

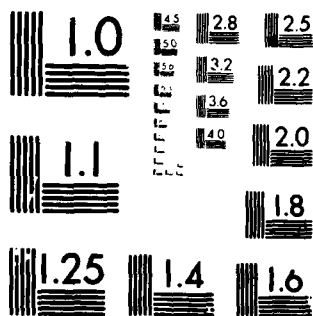
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DETERMINATION OF ASPIRATED AEROSOL SAMPLER EFFICIENCIES USING L--ETC(U)
APR 80 H R CARLON, D V KIMBALL, R J WRIGHT
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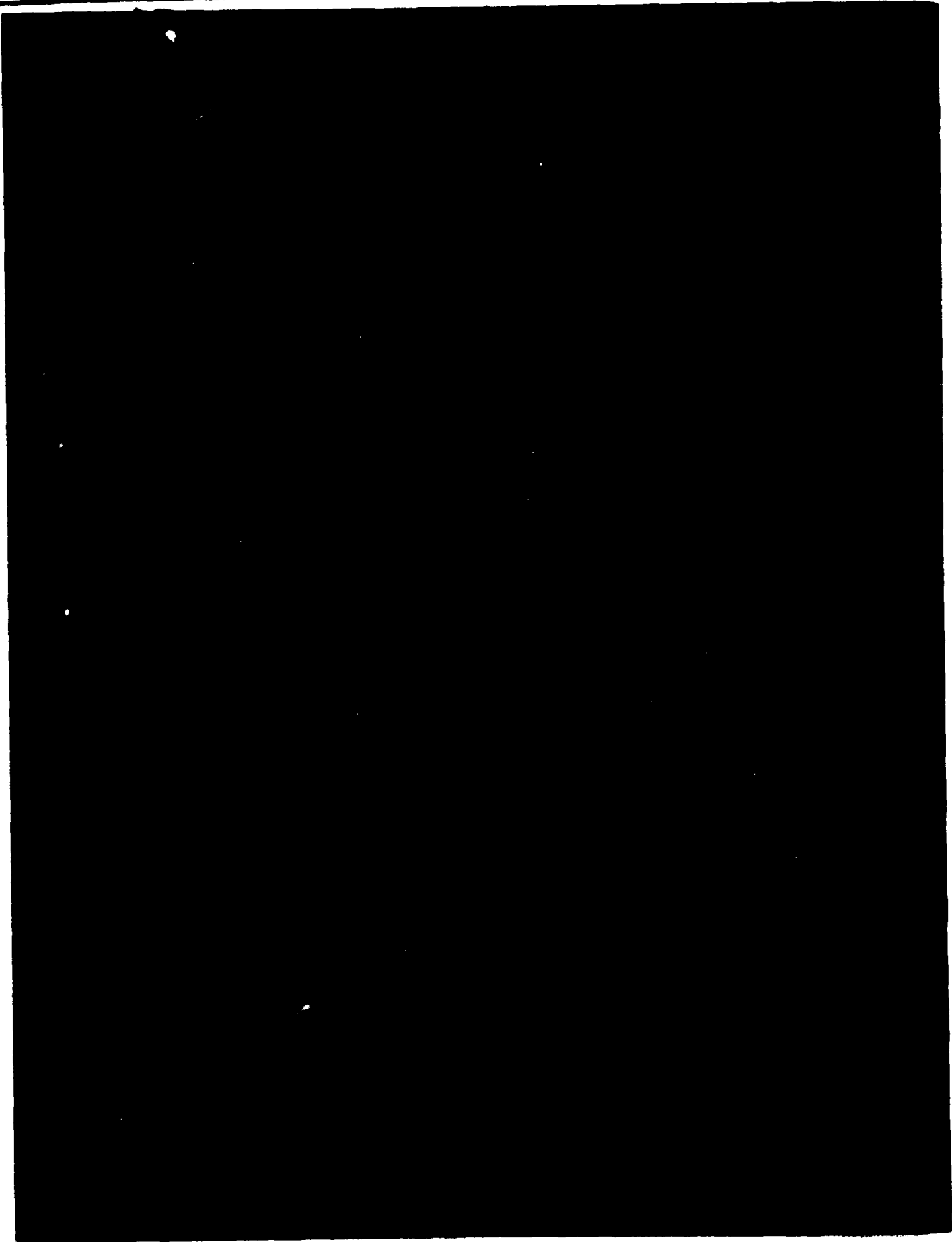




