THE APPLICABILITY OF PHOTOACOUSTIC MEASUREMENT TECHNIQUE FOR QUALITATIVE INVESTIGATION OF DIESEL EMISSION

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Abstract
In our work parallel measurement of wavelength dependent optical absorption, size distribution and number-concentration were produced using multi wavelength photoacoustic spectrometer (4λ-PAS) and scanning mobility particle sizer (SMPS). For comparative study two different fuel type was tested at three different working points of the engine. The thermal evolution of the emission was also examined using thermodenuder (TD) unit. Bimodal size distribution of emissions at reference temperature was achieved using pure petroleum-based fuel (B0). The OAC values measured at the operating wavelengths of the instrument decreased with increasing rev and rated torque at all wavelengths. The wavelength dependence quantified by Aerosol Angström Exponent (AAE) can be used here for qualitative analysis of carbon emission and showed increased volatility of organic particles towards higher temperatures.

Introduction
In present days due to their climate and adverse health impact the investigation of diesel particulate matter (DPM) have been in gradually increased scientific interest. The diesel emitted particle is one of the dominant source of light absorbing carbonaceous particulate matter (LAC), which is the second most important climate relevant atmospheric constituent too (Bond et al., 2013). Diesel engines equipped with a modern, sophisticated after-treatment system also meet the new emission standards. However, further restriction of emissions in this way is limited by durability and maintenance. Emission-based fuel development is one of the most promising alternatives not only for reducing emissions but also for more environmentally friendly fuel development. The controlled parameter for soot emitted by a diesel engine is the number and mass concentration that has a limited ability to describe the air quality and climate implications of the DPM assembly. The size distribution, volatile classification and spectral responses of diesel carbon are critical parameters both in climatic and also in health relevancies. A recently introduced in-situ measurement method for volatile classification of DPM is based on measuring the size distribution of a temperature-treated and denuded aerosol assembly (Burtscher et al., 2001). The use of a thermodenuder (TD) for the pretreatment of depleted DPM not only allows the classification of volatiles, but also provides an indirect opportunity to study the state of the particles in relation to a given exhaust gas temperature under steady-state measurement conditions. Measuring aerosol light absorption is also a key, climate-relevant quantity. Moreover, the absorption spectrum of the LAC, which is quantified by its wavelength dependence (AAE) is the only physical quantity that can be measured in real-time and which serves composition and air quality relevant informations (Utry et al., 2014; Ajtai et al., 2015).
In this work, we demonstrate the experimental results of number concentration, size distribution and absorption spectra measurement of DPM in the function of the operational condition of diesel engine using different fuel types using scanning mobility particle sizer (SMPS) and multi-wavelength photoacoustic spectrometer (4λ-PAS). We also study the measured quantities in the function of thermal stability.

Experimental

The experimental set up of sampling system what we used is shown in Fig.1. For the measurement, a four-cylinder EURO 4 PC diesel engine with a 2-liter turbocharged common rail injection system was used to generate diesel exhaust emissions. The rear exhaust gas concentration was further reduced 10-fold with ejector diluter (Palas GmbH VKL 10). In any given operating condition of the engine, the exhaust particles were treated thermally before measurement. In our experiments the measurements were performed with two different fuel compositions (B0 and B7) under three different engine loads (defined on fig. 1 as wp#1, wp#2 and wp#3) at three different denuding temperatures (40°C, 150°C, 300°C). B7 For reference petroleum based B0 (biofree) fuel was used. For the investigation of biofuel effect B0 was blended with 7% FAME (Fatty Acid Methyl Ester) (B7). For reference measurements the heating unit of TD was set to 40°C. While, for volatility measurement the TD was heated to 150°C and 300°C respectively.

