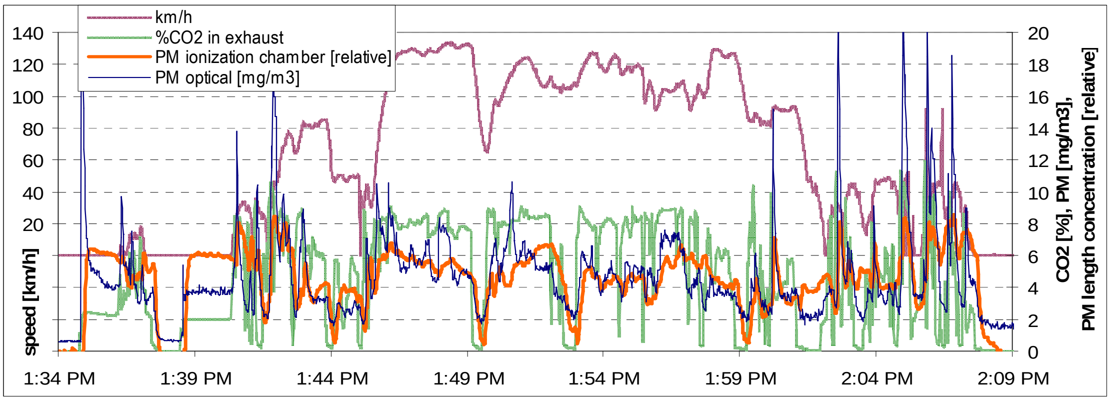
The emissions during "urban crawl", dynamic driving, and other regimes have been investigated with a simple, low-cost, portable on-board emissions monitoring system (presented at this conference in 2007 and 2010), with a newly added measuring ionization chamber fabricated from a low-cost household smoke detector for total particle length measurements. Measurements were conducted on several cars, vans and heavy trucks in Prague, Czech Republic.

The results presented here represent work in progress.