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1. REPORT NUMBER ARCSL-TR-80003 ✓	2. GOVT ACCESSION NO. AD-A085721	3. RECIPIENT'S CATALOG NUMBER						
4. TITLE (and Subtitle) DETERMINATION OF ASPIRATED AEROSOL SAMPLER EFFICIENCIES USING LASER REFERENCE TECHNIQUES		5. TYPE OF REPORT & PERIOD COVERED Technical Report February 1979-September 1979						
7. AUTHOR(s) Hugh R. Carlon David V. Kimball Robert J. Wright		6. PERFORMING ORG. REPORT NUMBER						
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander/Director, Chemical Systems Laboratory ATTN: DRDAR-CLB-PO Aberdeen Proving Ground, Maryland 21010		8. CONTRACT OR GRANT NUMBER(s)						
11. CONTROLLING OFFICE NAME AND ADDRESS Commander/Director, Chemical Systems Laboratory ATTN: DRDAR-CLJ-R Aberdeen Proving Ground, Maryland 21010		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 1L162706A553 Technical Area 3-4						
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE April 1980						
		13. NUMBER OF PAGES 23						
		15. SECURITY CLASS. (of this report) UNCLASSIFIED						
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA						
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.								
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)								
18. SUPPLEMENTARY NOTES								
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) <table border="0"> <tr> <td>Aerosol sampling</td> <td>Propagation</td> </tr> <tr> <td>Laser</td> <td>Scattering, aerosol</td> </tr> <tr> <td>Aerosol concentration</td> <td>Attenuation, aerosol</td> </tr> </table>			Aerosol sampling	Propagation	Laser	Scattering, aerosol	Aerosol concentration	Attenuation, aerosol
Aerosol sampling	Propagation							
Laser	Scattering, aerosol							
Aerosol concentration	Attenuation, aerosol							
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Aerosol sampling is a complicated problem in aerosol physics. A technique is described to continuously monitor the mass concentration of monodisperse test aerosols using a He-Ne laser. Precise approximations are possible from the Mie theory. The method is fast and accurate, and it eliminates the need for precalibration of a "standard" sampler against which candidate samplers must be compared. It is not limited to sampler efficiency measurements but (Continued on reverse side)								

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20. ABSTRACT (Contd)

can be used wherever it is desirable to continuously monitor test aerosols of spherical droplets, e.g., in studies of the human respiratory system.

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PREFACE

The work described in this report was authorized under Project 1L162706A553, CB Defense and General Investigation; Technical Area 3-4, Operational Science/Technology. This work was started in February 1979 and completed in September 1979. The experimental data are recorded in notebook 9698.

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DETERMINATION OF ASPIRATED AEROSOL SAMPLER EFFICIENCIES USING LASER REFERENCE TECHNIQUES

I. INTRODUCTION.

Aerosol sampling is usually considered to be a very complicated problem¹ in aerosol physics. Often it is desired to determine the efficiency, as a function of particle diameter D_μ [micrometers (μm)], with which aerosol particles of various kinds are drawn into an aspirated sampling tube or head or into the human respiratory system. The principal experimental difficulty is one of establishing and maintaining a test aerosol of known characteristics including composition, mass or number concentration, and particle-size distribution. The aerosol sampler is placed in the test aerosol and is operated at a known flow rate for a known period of time after which a determination is made, usually by weighing a filter paper in the sampler, of the mass of collected aerosol. This is ratioed to the particle mass contained in the sampled volume of the test aerosol to determine the sampler efficiency.

The problem of maintaining the test aerosol is not a trivial one. It must be sampled periodically to determine if (and how) it is changing with time as, for example, particles settle or agglomerate. This sampling disturbs and draws material from the test aerosol, and the subsequent analyses usually require at least several minutes to complete, during which the characteristics of the test aerosol may continue to change.

This paper describes a technique by which the test aerosol mass concentration is continuously sampled by a laser beam. This requires that the optical constants, particle-size distribution, and other properties of the aerosol particles be known. The test aerosol materials discussed in this paper are liquids which are generated as spherical droplets, for which accurate ($\pm 10\%$) optical calculations can be made using the Mie theory.² For approximation purposes in optical calculations, it is often useful to treat an aerosol as if it consisted entirely of monodisperse particles of some equivalent diameter.³ But a better approach is to generate monodisperse droplet aerosols directly, as was done in the work reported here.

II. THEORY.

In the geometric optical scattering regime, particle diameters are much larger than the wavelength, λ (μm), of observation: that is, $D_\mu \gg \lambda$. Under these conditions, it is straightforward to show⁴ that:

$$a_\lambda = \frac{3 (Q)_\lambda}{2 D_\mu \rho} \quad (1)$$

where a (m^2/gm) is the mass extinction coefficient of the spherical particles, ρ (gm/cm^3) is the particle density, and $(Q)_\lambda$ is the cross-section efficiency factor which is very nearly constant and equal to 2.0 for the liquid aerosol droplets discussed in this paper,³ so that:

$$a_\lambda \approx \frac{3}{D_\mu \rho} \quad (2)$$

The mass extinction coefficient is used in the Beer-Lambert law:

$$\ln (1/T_\lambda) = a_\lambda C L, \quad (3)$$

where T_λ is the optical transmittance at the laser wavelength, λ ; C (gm/m^3) is the aerosol mass concentration; and L is the optical pathlength (in meters) which is uniformly filled by the aerosol. C , the quantity sought for a test aerosol, is then:

$$C = \frac{1}{a_\lambda \cdot L} \ln(1/T_\lambda) \approx \frac{D_\mu \cdot \rho}{3L} \ln(1/T_\lambda) \quad (4)$$

