



Calibrating filter photometers with direct measurements of aerosol absorption using a dual-wavelength photo-thermal interferometer

Drinovec L^(1,2,3), Jagodič U^(1,2), Pirker L^(2,4), Škarabot M⁽²⁾, Kurtjak M⁽⁵⁾, Vidović K⁽⁶⁾, Ferrero L⁽⁷⁾, Visser B⁽⁸⁾, Röhrbein J⁽⁸⁾, Weingartner E⁽⁸⁾, Kalbermatter DM⁽⁹⁾, Vasilatou K⁽⁹⁾, Bühlmann T⁽⁹⁾, Pascale C⁽⁹⁾, Müller T⁽¹⁰⁾, Wiedensohler A⁽¹⁰⁾, Močnik G^{(1,2,3)*}

(1) Haze Instruments d.o.o., Ljubljana, Slovenia

(2) Department of Condensed Matter Physics, Jožef Stefan Institute, Ljubljana, Slovenia

(3) Center for Atmospheric Research, University of Nova Gorica, Nova Gorica, Slovenia

(4) Faculty for mathematics and physics, University of Ljubljana, Ljubljana, Slovenia

(5) Advanced Materials Department, Jozef Stefan Institute, Ljubljana, Slovenia

(6) Department for Analytical Chemistry, National Institute of Chemistry, Ljubljana, Slovenia

(7) GEMMA center, University of Milano-Bicocca, Milano, Italy

(8) Institute for Sensors and Electronics, University of Applied Sciences
Northwestern Switzerland, Windisch, Switzerland

(9) Federal Institute of Metrology METAS, Bern, Switzerland

(10) Leibniz Institute for Tropospheric Research, Leipzig, Germany

*Corresponding author's email: grisa.mocnik@ung.si

The direct measurement of aerosol light absorption coefficient is preferable over indirect methods. Using filter photometers is challenging due to systematic artifacts and the lack of standardized calibration procedures [1]. A photothermal interferometer probes the change of the refractive index caused by light absorption in (and the subsequent heating of) the sample – the detection is linear and can be traced to first principles. Measurement at two wavelengths determines the absorption wavelength dependence and the Ångström exponent (AAE).

The photothermal aerosol absorption monitor (PTAAM) uses a folded Mach-Zender interferometer (similar to that described in [2] and [3]). Pump lasers at 532 and 1064 nm are modulated at different frequencies and focused in the sample using an axicon for simultaneous measurement. The signal is detected by two photodiodes and resolved by dual-channel lock-in amplifiers measuring at the two frequencies.

The photo-thermal aerosol absorption monitor PTAAM-2 λ (Haze Instruments) was used to directly measure the absorption coefficient at 532 nm. The green channel is calibrated traceably to primary standards using $\sim 1 \mu\text{mol/mol}$ NO₂ and calibration is transferred to the IR using aerosolized nigrosin [4].

Aerosol optical properties can be calculated if the particle shape and the complex refractive index (RI) are known. Soot particles form complex agglomerates that make the calculation of mass concentration and optical properties difficult. On the other hand, particles generated by nebulisation of water-soluble pigments are spherical, which enables Mie calculations using the measured size distribution.

We have used water-soluble nigrosin pigment (CAS 8005-03-6) for the calibration of photo-acoustic instruments [5,6]. Nigrosin has a wide absorption spectrum and allows for calibration also in the infrared. Unfortunately, the RI of nigrosin has been reported for the visible part of the spectrum only.

We have prepared thin film samples of nigrosin and measured their absorbance (400-1200 nm) using an integrating sphere photometer (Shimadzu UV-3600). We used nigrosin film thickness, measured using atomic force microscopy, and the absorbance, to determine the imaginary part of the RI. The real part of the RI at 1064 nm was determined by a Brewster angle measurement.

Nigrosin solution was aerosolized using a Topas ATM 226 nebuliser. The size distribution of the aerosol particles was measured using a scanning mobility particle sizer (TSI model 3080). These data were used in a Mie calculation of the aerosol absorption coefficient for wavelengths between 400 and 1200 nm.

PTAAM was characterized and its uncertainties quantified (Table 1). We calibrated filter photometers (CLAP, AE33) in green and near IR with soot, and determined their cross-sensitivity to scattering for ammonium sulfate particles, resulting in wavelength and size dependent calibration parameters.

Table 1. Uncertainties of the measured parameters.

$b_{\text{abs},532\text{nm}}$	4%
$b_{\text{abs},1064\text{nm}}$	6%
AAE	9%

Similar multiple scattering parameter values were found for ambient aerosols and laboratory experiments. We determined the absorption enhancement using laboratory measurements with uncoated and soot and soot coated with secondary organic matter - Fig. 1 [7].

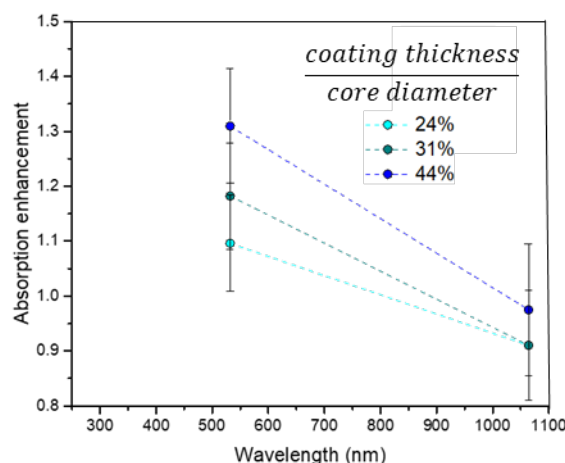


Fig. 1. Absorption enhancement due to coating of BC cores with secondary organic matter as a function of the wavelength.

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References

- [1] E. Weingartner et al., Absorption of light by soot particles: Determination of the absorption coefficient by means of aethalometers, *J. Aerosol Sci.* 34 (2003) 1445-1463.
- [2] H. Moosmüller, W.P. Arnott, Folded Jamin interferometer: a stable instrument for refractive-index measurements, *Opt. Lett.* 21 (1996) 438-440.



[3] A.j. Sedlacek, Real-time detection of ambient aerosols using photothermal interferometry: Folded Jamin interferometer, *Rev. Sci. Instrum.*, 77:064903 (2006) 1-8.

[4] L. Drinovec et al., A dual-wavelength photothermal aerosol absorption monitor: design, calibration and performance, *Atmo. Meas. Tech. Discuss.* (2022) *accepted for publication*. 10.5194/amt-2022-21.

[5] D. Lack et al., Aerosol Absorption Measurement using Photoacoustic Spectroscopy: Sensitivity, Calibration, and Uncertainty Developments, *Aerosol Sci. Technol.* 40:9 (2006) 697-708.

[6] N. Bluvshstein et al., Calibration of a multi-pass photoacoustic spectrometer cell using light-absorbing aerosols, *Atmos. Meas. Tech.* 10 (2017) 1203–1213, <https://doi.org/10.5194/amt-10-1203-2017>.

[7] D.M. Kalbermatter et al., Comparing black-carbon- and aerosol-absorption-measuring instruments – a new system using lab-generated soot coated with controlled amounts of secondary organic matter (2022). *Atmos. Meas. Tech.*, 15 (2022) 561–572.