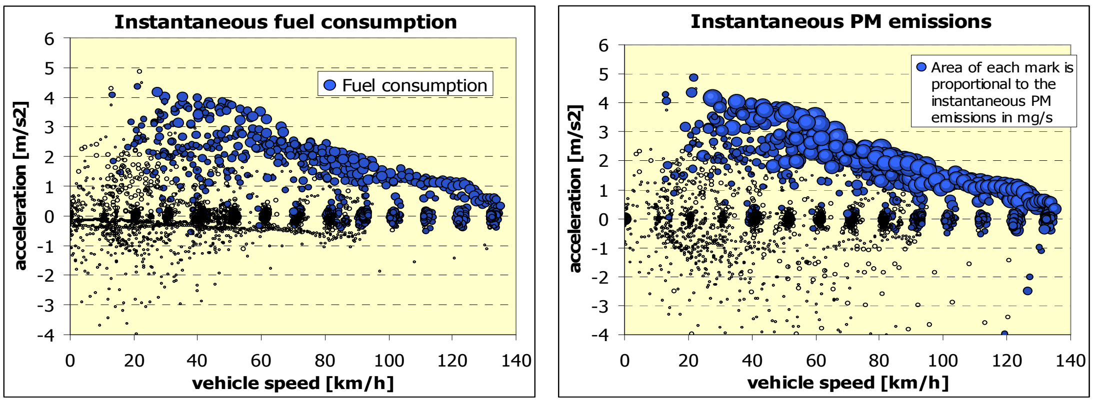
Sample results



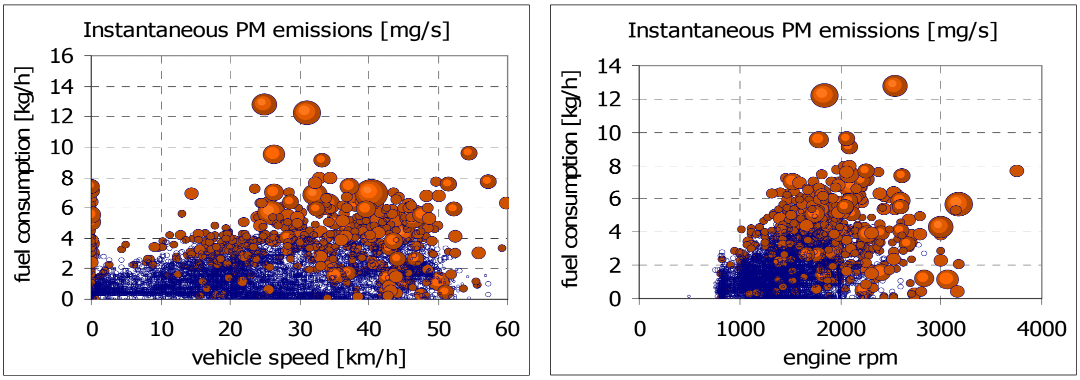
Instantaneous (thin line) and moving average (thick lines) road speed and fuel-specific NO_x and PM emissions from a Euro 5 tractor-trailer during repeated runs on the Prague Circle (perimeter expressway road) at varying levels of congestion.



PM measurements by optical sensor and by measuring ionization chamber during a expressway and urban operation of a Euro 4 Renault Trafic van with a CR diesel engine.



PM emissions measured by an optical sensor and fuel consumption on a Euro 4 gasoline Škoda Fabia car during preliminary practice runs on a test track.



PM emissions measured by an optical sensor and fuel consumption on a Euro 4 diesel Škoda Octavia car during operation in core urban area of Prague. Fuel consumption is used as a surrogate for engine load.

Discussion on preliminary results and planned future work

The preliminary results of the ongoing work reported on here seem to confirm the concerns about real-world emissions in urban areas, notably during congested driving and during dynamic, high power driving, which could be higher than emissions inferred from laboratory measurements using established driving cycles.

In the light of these findings, seeking further answers about the quality of the improvements brought by Euro 4-5 emissions legislation, and the benefits of low emissions zones (LEZ), may be of some merit, at least in cases where the purported emissions benefits are obtained without a particle filter.

Given the potential emissions benefits stemming solely from reduced congestion, a question may arise as to the extent to which the benefits of LEZ are an effect of reduced traffic volumes and thus reduced congestion and low-load operation occurrence.

Another question arises as to the differences in the relative toxicity of vehicular exhaust in laboratory settings and in everyday operation in dense urban areas, where most of the exposure occurs.

In the pursuit of the last question, and as a part of international efforts to evaluate the effects of new fuels and engine technologies on human health, a cooperation has been established between the Department of Genetic Ecotoxicology of the Institute of Experimental Medicine of the Czech Academy of Sciences and the Internal Combustion Engine laboratories at Technical University of Liberec and Czech Technical University in Prague.

A Czech project MEDETOX – Innovative Methods of Monitoring of Diesel Engine Exhaust Toxicity in Real Urban Traffic – has been recommended for funding by EU under the LIFE+ program. The goal of this project is to sample exhaust from on-road engines during laboratory and real-world operation for subsequent toxicological assays.

Acknowledgments

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KVM Katedra vozidel a motorů
Fakulta strojní
Technická univerzita v Liberci

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Background and aims:

- **Many newer engines rely on electronics and catalytic aftertreatment devices – how well do they work at prolonged low loads and during other „challenges“?**
- **What are the actual emissions during everyday operation of modern engines?**
- **And what about actual, “real-world” toxicity of the exhaust gases?**