Several liquids, used to generate test aerosols in work described in this paper, are shown in table 1. Mie calculations were performed for the He:Ne laser ($\lambda = 0.63 \mu\text{m}$) (figure 1), and it was confirmed that the approximation of equation 2 is quite precise; i.e., that the functional dependence of $a_{0.63}$, the extinction coefficient, upon D_μ is very similar for all aerosol materials considered, with only liquid densities, ρ , having a predictable effect. The laser wavelength ($0.63 \mu\text{m}$) lies very close to the sodium "D" line ($0.589 \mu\text{m}$), and the materials listed in table 1 are transparent and colorless in the visible wavelengths (i.e., they have a real refractive index, n , but a negligible absorption coefficient or imaginary index, k). Thus, it was very convenient to obtain the real indices of these materials using a standard laboratory refractometer at the sodium D line and to use them in Mie calculations for the $0.63\text{-}\mu\text{m}$ wavelength. The error introduced by doing this is very small, as indicated by figure 2 which compares the a_λ versus D_μ functions for dimethyl phthalate (DMP) calculated at $\lambda = 0.589 \mu\text{m}$ and $\lambda = 0.63 \mu\text{m}$.

Table 1. Refractive Indices of Liquid Simulants

Symbol	Substance	Density, ρ	Temperature	Real index,* n_D
		gm/cm^3	$^\circ\text{C}$	
DMP	o-Dimethyl phthalate	1.192	20.8	1.5155
DEP	o-Diethyl phthalate	1.12	17.7	1.5029
DBP	n-Dibutyl phthalate	1.045	25.0	1.4925
DOP	Diethyl phthalate	0.98	20.0	1.4550

* The sodium "D" line is at the $0.589\text{-}\mu\text{m}$ wavelength, and the real index at the He:Ne laser wavelength of $0.63 \mu\text{m}$ is nearly identical to this value for transparent, colorless liquids.

After preliminary testing, it was found convenient to use the simulant DOP (figure 3) in most subsequent work. Since $\rho = 0.98 \text{ gm}/\text{cm}^3$ for DOP, the approximation equations 2 and 4 can be still further simplified:

