Lawrence Berkeley National Laboratory

Recent Work

Title

OPTICAL TRANSMISSION THROUGH AEROSOL DEPOSITS ON DIFFUSELY REFLECTIVE FILTERS: A METHOD FOR MEASURING THE ABSORBING COMPONENT OF AEROSOL PARTICLES

Permalink

<https://escholarship.org/uc/item/4c58p5ss>

Authors

Rosen, H.
Novakov, T.

Publication Date

1982-12-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE

BERKELEY LABORATORY

ENERGY & ENVIRONMENT DIVISION

FEB 9 1983

LIBRARY AND
DOCUMENTS SECTION

Submitted to Applied Optics

OPTICAL TRANSMISSION THROUGH AEROSOL DEPOSITS ON
DIFFUSELY REFLECTIVE FILTERS: A METHOD FOR
MEASURING THE ABSORBING COMPONENT OF AEROSOL PARTICLES

H. Rosen and T. Novakov

December 1982

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782.*

**ENERGY
AND ENVIRONMENT
DIVISION**

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

OPTICAL TRANSMISSION THROUGH AEROSOL DEPOSITS
ON DIFFUSELY REFLECTIVE FILTERS: A METHOD FOR MEASURING
THE ABSORBING COMPONENT OF AEROSOL PARTICLES*

H. Rosen and T. Novakov
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Recent studies of aerosol particles in urban, rural, and remote environments show the presence of substantial concentrations of combustion-generated graphitic carbon particles.¹⁻³ Associated with these graphitic particles are large optical absorption coefficients, which could significantly affect radiation transfer through the atmosphere.⁴ Although a few in-situ measurements of this component have been reported,⁵⁻⁷ the predominant measurement technique involves collecting particles on a filter medium and determining the optical transmission of the deposit.^{1,8} A laser transmission technique developed at Lawrence Berkeley Laboratory has been used extensively to determine the absorption coefficient and the graphitic carbon content of aerosols in the United States,⁹ some areas of Europe, and the Arctic region.² The laser transmission apparatus compares the transmission

*This work was supported by the Director, Office of Energy Research, Carbon Dioxide Division and the Office of Health and Environmental Research, Physical and Technological Research, of the U.S. Department of Energy under contract no. DE-AC03-76SF00098.

of a 632.8-nm He-Ne laser beam through a loaded filter relative to the transmission through a blank filter, as shown in Fig. 1. After multiple scattering through the filter medium, the forward scattered light is collected by low f-number optics and detected by a photomultiplier. The filters used in our method are almost perfect diffuse reflectors, and only a small fraction of the incident beam is transmitted through them.

This technique appears to be a direct measure of the absorbing component of aerosol particles and is insensitive to its scattering properties. This has been shown directly in a photoacoustic study¹⁰ and indirectly by noting that most of the aerosol mass responsible for scattering can be removed by solvent extraction or heat treatment procedures without appreciably affecting the optical transmission measurement.¹¹ Furthermore, it has been shown that adding nonabsorbing particles to the filter substrate does not give an appreciable optical attenuation.¹² From a theoretical point of view, these results are not obvious, since it is unclear why the backscattered radiation from nonabsorbing particles should not make a significant contribution to the optical attenuation measurement. This is especially true where the absorbing component represents only a very small fraction of the aerosol mass. In this paper, we will present a simple theoretical model which accounts for all these observations and points out the critical role of the filter substrate as an

almost perfect diffuse reflector in the technique. Similar considerations may also apply to the opal glass method developed by Lin et al.⁸

For this model calculation, we will assume that the particles and the filter media can be treated independently and consider the geometry shown in Fig. 2. A similar treatment, where the light beam is first incident on the particles, gives identical results. After the light beam passes through the filter medium, it is incident on the particles with an intensity, I_0 . The particles forward scatter a fraction of the incident light, backward scatter a fraction, and absorb a fraction. These components in the low loading limit are respectively given by $n_s \sigma_F I_0$, $n_s \sigma_B I_0$, and $n_A \sigma_A I_0$, where n_s is the number of scattering aerosol particles per unit area, n_A is the number of absorbing aerosols per unit area, σ_F is the forward scattering cross section, σ_B is the backward scattering cross section, and σ_A is the absorption cross section.

