Influence of in-cylinder soot formation and oxidation on engine-out soot emission in operation with 1st and 2nd generation biofuels

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MOTIVATION

Challenges for developers of future diesel engines:

1. Reduction of particulate matter (PM) – nitrogen oxide (NO_x) trade-off [1,2]
2. Replacement of fossil fuel [3,4]

Potential **solutions**

1. Alternative combustion concepts, HCCI (at best $\lambda_{global} = \lambda_{local}$)
2. Biogenic fuels (1st and 2nd generation)

→ Development of biogenic fuels gives further degree to achieve HCCI operation mode

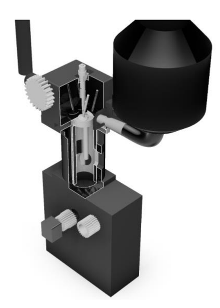
Target of the experiments:

Analyzing in-cylinder soot formation and oxidation process as well as engine-out soot emissions of a 1st and 2nd generation biogenic fuel in comparison to a reference diesel fuel

Engine and operating points

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,…)



Engine operating parameters

Fuel	Injection pressure p_i	Injected fuel mass m_i	Start of injection *SOI*	Engine speed *n*	Boost pressure p_b
B0	300 bar	12.0 mg	6 °CA BTDC	600 rpm	1.05 bar
	1000 bar	12.0 mg	6 °CA BTDC	600 rpm	1.05 bar
B100	300 bar	13.6 mg	6 °CA BTDC	600 rpm	1.05 bar
	1000 bar	13.6 mg	6 °CA BTDC	600 rpm	1.05 bar
DNBE	300 bar	13.4 mg	6 °CA BTDC	600 rpm	1.05 bar
	1000 bar	13.4 mg	6 °CA BTDC	600 rpm	1.05 bar

DIESEL FUELS

Summary of physical and chemical fuel properties

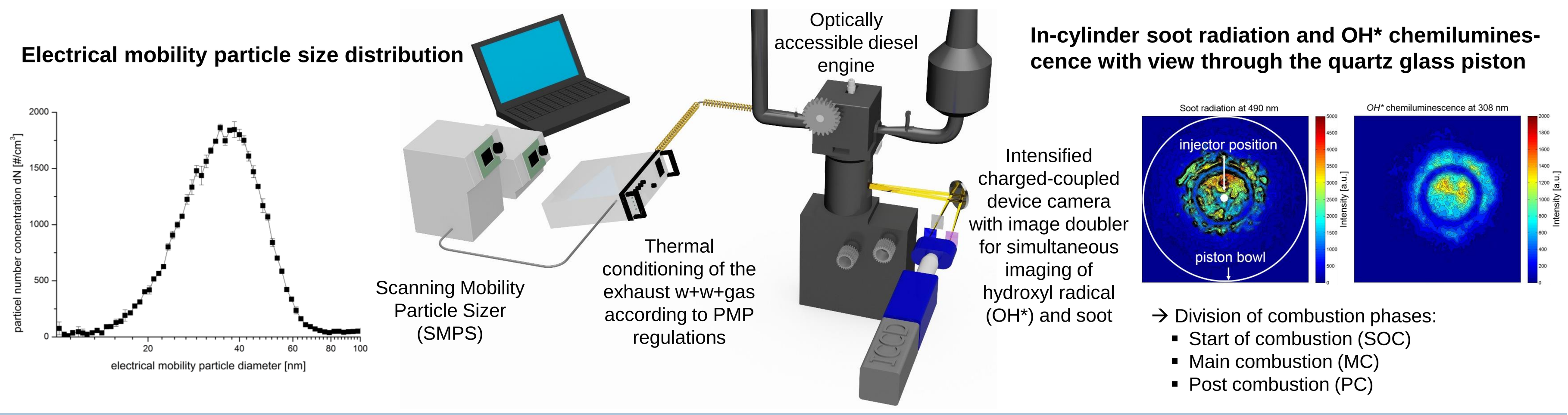
fuel	Density at 15 °C [kg/m³]	Cetane number [-]	Lower heating value [MJ/kg]	Dyn. Viscosity at 40 °C [mPa s]	Surface tension at 15 °C [mN/m]	Oxygen / Sulphur content [weight-%]	Initial / Final boiling point [°C]
Reference diesel fuel (B0)	834	53	42.5	2.2	28.6	0 / < 5	203 / 360
Rapeseed oil methyl ester (RME, B100)	883	53	37.5	3.5	31.9	11 / < 5	343 / 470
Di-n-butyl ether (DNBE)	767	100	38.0	0.5	23.1	12 / < 5	142 / 142