$$(\text{DOP}) \quad a_{0.63} \approx 3/D_\mu \quad (5)$$

$$(\text{DOP}) \quad C \approx \frac{D_\mu}{3L} \ln(1/T_{0.63}) \quad (6)$$

4 SAMPLES: DMP, DOP, DBP, DEP $\lambda = 0.63 \mu\text{m}$

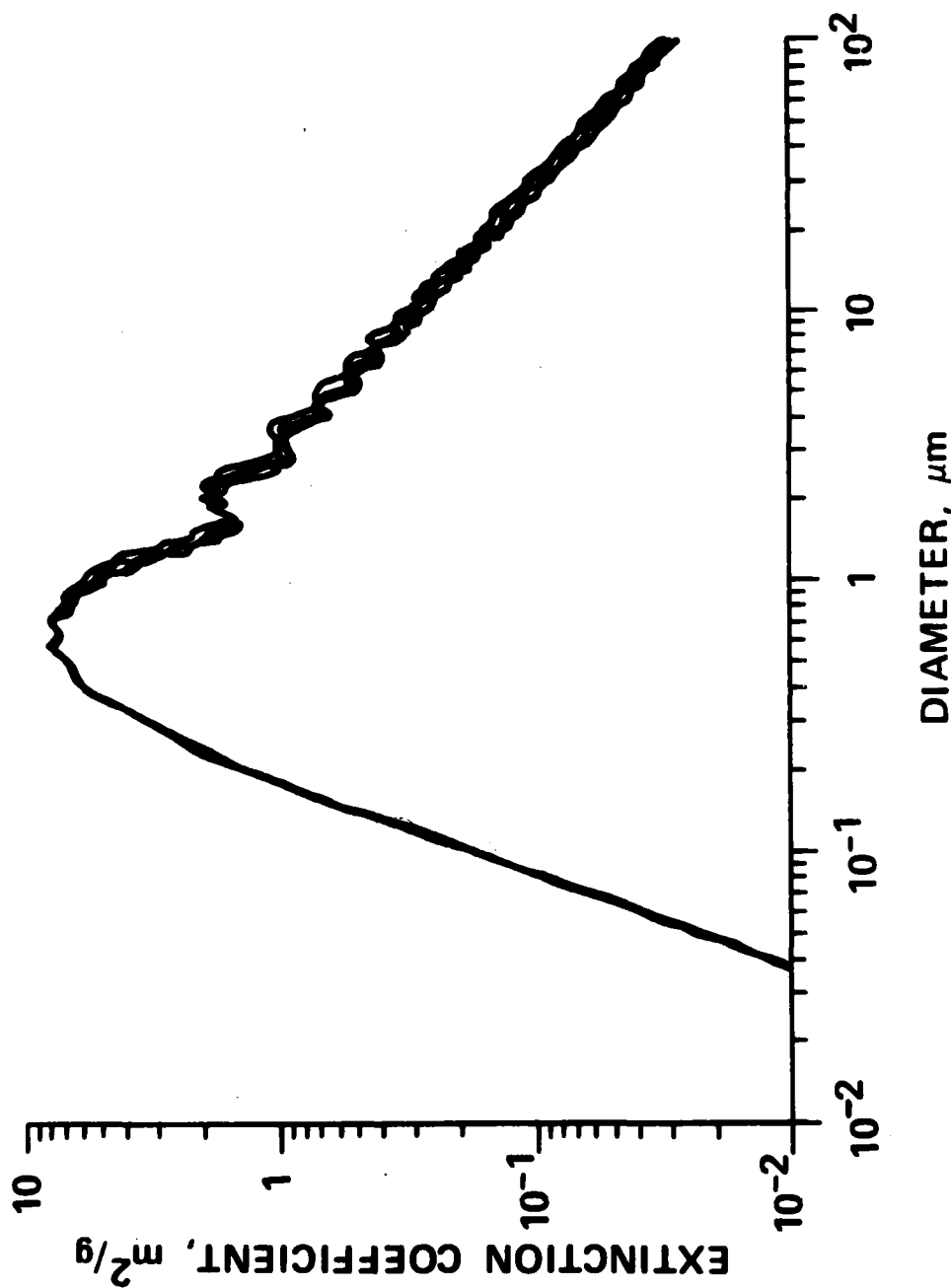


Figure 1. Values of $a_{0.63}$ versus D_{μ} Calculated from the Mie Theory for o-Dimethyl Phthalate (DMP), Diethyl Phthalate (DOP), n-Dibutyl Phthalate (DBP), and o-Diethyl Phthalate (DEP)

DMP $\lambda = 0.589 \mu\text{m}$ (dashed), $0.63 \mu\text{m}$ (solid)