Nanoparticles emitted by (internal combustion) engines - background

- In 2008, 4 Tg (4 millions of tons) of diesel fuel and 2 Tg of gasoline was sold in CZ. [Czech Ministry of Industry and Trade, http://www.mpo.cz/cz/energetika-a-suroviny/statistiky-energetika/]
- Most of this was probably burned in internal combustion engines.
- Nearly half of particulate matter emitted into the air in CZ originates from motor vehicles. [Czech Statistical Yearbook, 2001-2007. Czech Bureau of Statistics, online at http://www.czso.cz/csu/redakce.nsf/i/statisticke_rocenky_ceske_republiky]
- The particles emitted by the engines are very small – most are less than 100 nm in diameter [Kittelson, J. Aerosol Sci. Vol. 29, No. 5/6, pp. 575-588, 1998]
- Particles smaller than 100 nm are readily deposited in the lungs. [B. Alfoldy et al., Aerosol Science, 40 (2009) 652—663]
- Particles smaller than 100 nm have the ability to penetrate through cell membranes and to enter the blood stream. [B.M. Rothen-Rutishauser et al., Environ. Sci. Technol. 40 (1996) 4353-4359] [B. Nowack, T.D. Bucheli, Environmental Pollution 150 (2007) 5-22.]
- Inhalation of nanoparticles, exposure to vehicular exhaust, and proximity to major sources of vehicular exhaust were linked with increased risk of respiratory, cardiovascular and other illnesses. [A. Mayer, 12th ETH Conference on Combustion Generated Nanoparticles, Zurich, 2007.] [Gehr, P.; Blank, F.; Rothen-Rutishauser, B.: Fate of inhaled particles after interaction with the lung surface. Paediatric Respiratory Reviews, Vol. 7, Suppl. 1, 2006, pp. S73-S75.] [Peters, A.: Epidemiology on Health Effects of Solid Nanoparticles. Proceedings of the 12th ETH Conference on Combustion Generated Nanoparticles, Zurich, Switzerland, June 2008.] [Kuenzli, S.: Chronic pulmonary effects of ambient nano-PM: Lessons learned from PM. 13th ETH Conference on Combustion Generated Nanoparticles, Zurich, Switzerland, June 2009.] [Šrám, R., Ústav experimentální medicíny AVČR. Prezentace na jednání v rámci Plánu pro ozdravení Ostravy, MŽP ČR, 11. března 2010.]
- In pollution-impacted urban areas in CZ, most nanoparticles are of antropogenic sources. [Řimnáčová et al., Proceedings of the Annual meeting of the Czech Aerosol Socitety, Prague, 2008.] [Schwarz et al., Proceedings of the Annual meeting of the Czech Aerosol Socitety, Prague, 2008.] [Smolík, J., et al.: Proceedings of the Ovzduší konference, Brno, CZ, April 2009.]
- The current emissions limits for internal combustion engines are expressed in total particle mass. Newer engines emit less total particle mass, but not necessarily less nanoparticles. [Mayer, A.; Ulrich, A.; Kasper, M.: Nanoparticle-Emission of EURO IV and V compared to EURO III with and w/o DPF. Proceedings of the Xli. International Scientific Conference Of Czech And Slovak University Departments And Institutions Dealing With The Research Of Combustion Engines, September 6 - 7, 2010 – Liberec, Czech Republic.]
- This is important - smaller particles pose a higher risk than large particles of the same mass. [Giechaskiel et al., Aerosol Science, 40 (2009) 639—651] [D. Kittelson, J. Aerosol Sci., 29, No. 5/6, pp. 575-588, 1998.]
- The traffic intensity is increasing, in CZ approximately doubling every 15 years. [Czech Statistical Yearbook, 2001-2007. Czech Bureau of Statistics, online at http://www.czso.cz/csu/redakce.nsf/i/statisticke_rocenky_ceske_republiky]

Increased traffic – not only more km driven and more kg of fuel burned, but more emissions of nanoparticles per kg of fuel and per km due to congestion, and operation at low average loads, with many transients (see measurements on the right). [Vojtíšek, M., Proceedings of the Annual meeting of the Czech Aerosol Socitety, Prague, 2010.]

