Influence of different diesel fuels under variation of injection and boost pressure on combustion and on physicochemical properties of engine-out soot emissions

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MOTIVATION

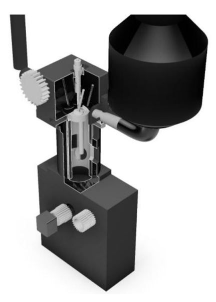
- Diesel particulate filters (DPF) for high efficient removal of particulate matter from diesel exhaust gas
- Increasing soot amount in the DPF → higher back pressure → higher fuel consumption of the engine
- Oxidation of trapped soot in the DPF [1-3]
- Soot reactivity depends on physicochemical properties of emitted particulate matter [4, 5]
- Particulate number and mass dependent on in-cylinder mixture formation and on combustion process [6, 7]

→ Influence of different (alternative) diesel fuels and engine operating parameters on

- **in-cylinder mixture formation, combustion and**
- **physicochemical properties of engine-out particulate matter**

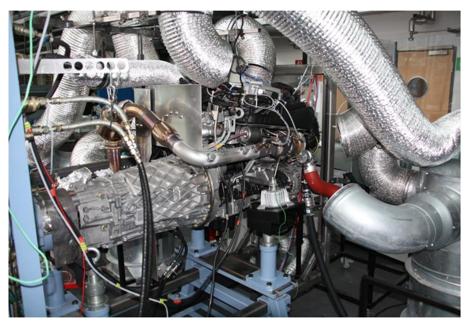
ENGINES

Optically-accessible single-cylinder diesel engine



Displacement	500 cm³
Injection pressure	Up to 160 MPa
Boost pressure	0.105 MPa – 0.30 MPa
Boost temperature	293-363 K
Piston bowl shape	Omega
Injector type	Bosch, solenoid, 6-hole
Injection system	Common rail
Exhaust gas recirculation	Adjustable with different gases (air, N_2, CO_2,…)

Light-duty production diesel engine (Daimler, OM651)



Displacement	2143 cm³
Engine design	4 cylinders (in-line)
Compression ratio	16.2 : 1
Injector type	Delphi, piezo
Injection system	Common rail
Electronic control unit	Open access

DIESEL FUELS

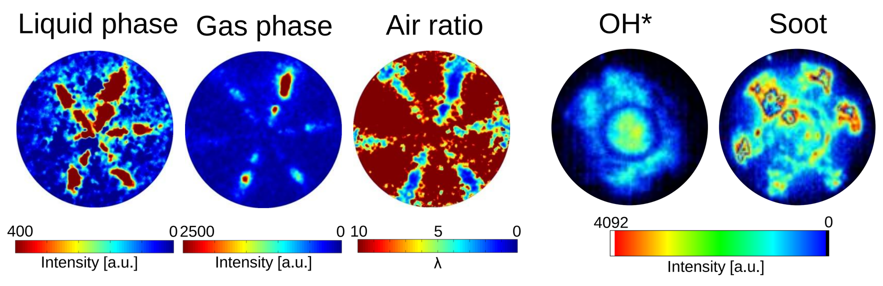
Summary of physical and chemical fuel properties

fuel	Density [kg/m³]	Cetane number [-]	Lower calorific value [MJ/kg]	Viscosity [mm²/s]	Sulfur content [mg/kg]	RME content [%]
Reference diesel fuel (B0)	834.2	52.5	42.5	2.885	< 5	< 0.1
Diesel fuel DIN EN 590:2010-05 (B7)	836.7	53.1	42.2	2.470	5.3	4.5
Rapeseed methyl ester (RME, B100)	882.8	52.5	37.5	4.438	< 5	> 99
Di-n-butyl ether (DNBE)	767.0	-	38.0	-	< 5	< 0.1