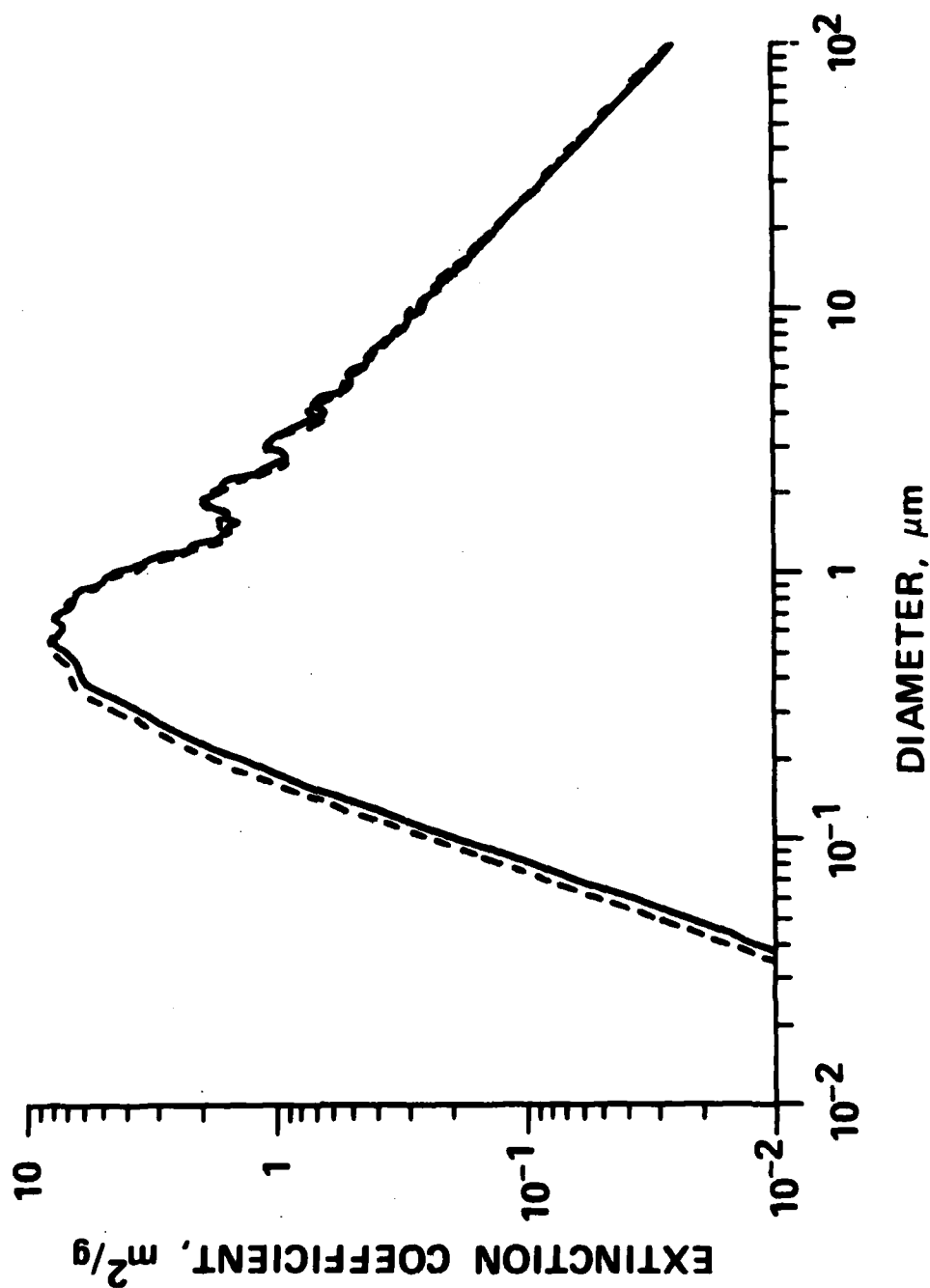


Figure 2. Values of α_λ versus D_μ Calculated from the Mie Theory for Dimethyl Phthalate (DMP), Using the Sodium "D" Line Refractive Index

It can be seen from figure 3 that the approximation of equation 5 is quite precise in the geometric regime ($D_\mu \gg \lambda$).