MEASUREMENT TECHNIQUES AND EVALUATION METHODS

Analysis of the in-cylinder combustion process and of physical properties of emitted particles

Electrical mobility particle size distribution

In-cylinder soot radiation and OH* chemiluminescence with view through the quartz glass piston

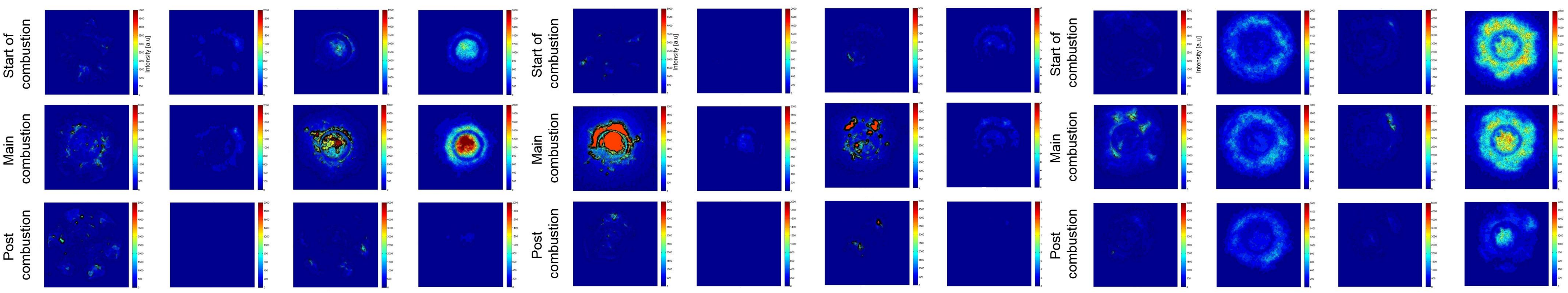


→ Division of combustion phases:
- Start of combustion (SOC)
- Main combustion (MC)
- Post combustion (PC)

RESULTS

Analyzing the in-cylinder soot formation and oxidation process by simultaneous imaging of OH* and soot

- **Reference diesel fuel (B0):** B0: p_b = 1.05 bar, p_i = 300 bar; B0: p_b = 1.05 bar, p_i = 1000 bar
- **Rapeseed oil methyl ester (B100)** B100: p_b = 1.05 bar, p_i = 300 bar; B100: p_b = 1.05 bar, p_i = 1000 bar
- **Di-n-butyl ether (DNBE)** DNBE: p_b = 1.05 bar, p_i = 300 bar; DNBE: p_b = 1.05 bar, p_i = 1000 bar