MEASUREMENT TECHNIQUES

Analysis of in-cylinder processes

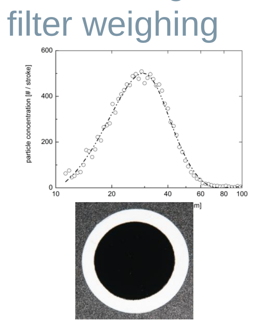
Injection / mixture formation — Combustion



Laser-induced exciplex fluorescence (LIEF) — Combustion spectroscopy

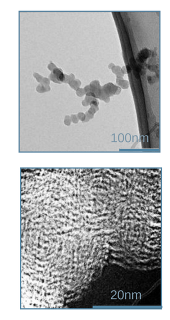
Physicochemical properties of emitted particles

SMPS, Pegasor, filter weighing



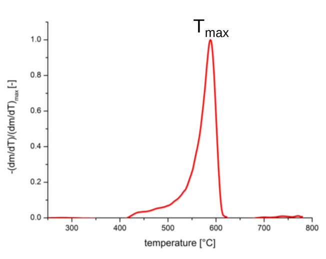
Mobility diameter, number, mass

HR-TEM



Primary particle diam., morphology

Thermogravimetry

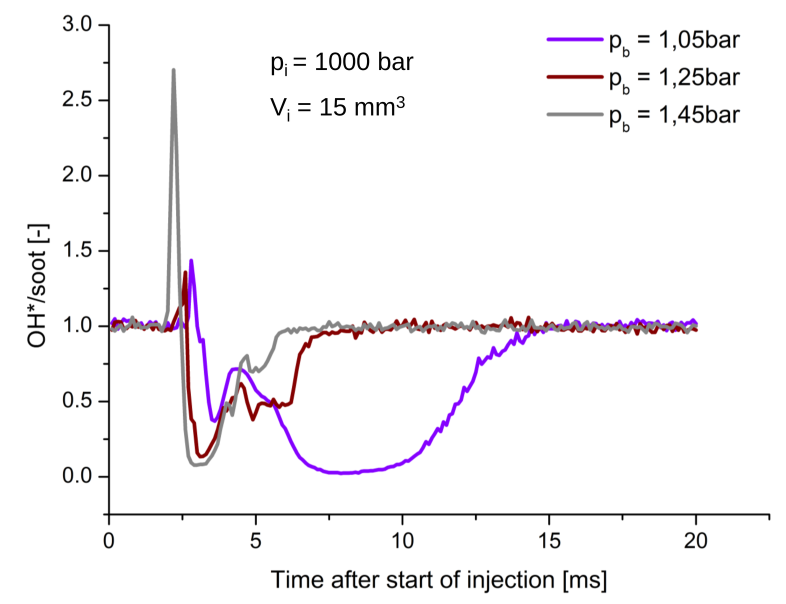


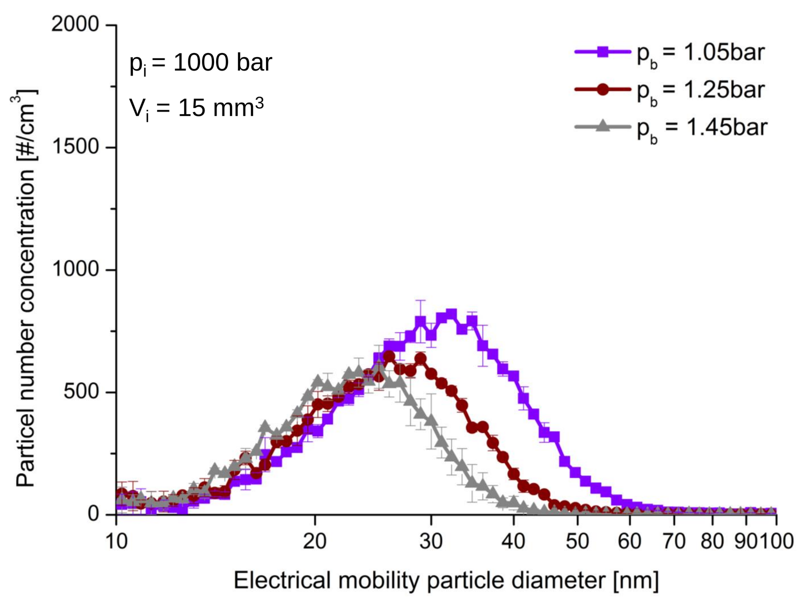
Soot reactivity

RESULTS

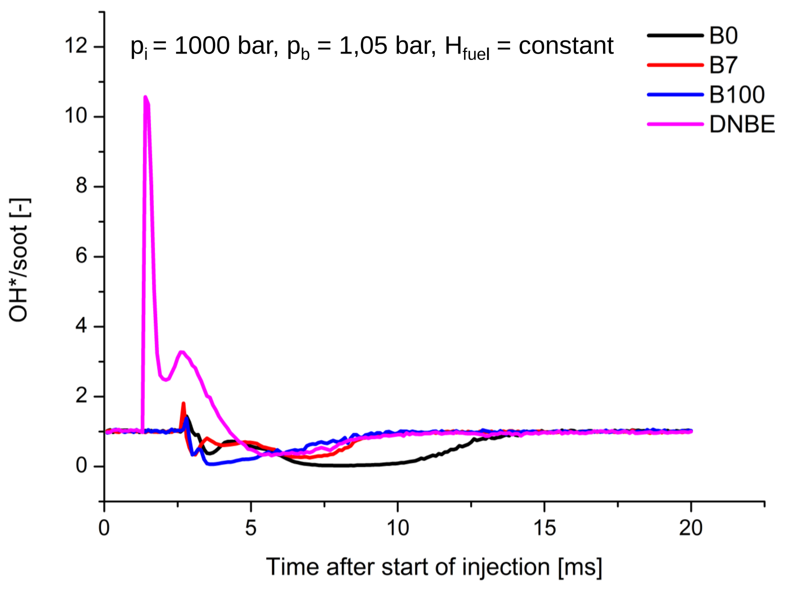
Optically-accessible single-cylinder diesel engine: optical combustion analysis, particle emissions

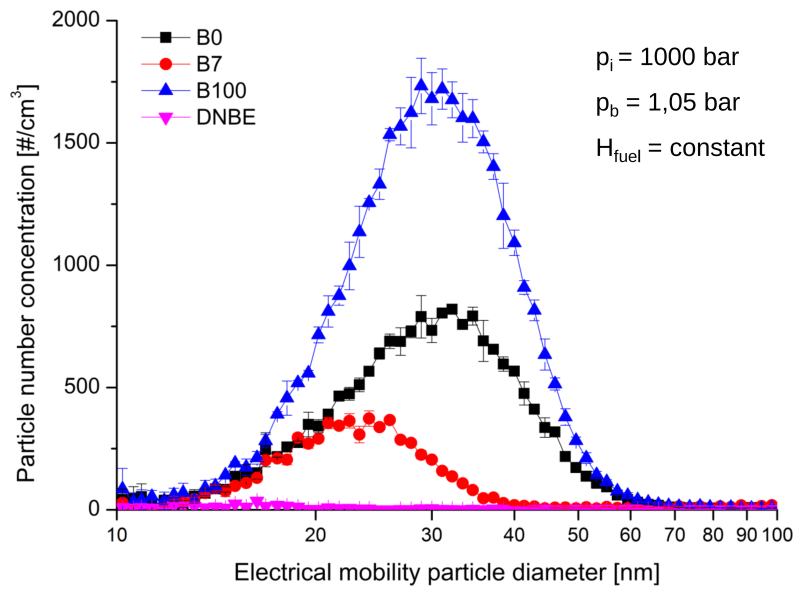
- **Influence of boost pressure on combustion and on physical properties of emitted particles (B0)**





- **Influence of different diesel fuels on combustion and on physical properties of emitted particles**

