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Evolution and characteristics of in-cylinder diesel soot

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The majority of European Black Carbon (BC) emissions may be attributed to diesel engines (Bond et al., 2013). Fresh diesel soot is commonly studied in or close to the exhaust pipe where soot properties for atmospheric relevance are determined (Park et al., 2003).

To improve and develop a mechanistic understanding of soot properties due to different engine operating conditions, particle measurements inside the engine cylinder are ideal. Such “in-cylinder” observations have been made by e.g. laser extinction in optical engines (Gallo et al., 2015), mounting TEM grids in the cylinder (Zhang et al., 2014) and extraction of the full cylinder volume in a Teflon bag (Li et al., 2011). These techniques have revealed how in-cylinder soot oxidation is very important in determining the final diesel soot emissions. We here present new results from measurements on in-cylinder particles extracted with a technique named the fast gas-sampling valve (FSV).

The FSV allows extraction of a small portion of the cylinder gases with a high temporal resolution. The result is a small semi-continuous aerosol flow of in-cylinder gases which may directly be analyzed with conventional on-line aerosol measurement techniques. We probed aerosol properties using a scanning mobility particle sizer (SMPS), an Aethalometer and a soot particle aerosol mass spectrometer (SP-AMS). Measurements were conducted at several points in the combustion phase to capture both soot production and soot oxidation. The oxygen to fuel ratio was adjusted by recirculating a part of the exhaust gases resulting in three engine operating conditions with 21%, 15% and 13% inlet air oxygen concentration.

The results illustrate how the peak soot concentration of the combustion cycle is two orders of magnitude higher than the late combustion cycle soot concentration (figure 1). The majority of the produced soot is quickly oxidized in the late combustion cycle. However, with lower inlet oxygen concentration the soot oxidation rate is markedly reduced. The total particle number remains fairly constant when reducing inlet oxygen concentration, but a strong shift to smaller particle mean mobility diameters was observed. Furthermore, soot light absorption properties display large variations in wavelength dependence during the combustion cycle and with varying inlet oxygen concentration.

This wavelength dependence was found to have a clear correlation to the total concentration of polyaromatic hydrocarbons (PAHs) and fullerenes. The correlation is illustrated in figure 1 (sub-graph) at 13% inlet oxygen concentration. The inlet oxygen concentration thus alters the soot emissions and the soot interaction with solar radiation in the atmosphere. The observations show that soot characteristics are linked to both the soot formation and oxidation phases of the combustion cycle.

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