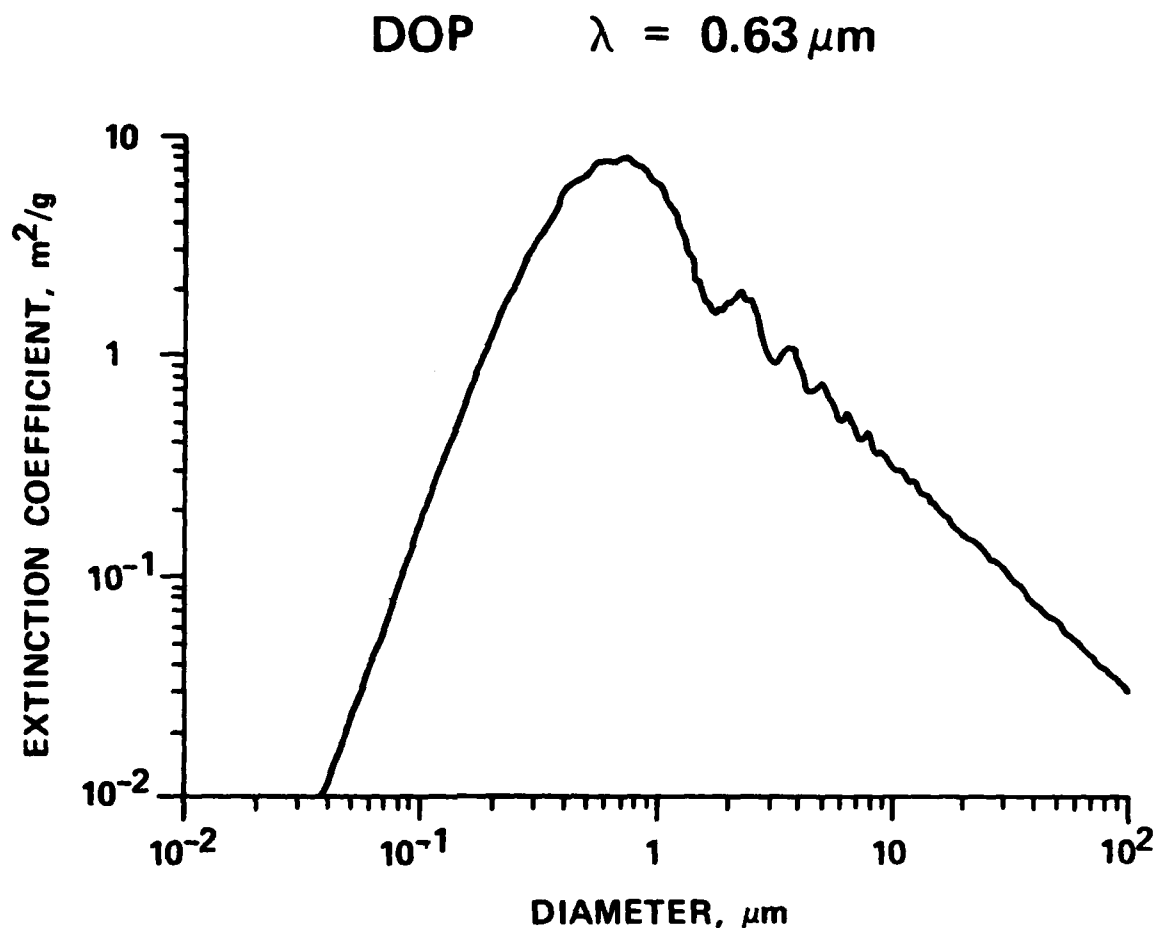


Figure 3. Values of $\alpha_{0.63}$ versus D_μ Calculated from the Mie Theory for Dioctyl Phthalate (DOP)

III. EXPERIMENTAL PROCEDURE.

A 1-m^3 test chamber was constructed and used as shown schematically in figure 4. The He:Ne laser was optically aligned through pinholes in opposite chamber walls. The pinholes were utilized to prevent window effects. A pressure-equalization scheme between the chamber interior and room air prevented aerosol particles from flowing in either direction through the pinholes during testing. Although figure 4 shows an aerosol cloud coming from the generator, the chamber was stirred during testing to insure uniform mixing. This was important because the laser pathlength, L , of the laser beam in the test chamber (which was about 1 m long) must be uniformly filled with the test aerosol during measurements.

AEROSOL PARTICLE SIZING BY LASER

(AFTER UNIFORM MIXING)

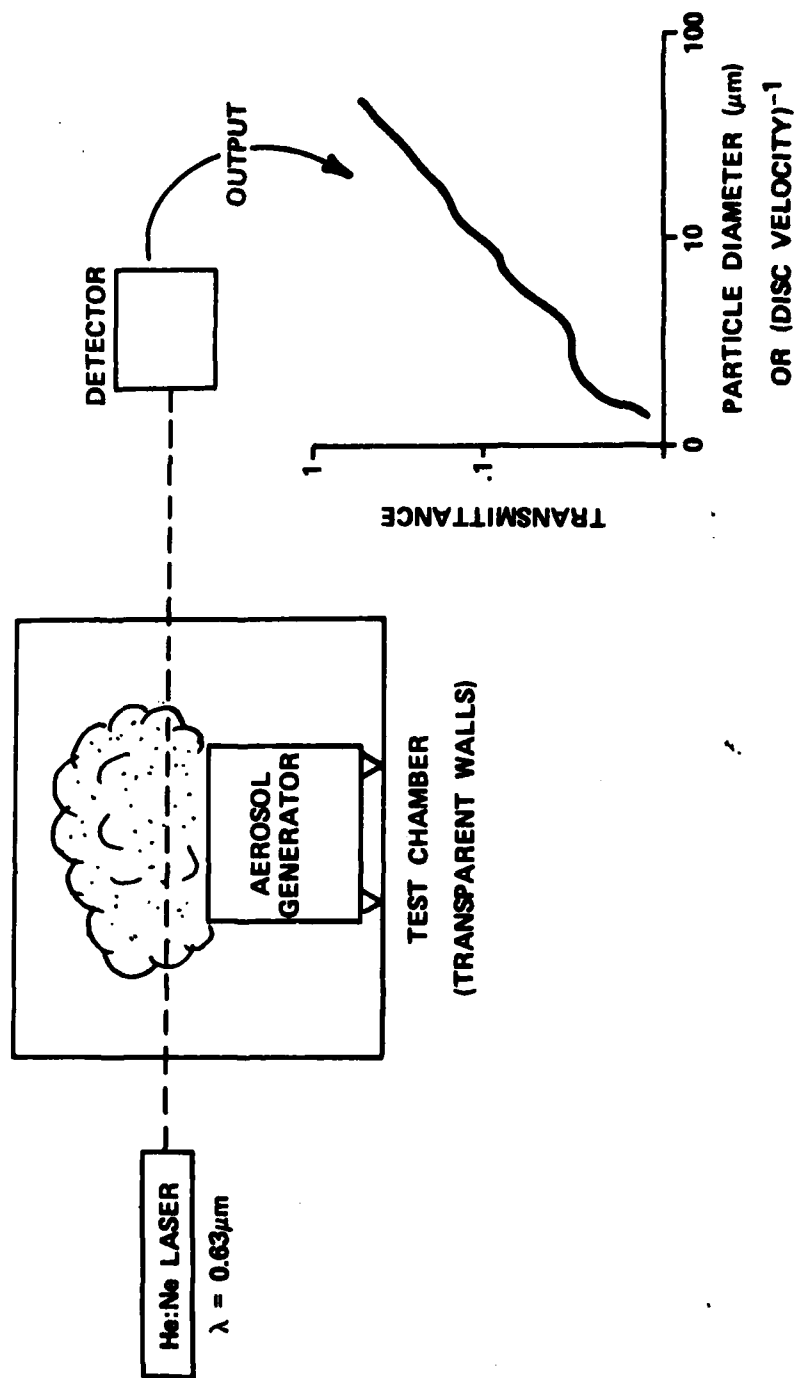


Figure 4. Schematic Representation of the Experimental Setup. Although an aerosol cloud is shown coming from the generator in the test chamber for illustrative purposes, the chamber was stirred to insure uniform aerosol mixing during testing since the laser beam must be uniformly filled with the test aerosol for accurate monitoring.