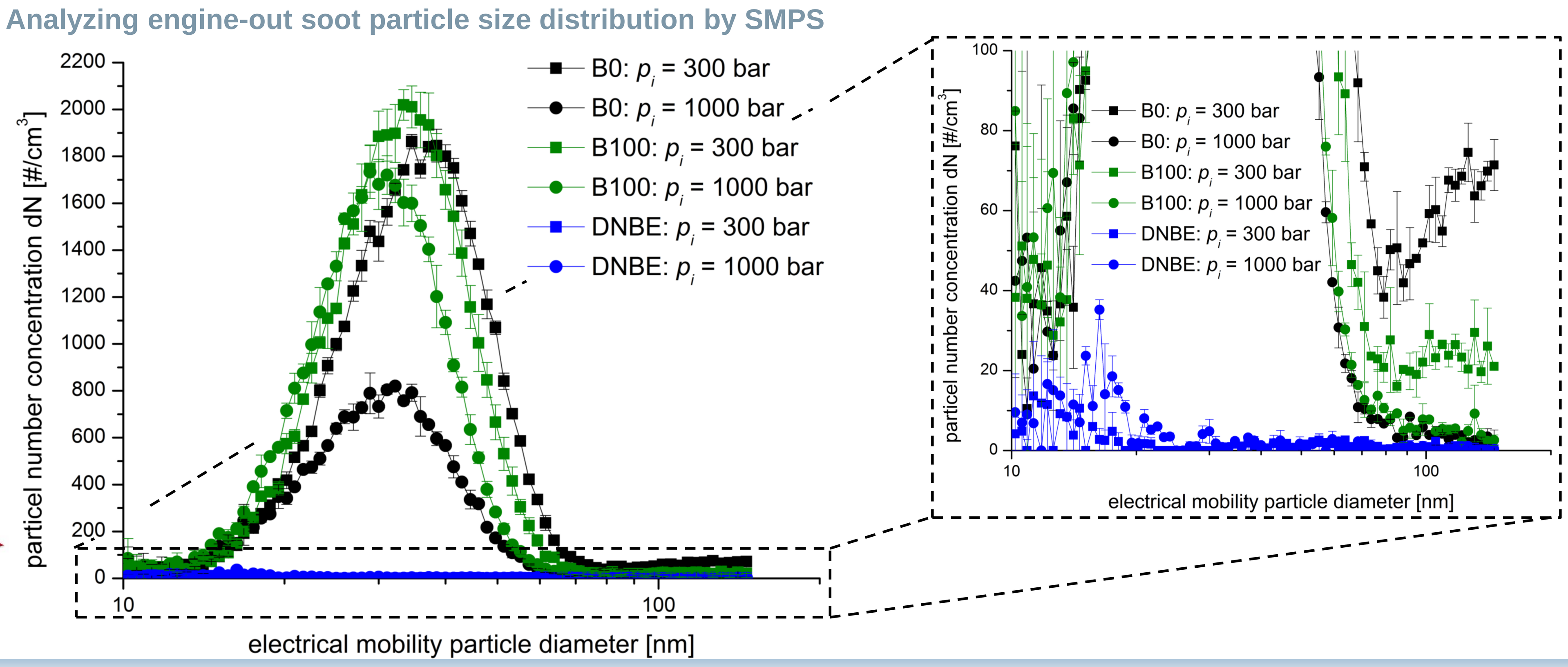


- At low p_i: SOC and PC near bowl wall, MC near the bowl center; low soot oxidation, high soot formation.
- At high p_i: SOC and MC near bowl center, PC near bowl wall; higher soot oxidation by OH*.