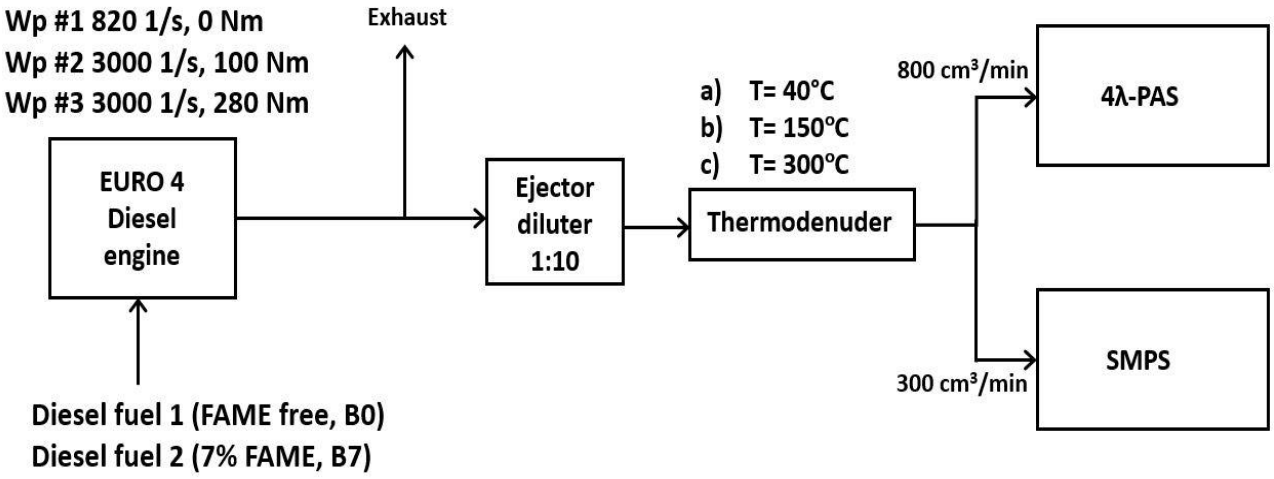

Figure 1. The experimental set-up of the sampling system. Operatory conditions of engine, type of fuels, posterior temperature treatment conditions.

Results and discussion

The results of number concentration and size distribution measurements using B0 and B7 fuels at three distinct operational conditions of engine and temperatures are shown in Fig. 2. From the fitted data, we derived the characteristic parameters of the identified modes, including the median count (CMD), the geometric standard deviation (GSD), and the total number concentration (TNC). Total volume concentration (TVC) was also inferred using a simple spherical approach in the calculations. Independently of the fuel used, a bimodal size distribution was identified at a reference temperature (40°C) of 820 rpm at 0 Nm. While at wp#2 and wp#3, a monomodal size distribution achieved at 40°C (Fig. 2). Regardless of engine operating condition and fuel type, the monomodal size distribution has shown similar characteristics than in several previously described diesel soot emission studies (Butcher et al., 2001). In general, regardless of fuel type, engine operating condition, and sample temperature, B7 fuel provides similar emission characteristics (i.e. GMD and GSD values) as B0, but with a total number concentration (TNC) approximately 10-20% lower for all case. In the transition from wp#1 to wp#2, the number concentration decreases significantly while further increasing the torque at a constant engine speed in the transition from wp#2 to wp#3 more or less remained unchanged. It is noteworthy, however, that although the torque increases from 100 Nm to 280

Nm at 2500 rpm (transition from wp#2 to wp#3), the TNC values and the population of particles show a high degree of similarity but varies slightly in population statistics.