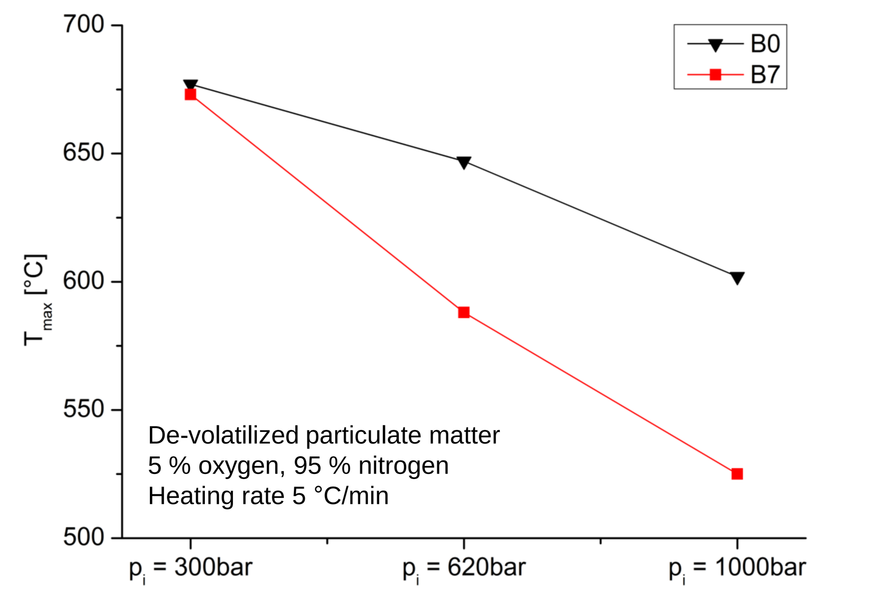


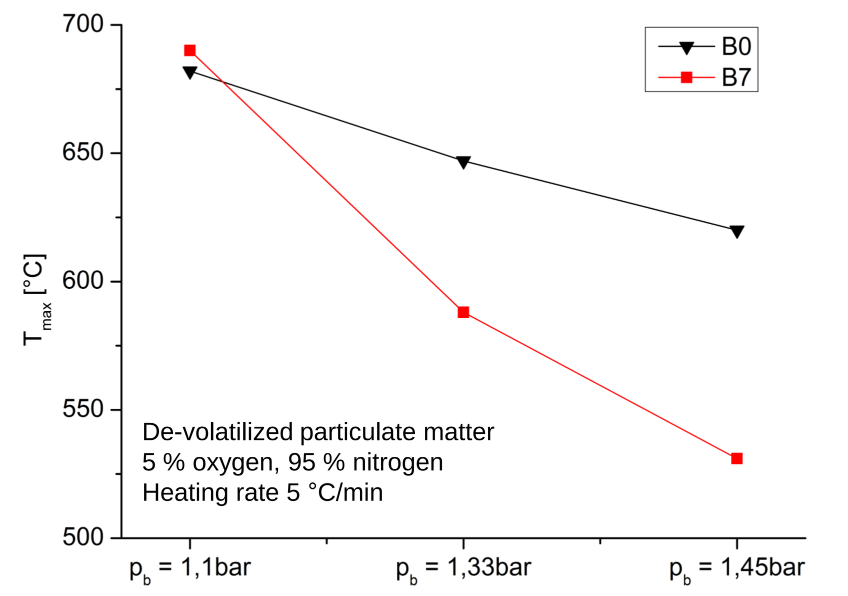


- Shorter ignition delay with increasing boost pressures for B0 fuel (top left)
- Shorter / weaker diffusive combustion at high boost pressures for B0 fuel
- Lower particle number concentrations (PN) / smaller particle diameters at advanced boost pressures for B0 fuel (top right)
- DNBE: very short ignition delay, intensified premixed combustion over the whole combustion phase (bottom left) → very low PN (bottom right)
- B0 / B7: longer ignition delay, longer / intensified diffusive combustion → higher PN / larger particles
- B100: shorter diffusive combustion → higher PN / smaller particles