Work in progress: Assessment of exhaust emissions under real-world driving conditions using on-board measurement systems

Planned future work: Assessment of the toxicity potential of particles in exhaust emissions under real-world driving conditions

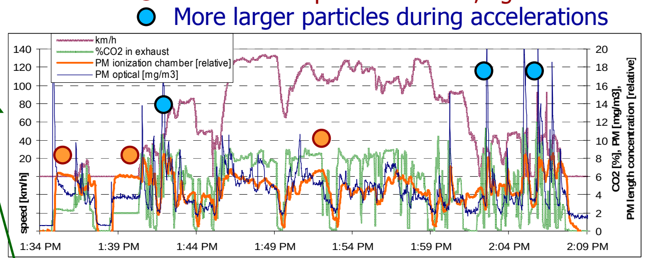
- **Project MEDETOX to be funded under EU LIFE+ program**
- **Sampling of particulate matter during on-road operation and in laboratory during conventional cycles and recorded/reproduced real-world operation**
- **Toxicological assays on collected material**

Measurement of total PM length with ionization chamber

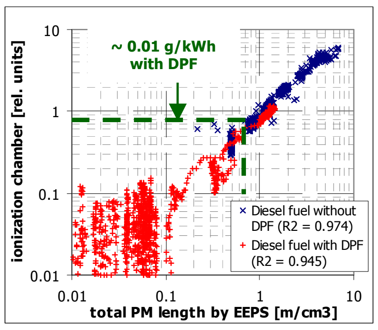
- A time-proven, robust, inexpensive technology used in building smoke alarms
- Alpha-particles generated by radioactive decay of ^{241}Am generate small ionization current in free air – this current is decreased as particles intercept ions
- Response proportional to total particle length (verified on diesel engines with and without DPF, running on diesel fuel and non-esterified vegetable oil) [Vojtisek-Lom, Journal of the Air and Waste management Association, 61, 2001, 126-134.]
- **Supplemental measurement to provide qualitative indication of mean particle size or relative fraction of nanoparticles.**

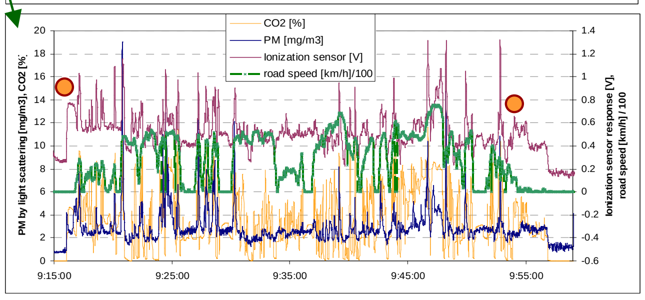
More smaller particles at idle, light load
More larger particles during accelerations

Measurement of PM length in urban driving (Renault Trafic van, Euro 4 diesel)

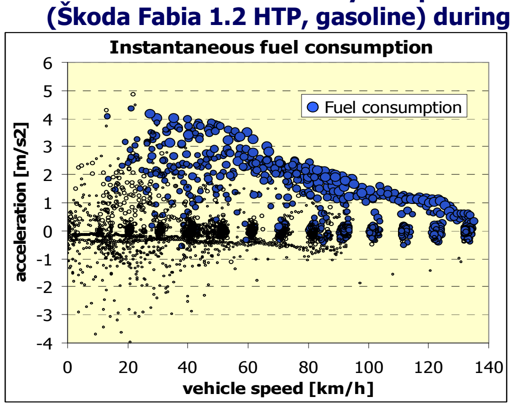


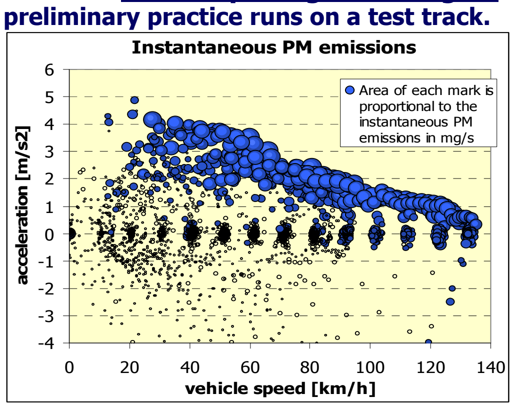
Laboratory comparison of PM length measurement: EEPS vs. ionization chamber





PM emissions measured by an optical sensor on a Euro 4 spark ignition engine (Škoda Fabia 1.2 HTP, gasoline) during preliminary practice runs on a test track.