The aerosol generator, shown in figure 5 in a side compartment of the test chamber, was of the "spinning disc" design⁵ to produce essentially monodisperse liquid droplets of the test aerosol. The droplet size, D_μ , disseminated by the spinning disc generator is determined by the diameter and angular velocity of the disc, by the liquid flow rate, and to a lesser extent by other parameters including temperature. Aerosol droplet size was checked by microscopic examination of samples deposited on glass slides. The generator shown in figure 5 was easily capable of disseminating concentrations of test aerosols in the range $C = 0.1$ to 1.0 gm/m^3 for these tests. Other monodisperse aerosol generators are available commercially, although some* do not have the aerosol output capability of the unit used in these tests. Plastic microspheres** also were used in some trials, for which the $a_{0.63}$ versus D_μ function was not much different from those in figure 1.

Each aspirated sampler consisted of a filter holder, connected to a vacuum line, and the inlet tube to be tested mounted in the face of the filter holder. Samplers were aspirated at flow rates of 1 liter/min or more. Results using similar samplers to monitor mass concentrations of smoke aerosols have been reported previously.⁶ Figure 6 shows the chamber in operation. The He:Ne laser beam can be seen passing through the test aerosol (32- μm DOP droplets). An aspirated sampler is mounted in a circular port in the forward wall of the chamber. The inlet tube being tested (cylinder) can be seen projecting from the filter holder toward the center of the chamber. In later tests, however, the filter holders were mounted completely inside the chamber, with the openings of the inlet tubes positioned perpendicular to and directly adjacent to the laser beam. This insured that the laser beam and the inlet tubes intercepted identical samples. A refinement to this procedure involves using a second laser beam perpendicular to the first and nearly intersecting it, e.g., from the top to the bottom of the chamber in figure 6, thus providing laser "cross hairs" which can be positioned directly in front of a sampler inlet tube under test.

IV. RESULTS AND DISCUSSION.

The purpose of this paper is to describe a technique by which the mass concentration of a sized test aerosol can be continuously sampled by a laser beam to improve experimental procedures. Only a brief discussion of typical test data on aspirated sampler efficiencies will be given here. Figure 7 presents some data for DOP droplets and illustrates the methodology discussed in this paper.

In figure 7, the solid and dashed curves labeled "aspirated sampler" are typical of the efficiencies measured for filter holders without inlet tubes and for holders with inlet tubes (as in figure 6), respectively. For these aspirated samplers, the sampling efficiency drops to less than 10% in the DOP droplet size range $30 \leq D_\mu \leq 40 \mu\text{m}$. The He:Ne laser can be considered 100% efficient in sampling the test aerosol, since laser attenuation depends entirely upon extinction by the aerosol droplets ($e_L = 100\%$). Multiple scattering of the laser beam is not a problem, since the test aerosol concentration is always chosen to give high transmittances (0.7 to 1.0), thus conserving the aerosol material. The assumption that the actual mass concentration of the test aerosol, C_{actual} , is equal to that determined from the laser using equation 6, C_{laser} , is valid to within

* The Berglund-Liu monodisperse aerosol generator is marketed by Thermo-Systems, Inc. (TSI), P.O. Box 3394, St. Paul, Minnesota 55165.

** Microspheres of glass, polystyrene, and other materials are available from Duke Scientific Corporation, 445 Sherman Avenue, Palo Alto, California 94306.