Light-duty production diesel engine (Daimler, OM 651): 1000 rpm, 25 %, SOI = -6 °CA BTDC, EGR = 0 %

- **Soot reactivity of de-volatilized particulate matter (400 °C in nitrogen) at exhaust gas relevant conditions**





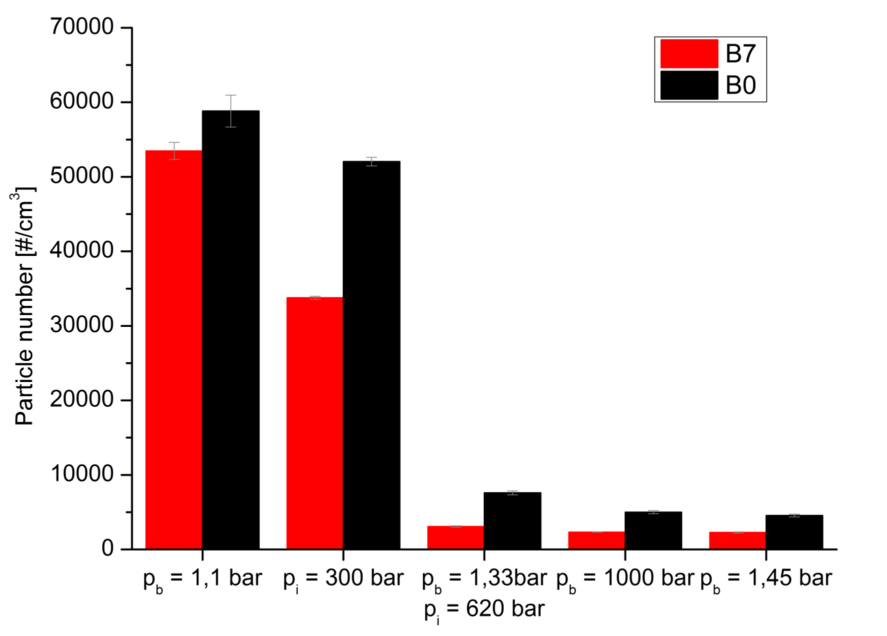
→ T_{max}: Temperature with highest oxidation rate → high reactivity = low T_{max}; low reactivity = high T_{max}

→ Higher reactivity of soot generated with higher injection (p_i, left) and with higher boost pressures (p_b, right): ΔT_{max} between engine operating parameters significant higher for B7 (~170 °C) than for B0 fuel (~80 °C)

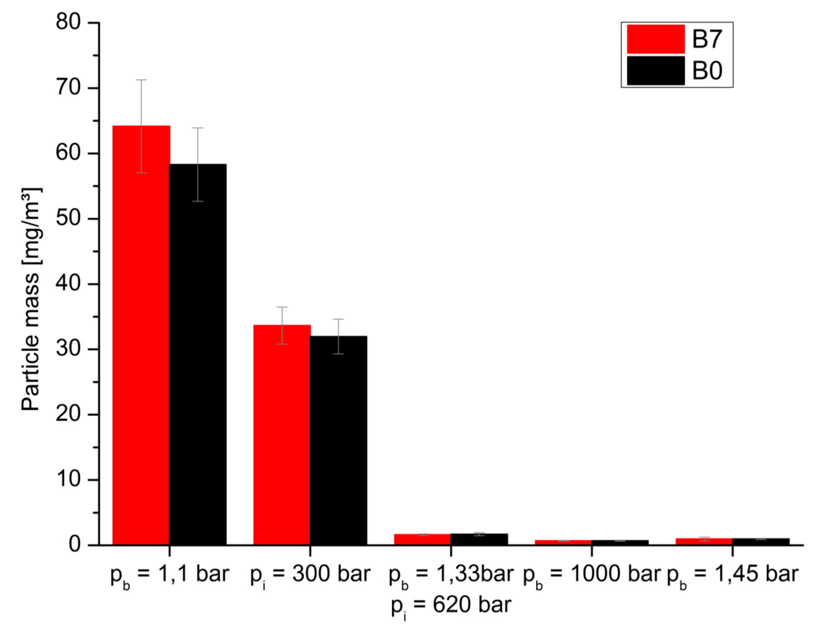
→ B7 soot more reactive than B0 soot: low difference for the low injection and the low boost pressure (4-8°C), highest difference for the high injection and for the high boost pressure (~70-80 °C)