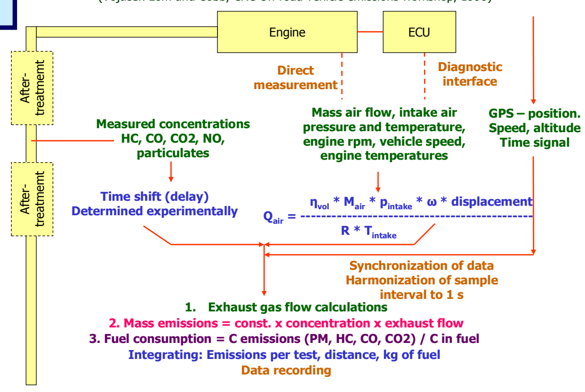




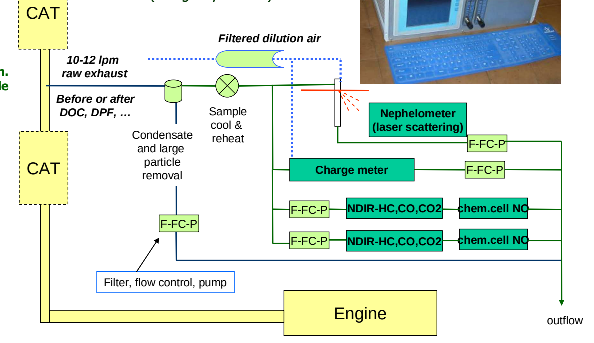
Measurement of particulate matter emissions during real-world on-road operation using a portable, on-board monitoring system

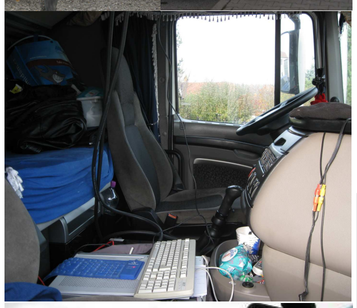
Real-world is different from laboratory… less repeatable, more variable, unique…
Engines are tuned for low emissions in the laboratory – on the road, emissions are very often higher…

On-board system functional overview
(Vojtisek-Lom and Cobb, CRC On-road vehicle emissions workshop, 1998)



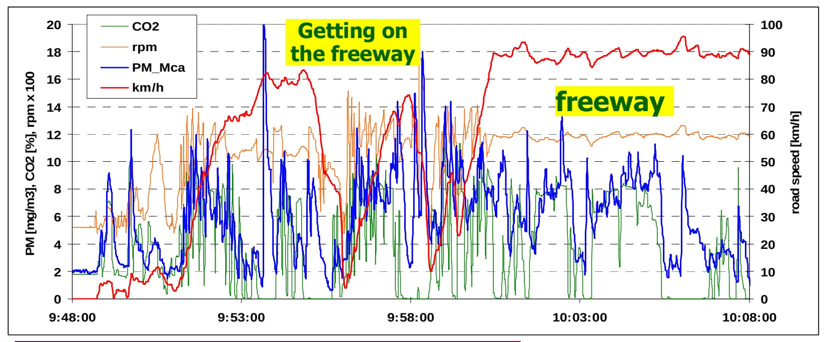
On-board system analytical hardware
(design by author)





