PARALLEL MEASUREMENT OF SIZE DISTRIBUTION AND SPECTRAL RESPONSES OF PARTICULATE MATTER OF DIESEL ENGINES USING 4-PAS AND SMPS

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Abstract

Diesel engine emissions are under scrutiny in various fields. Due to its complex air quality and climate relevancies, the parallel measurement of size distribution and the spectral responses of thermally pretreated diesel particulate matter (DPM) provides a powerful opportunity to better understand its environmental impact and serve as a novel method for emission-based fuel development. In this study, we demonstrate the experimental results of number concentration, size distribution, and absorption spectra measurements of DPM as function of the operational conditions of diesel engines using different fuel types by 4-PAS and SMPS. The number-concentration and the population statistics including TNC, TVC and GMD values as well as the absorption responses including OAC and AAE data at different operational wavelengths were measured at each operational mode of the engine using pure petroleum based B0 and FAME mixed diesel fuels at three different TD temperatures. The thermal evolution of the investigated emission was also investigated at all measurement conditions. The results demonstrate the applicability of multi-wavelength PA spectroscopy for the qualitative investigation of diesel emissions and thermal evolution using a multi wavelength PA instrument - thermodenuder unit combination.

Introduction

In present days due to their climate and adverse health impact the investigation of diesel particulate matter (DPM) has been in gradually increased scientific interest. The diesel emitted particle is one of the dominant sources of light absorbing carbonaceous particulate matter (LAC), which is the second most important climate relevant atmospheric constituent too [1,2]. 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 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 [3]. 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 information's [4,5].

Experimental

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 (bio free) 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.

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. 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.

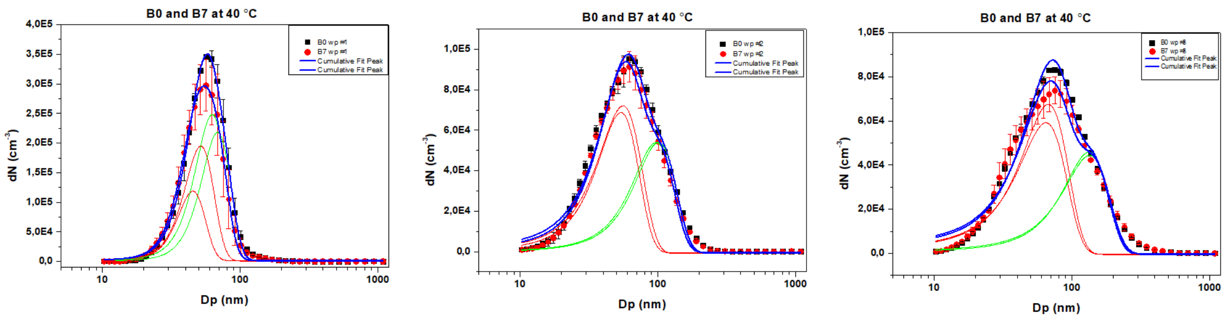

Figure 2. Size distribution and its characteristic parameters using B0 and B7 fuels at three different operatory parameters of the test engine.

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. 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. This tendency means that the volatile organic compounds evaporate from the surface of the particles at higher temperatures.

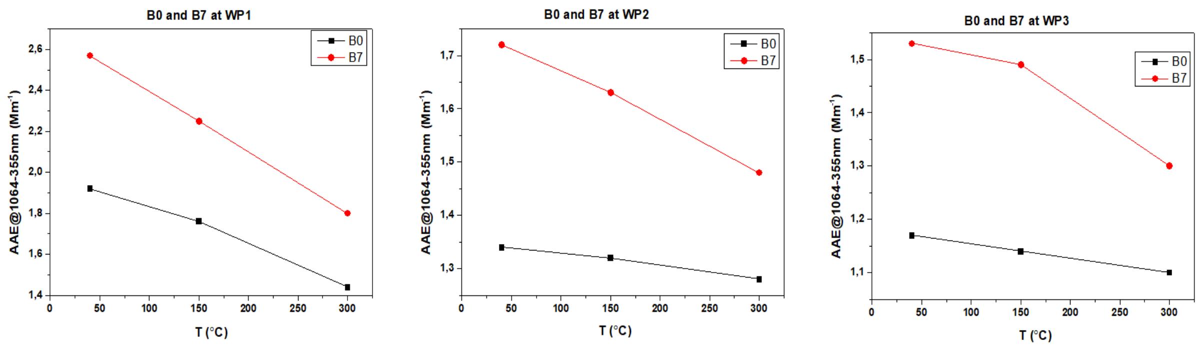

Figure 3. AAE of diesel emission in the function of working points of engine using different type of fuels and sampling temperature.

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.

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