- **Particulate number and particulate mass emissions**

Scanning Mobility Particle Sizer (conditioned partial-exhaust flow)



Pegasor Particle Sensor (PPS)



→ Lower particle number and mass at higher injection and at higher boost pressures (for B7 and for B0 fuel)

→ Higher particle number for B0 than for B7, but lower particle mass for B0 than for B7 because of additive compounds in the B7 fuel (e.g. sulfur)

CONCLUSIONS

- Differences in soot formation and oxidation process with advanced boost pressures →high differences in particle number emissions and particle diameters
- High differences in combustion between the fuels → different particle number emissions and particle diameters
- High differences in soot reactivity, in particle number and mass emissions for different boost and injection pressures as well as for different diesel fuels

FUTURE WORK

- LIEF measurements for visualization of injection and mixture formation processes
- Further research with alternative diesel fuels (first and second generation bio fuels)
- Correlation between primary particle structure and reactivity of particulate matter?
- Correlation between chemical composition of the particulate matter and its reactivity?
- Spatially resolved differences in combustion?

Acknowledgements

The research project is funded by the German Ministry of Food, Agriculture and Consume Protection (BMELV) through its Agency for Renewable Resources (Fachagentur Nachwachsende Rohstoffe e.V. – FNR) as well as by the Research Association for Combustion Engines e.V. (Forschungsvereinigung Verbrennungskraftmaschinen e. V. – FVV).

Gefördert durch: Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz
aufgrund eines Beschlusses des Deutschen Bundestages

FVV

References

[1] Johnson, T., "Diesel Emissions in Review," *SAE Int. J. Engines* 4(1):143-157, 2011, doi:10.4271/2011-01-0304.
[2] Johnson, T., "Review of Diesel Emissions and Control," *SAE Int. J. Fuels Lubr.* 3(1):16-29, 2010, doi:10.4271/2010-01-0301.
[3] Bermudez, V., Serrano, J., Piqueras, P., and García-Afonso, Ó., "Influence of DPF Soot Loading on Engine Performance with a Pre-Turbo Aftertreatment Exhaust Line," SAE Technical Paper 2012-01-0362, 2012, doi:10.4271/2012-01-0362.
[4] Leidenberger, U., Mühlbauer, W., Lorenz, S., Lehmann, S., Brüggemann, D., "Experimental studies on the influence of diesel engine operating parameters on properties of emitted soot particles," Combust. Sci. and Technol. 184(1): 1-15, 2012, doi: 10.1080/00102202.2011.611551.
[5] Liati, A., Dimopoulos Eggenschwiler, P., Schreiber, D., Zelenay, V., Ammann, M., "Variations in diesel soot reactivity along the exhaust after-treatment system, based on the morphology and nanostructure of primary soot particles," Combust. Flame 160(3): 671-681, 2013, doi: 10.1016/j.combustflame.2012.10.024.
[6] Mühlbauer, W., Leidenberger, U., Lorenz, S., and Brüggemann, D., "Optical Studies about the Influence of Diesel Engine Operating Parameters on the Physicochemical Properties of Emitted Soot Particles," *SAE Int. J. Engines* 6(3):1866-1876, 2013, doi:10.4271/2013-24-0184
[7] Lapuerta, M., Oliva, F., Agudelo, J., Boehman, A., "Effect of fuel on the soot nanostructure and consequences on loading and regeneration of diesel particulate filters, "Combust. Flame 159(2): 844-853, 2012, doi: 10.1016/j.combustflame.2011.09.003.

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