A portable optoacoustic Black Carbon Sensor for Exhaust Emissions Measurement

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Introduction

Black Carbon (BC) is a significant pollutant that has strong absorption in the visible spectrum hence heavily contributing to climate change [1] while it also has significant negative effects on human health [2]. Despite these, there are currently no legislations to reduce BC emissions mainly due to lack of a consensus on definition and standardised measurement methods. Only recently IMO has started considering monitoring of BC emissions from ships (5th meeting of the Sub-Committee on Pollution Prevention and Response (PPR 5)). Optoacoustics is a promising technology for BC measurement because it is a non-destructive absorption based technique that allows for low-maintenance operation and offers miniaturization potential. Here we present a portable optoacoustic sensor for real-time emissions measurement that has been deployed in various campaigns including ships, cars and motorbikes.

Sensor Technology

The sensor is based on an innovative geometry that comprises an ellipsoid chamber [3]. The sample flow meets with the light path at the first focal point of the ellipse where sound waves are produced due to the optoacoustic phenomenon. A very sensitive yet inexpensive sound transducer (QTF) is placed at the second focal point where the signal is captured. This way the QTF is protected from particle contamination without inducing significant loss of sensitivity of the measurement. Currently the sensor has a lower detection limit of ~1 μg/m3.

Test cases

The first application of the sensor was on-board two ships, measuring directly from the funnel. The first was a RoRo ferry transporting passengers and cargo in the Baltic. Exhaust from one of the main engines of the ship was sampled with an eDiluter Pro (Dekati, eDiluter Pro). An aethalometer (ObservAir) is used as a reference. The second implementation was on a large container ship with a scrubber where measurements were performed both before (Upstream-US) and after (Downstream - DS) the scrubber. An eDiluter Pro was used for sampling and an optoacoustic instrument (AVL MSS) was used as a reference.

The sensor was also tested in real-world driving conditions on a vehicle using PEMS as a reference device. Even though the PEMS device measures particle number correlation is found between the measurements. Finally, exhaust measurements were also performed in real-world driving conditions for motorbikes. Since PEMS is too large to be attached to a motorbike, there was no reference instrument for the road measurements. Some comparisons were made in the lab while performing various testing cycles.

Conclusions

We demonstrate a portable optoacoustic BC sensor that is able to measure real-time (1 s resolution) exhaust emissions of various internal combustion engine sources that are comparable to reference instruments. Its dynamic response makes it suitable for on-board real-world measurement of different vehicles. Also the high sensitivity of the sensor makes it suitable for in-field source apportionment measurements, which is a next goal moving forward.

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