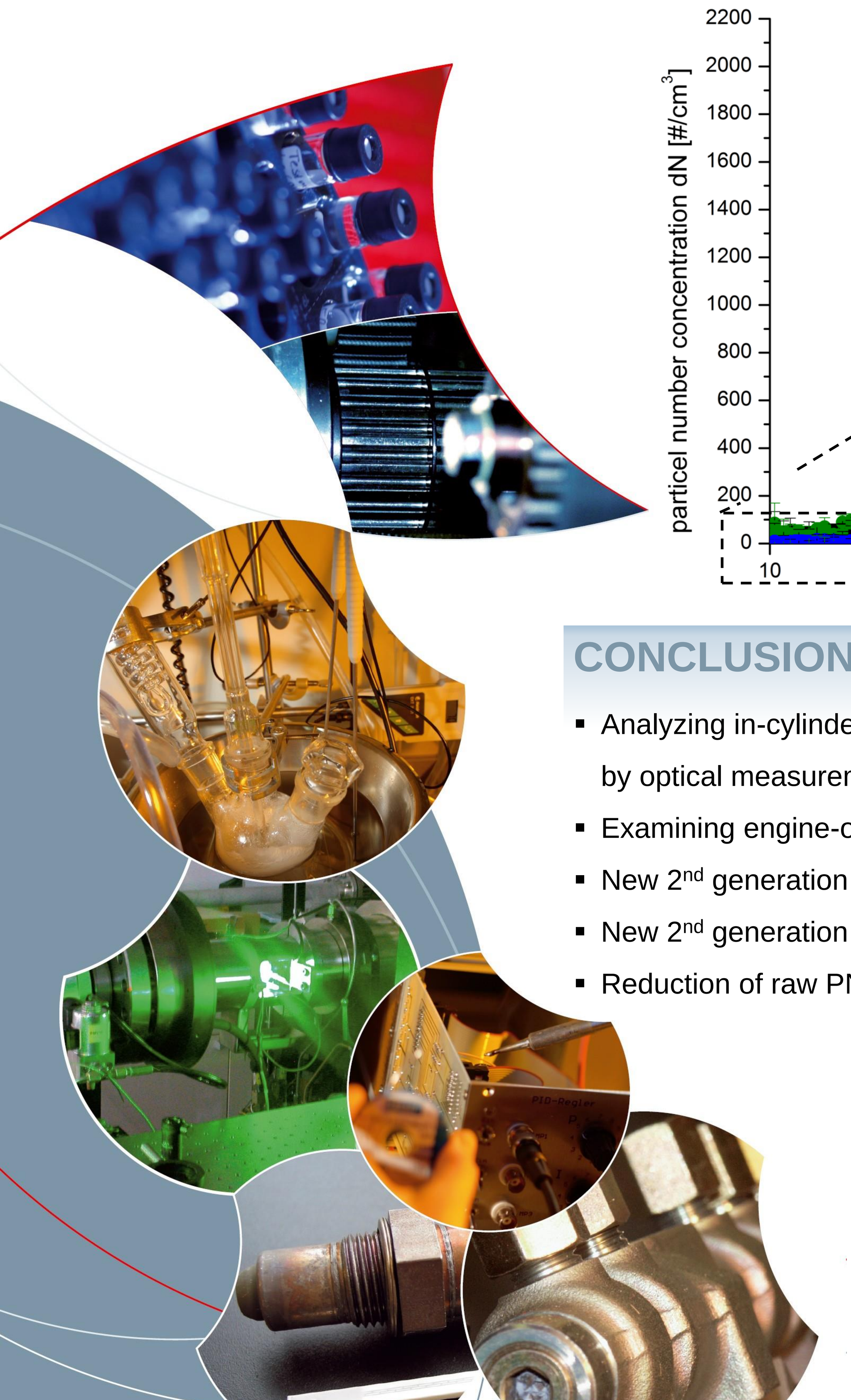
- At low p_i: SOC and PC near bowl wall, MC more distributed near the bowl center; low soot oxidation, high soot formation.
- At high p_i: SOC and MC near bowl center, PC near bowl wall; higher soot oxidation by OH* and molecular (fuel containing) oxygen, lower soot formation.

- Low soot formation at both p_i, high soot oxidation by OH* and by molecular (fuel containing) oxygen during all combustion phases.
- More homogeneous combustion at both p_i for DNBE than for B0 and B100 due to better mixture preparation based on fuel properties (low boiling point, dynamic viscosity and surface tension).

Analyzing engine-out soot particle size distribution by SMPS



- Lower particle number concentrations (PNC) with smaller particles at higher p_i for B0 and B100.
- A bit higher PNC with smaller particles for B100 than for B0 due to higher m_i (based on its lower heating value).
- Lowest PNC for DNBE in contrast to B0 and B100 due to soot free and more homogeneous in-cylinder combustion.



CONCLUSIONS

- Analyzing in-cylinder soot formation and oxidation process of 1st and 2nd generation biofuels by optical measurement techniques.
- Examining engine-out particle size distribution by a SMPS.
- New 2nd generation biofuels (e.g. DNBE) for soot free in-cylinder combustion.
- New 2nd generation biofuels support to achieve HCCI.
- Reduction of raw PN emissions during in-cylinder combustion.

FUTURE WORK

- Further engine operating points (injection, boost pressure, start of injection exhaust gas recirculation).
- Further fuels (synthetic, 2nd generation).
- Optical measurement technique for local temperature and soot fraction determination.
- Optical examination of fuel injection and mixture formation.

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