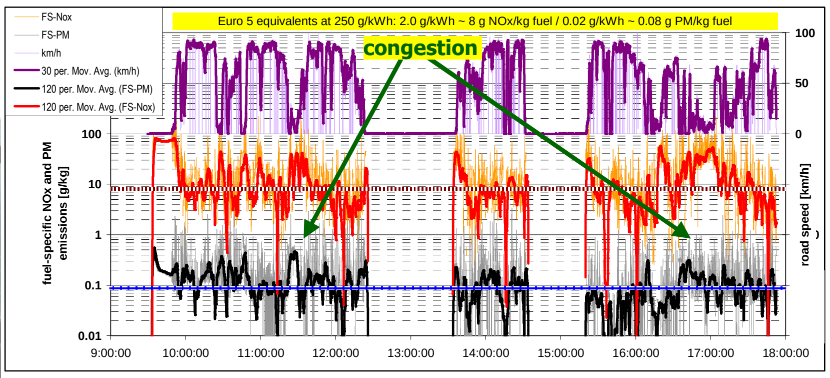
Emissions from Euro 5 heavy vehicles during congested driving

2006 DAF 105 tractor-trailer, 12.9-liter Paccar engine – Prague perimeter road



Higher emissions of PM and NOx / kg fuel during driving in heavily congested area

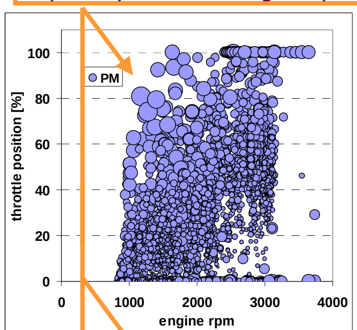
Very transient operation, even during freeway cruise

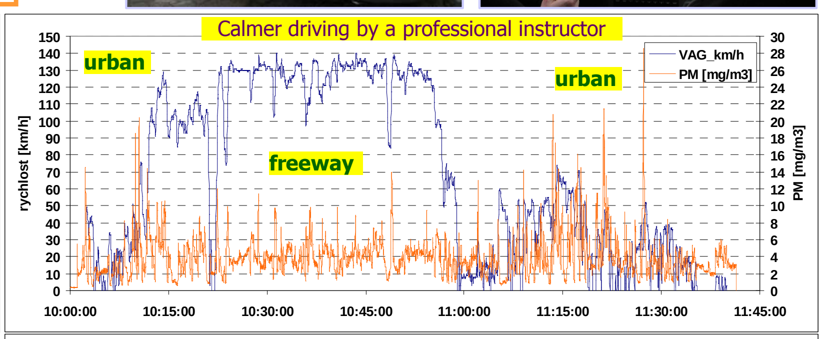


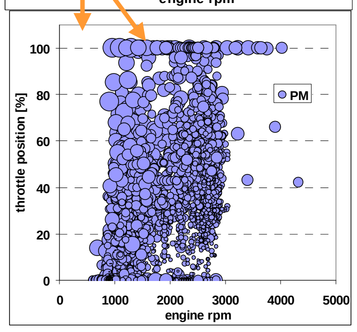
Light-duty diesels in urban driving

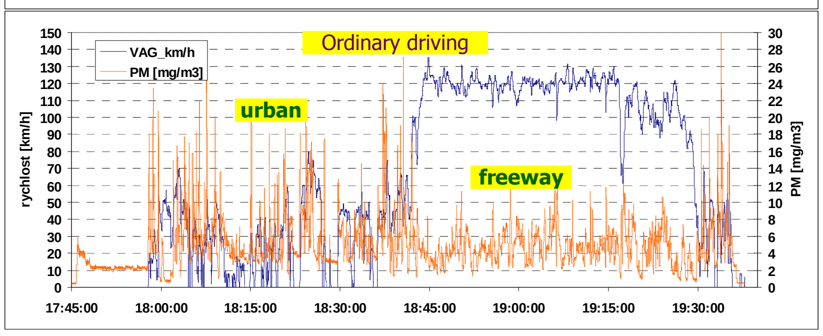
Example: A 2003 Škoda Octavia car with turbodiesel engine – PM emissions during travel from TU Liberec to Czech Technical University in Prague

Highest PM concentrations: During full-load accelerations, especially from low engine rpm









Acknowledgments

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PM emissions from a 2003 Škoda Octavia car with 103 kW turbodiesel during tests in Prague and trips between Prague and Liberec