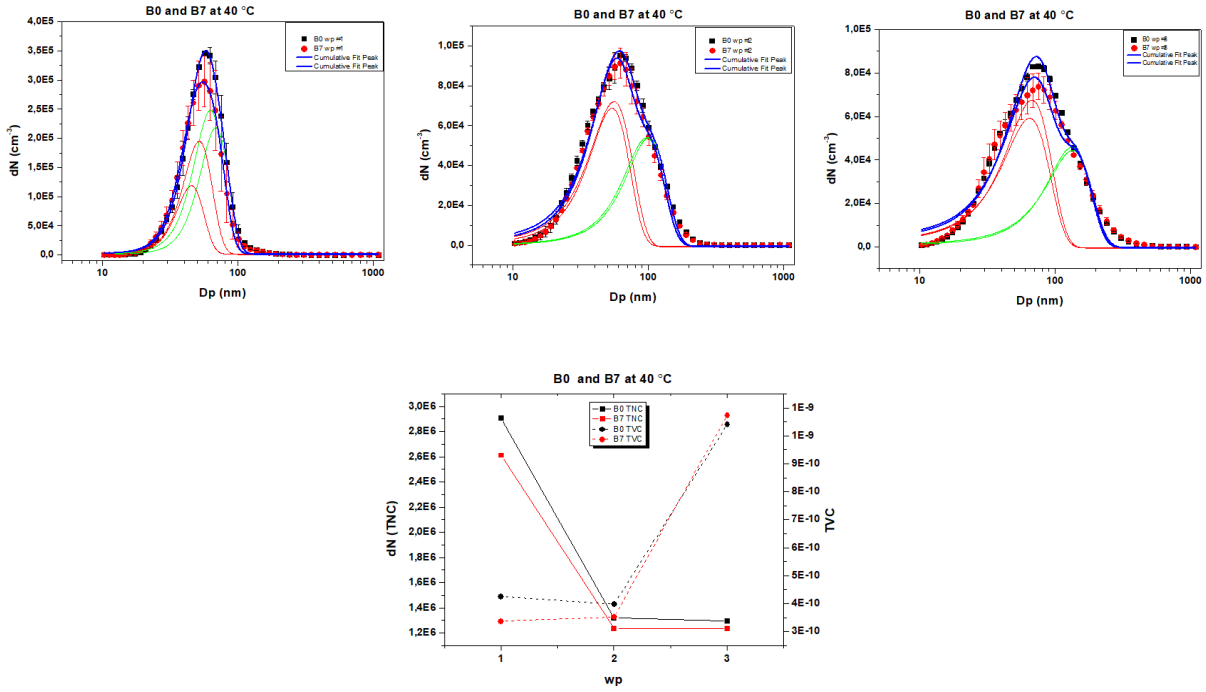

Figure 2. Size distribution and its characteristic parameters using B0 and B7 fuels at three different operatory parameters of the test engine. Total Number Concentration (TNC), Count Median Diameter (CMD), Geometric Standard Deviation (GSD). Total Volume Concentration (TVC)

At higher torque (280 Nm), the population contains fewer small (less than GMD) but more large (greater than GMD) particles than at lower torque (100 Nm) at the same speed (2500 rpm) (Fig. 2). This seemingly marginal change as a function of size distribution resulted in significant differences in TVC values. Similarly, despite significant differences in TNC values measured in wp#1 to wp#2 transition the TVC concentration has remained more or less similar. This can also be explained by the differences in the population statistics of the emitted diesel aerosol assembly.

The AAE value deduced from the measured absorption at the operational wavelengths of the multi-wavelength photoacoustic instrument using B0 and B7 fuels at different working points of the engine are drawn in Fig. 3. Based on that the AAE value around 1 means the elemental or black carbon fraction dominancy, while the higher value of that indicates presence of organic or in spectral terminology brown carbon fractions. In this context Fig.3 can be interpreted as the following. The AAE value of B7 is higher than that of B0. This indicates the presence of organic carbon soot with high absorption ability towards the shorter wavelengths. Increasing the rev and torque the AAE value is decreasing and indicates increasing elemental and black carbon dominancy in the emitted aerosol assembly. Finally, the increasing denuder temperature resulted in decreasing AAE values. This tendency means that the volatile organic compounds evaporates from the surface of the particles at higher temperatures.

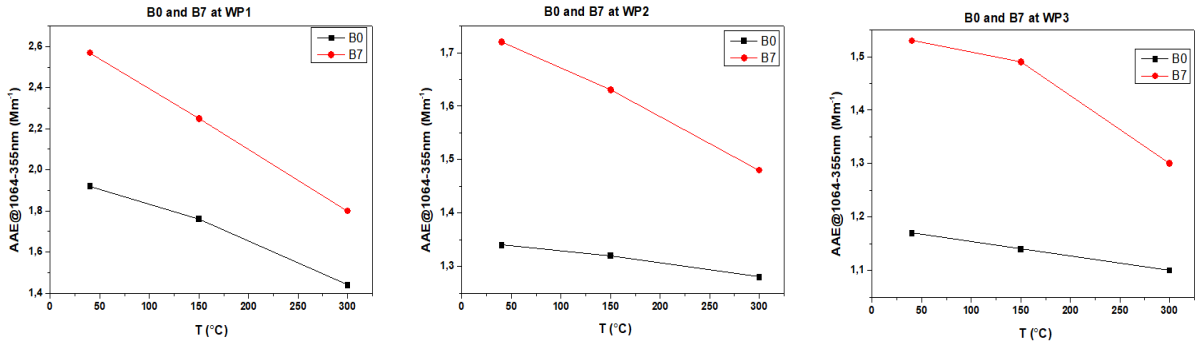

Figure 3. AAE of diesel emission in the function of working points of engine using different type of fuels and sampling temperature.

Because AAE indirectly determines the ratio of organic to inorganic in the test sample, examining the relationship between the number concentration in the population statistics and the AAE data requires more extensive measurement that goes beyond this work.

Summary and conclusion

The number-concentration and the population statistics including TNC, TVC and GMD values as well as the absorption responses including OAC and AAE values were measured at three different engine operating points using pure petroleum based B0 and B0 blended with 7% FAME content (B7) fuels. The absorption spectra quantified by its wavelength dependency (AAE) were deduced from the measured data at any operating condition of engine and fuel types. We have demonstrated experimentally that the size distribution of the wp#1 has bimodal distribution. We also demonstrated in this work that biofuel content cause higher absorption responses towards the shorter wavelengths and that the TNC values shows increased dynamics than that of AAE values with the increased number of wp's. We also experimentally demonstrated the applicability of the multi-wavelength PA spectroscopy for the emission based fuel development purposes. Finally, we also demonstrated a novel methodology for particle evolution measurement using the combination of PA instrument and a thermodenuder unit.

Acknowledgements

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