Since the optical attenuation technique only measures the forward scattering light, it would seem as if the backscattered light would be lost to the system and would contribute to the attenuation. However, the filter, in our method, is almost a perfect reflector. Under these circumstances, the backscattered light will be reflected in the forward direction and will again be incident on the particles. This process will continue until almost all the backscattered radiation is collected by the optics and therefore does not contribute to the optical attenuation. This result can be put in

mathematical form, where I is the light detected by the collection optics and R_F is the reflectivity of the substrate.

$$\begin{aligned}
 I &= I_0(1 - n_s \sigma_b - n_A \sigma_A) + I_0(1 - n_s \sigma_B - n_A \sigma_A) n_s \sigma_B R_F \quad (1) \\
 &+ I_0(1 - n_s \sigma_B - n_A \sigma_A) n_s^2 \sigma_B^2 R_F^2 + \dots I_0(1 - n_s \sigma_B - n_A \sigma_A) n_s^n \sigma_B^n R_F^n \\
 &= I_0 \frac{(1 - n_s \sigma_B - n_A \sigma_A)}{(1 - n_s \sigma_B R_F)} .
 \end{aligned}$$

Consider several limits. Where $R_F \approx 0$, which normally would be considered an ideal substrate, Eq. (1) reduces to

$$I = I_0(1 - n_s \sigma_B - n_A \sigma_A) .$$

Under these conditions, the backscattered radiation will contribute significantly to the optical attenuation and make the technique unsuitable for exclusively measuring the absorbing properties of the aerosol. In our method, however, $R_F \approx 1$ and Eq. (1) becomes

$$I = I_0 \left(1 - \frac{n_A \sigma_A}{1 - n_s \sigma_B} \right) .$$

From this expression it is clear that a nonabsorbing aerosol will not contribute to the optical attenuation; this is consistent with our experimental results. The magnitude of the optical attenuation is somewhat dependent on the scattering properties of the aerosol; however, in the low loading limit, this effect is small. For example, if the substrate has 50% coverage, the scattering cross section of the particles, σ_s , is twice the particle area, and σ_B is 20% of σ_s . Then

$$1 - n_s \sigma_B \approx .8 .$$

This implies that even for these large scattering cross sections and rather high loading, the error in the absorption measurement due to scattering of the aerosol is only about 20%. This treatment should only be viewed as giving physical insight into why transmission measurements through aerosol particles collected on highly reflecting substrates selectively measures the absorbing component of the aerosol particles. It is clearly approximate since it assumes that the optical properties of the particles are not affected by the filter substrate and neglects penetration of the particles into the substrate, which can lead to enhanced absorption due to multiple scattering within the filter media. These effects could be substantial and require further investigation.

References

1. H. Rosen, A.D.A. Hansen, L. Gundel, and T. Novakov, Appl. Opt. 17, 3859 (1978).
2. H. Rosen, T. Novakov, and B.A. Bodhaine, Atmos. Environ. 15, 1371 (1981).
3. G.T. Wolff and R.L. Klimisch, eds., Particulate Carbon; Atmospheric Life Cycle (Plenum, New York, 1982).
4. G.W. Paltridge and C.M.R. Platt, Radiative Processes in Meteorology and Climatology (Elsevier, Oxford, 1976).
5. R.W. Terhune and J.E. Anderson, Opt. Lett. 1, 70 (1977).
6. H.E. Gerber, Appl. Opt. 18, 1009 (1979).
7. A.C. Szkarlat and S.M. Japar, Appl. Opt. 20, 1151 (1981).
8. C.I. Lin, M. Baker, and R.J. Charlson, Appl. Opt. 12, 1356 (1973).
9. H. Rosen, A.D.A. Hansen, R.L. Dod, and T. Novakov, Science 208, 741 (1980).
10. Z. Yasa, N.A. Amer, H. Rosen, A.D.A. Hansen, and T. Novakov, Appl. Opt. 18, 2528 (1979).
11. L. Gundel, R. Dod, and T. Novakov, Environmental Pollutant Studies (Lawrence Berkeley Laboratory report LBL-11986, 1981), p. 5-26.
12. H. Rosen and T. Novakov, Light Absorption by Aerosol Particles, H.E. Gerber and E.E. Hindman, eds. (Spectrum, Hampton, Virginia, 1982), p. 321.

Figure Captions

Figure 1. Schematic of the Lawrence Berkeley Laboratory laser transmission apparatus.

Figure 2. Schematic of the experimental arrangement used for the model calculation.

Figure 1. Schematic of the Lawrence Berkeley Laboratory laser transmission apparatus.

XBL 787-1361

XBL 791-280

Figure 2. Schematic of the experimental arrangement used for the model calculation.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720