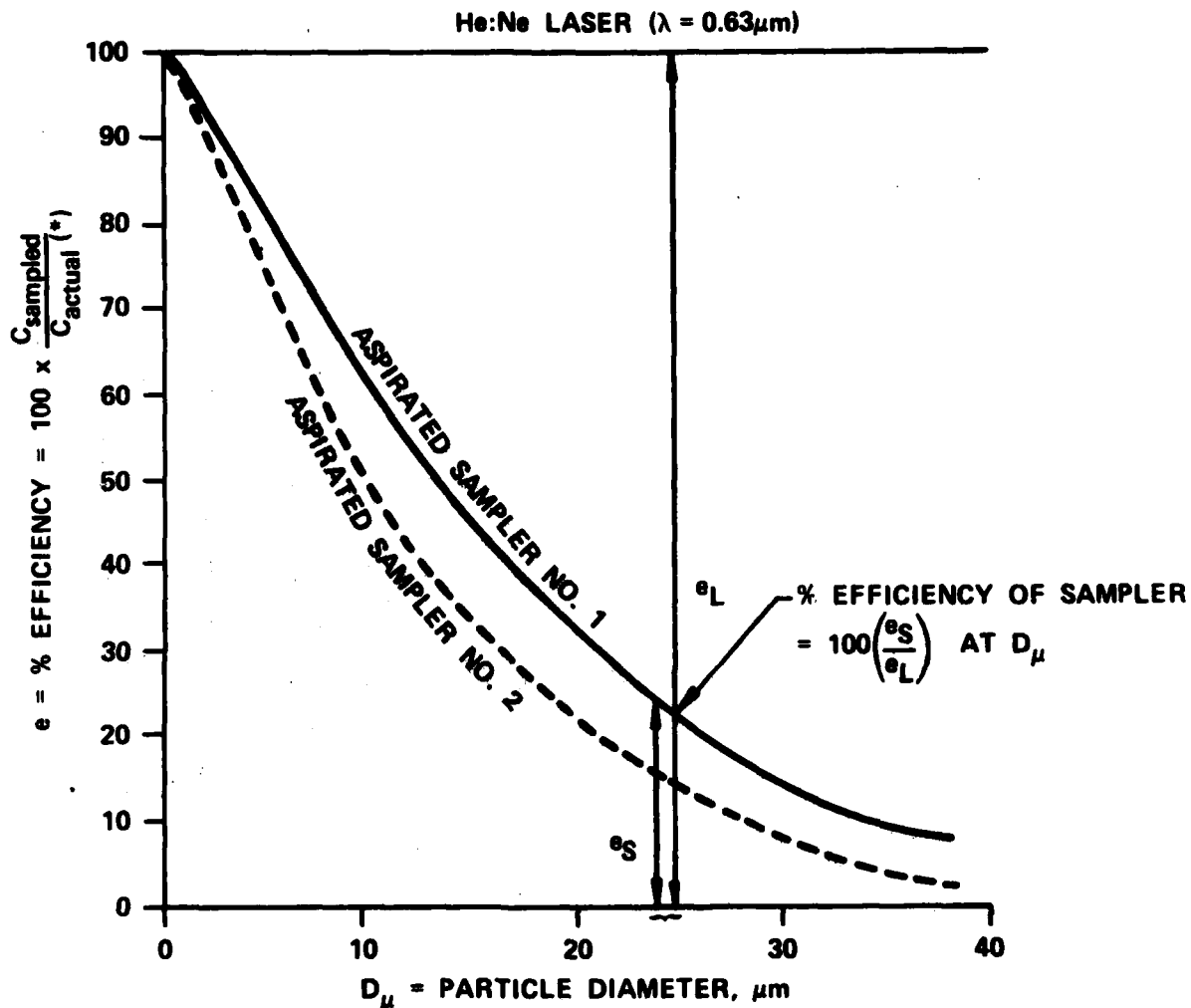


Figure 5. "Spinning Disk" Aerosol Generator Used to Produce Essentially Monodisperse Liquid Droplets of the Test Aerosol at Mass Concentrations of 0.1 to 1.0 gm/m^3



Figure 6. Operation of the Aerosol Test Chamber. The He:Ne laser beam is visible passing through the test aerosol ($32\text{-}\mu\text{m}$ DOP droplets). An aspirated sampler is mounted in the center circular port, with the inlet tube under test (cylinder) projecting from the filter holder toward the center of the chamber. In later tests, the filter holders were mounted completely inside the chamber, with the openings of the inlet tubes positioned perpendicular, as well as directly adjacent, to the laser beam to insure that the laser beam and inlet tubes intercepted identical aerosol samples.

DIRECT DETERMINATION OF ASPIRATED SAMPLER EFFICIENCY USING LASER REFERENCE BEAM



(*) where C_{actual} is taken ($\pm 10\%$) as

$$C_{\text{laser}} = \frac{\ln(I/T_{\lambda})}{a_{\lambda} L} \approx \frac{\ln(I/T_{\lambda})}{(D_{\mu})/3L}$$

Figure 7. Typical Sampling Efficiencies for DOP Test Aerosols. The solid curve labeled "Aspirated Sampler No. 1" represents filter holders without inlet tubes, and the dashed curve labeled "Aspirated Sampler No. 2" represents filter holders with inlet tubes. The figure also illustrates the methodology of the measurements, as described in the text.

the error of the Mie calculations which was found to be as good as $\pm 10\%$ in this application. The equivalent mass concentration collected by the aspirated sampler, C_{sampler} , is determined by weighing the filter paper in a filter holder before and after an aerosol trial and is reproducible to within about $\pm 10\%$. The percent efficiency of the sampler, e , is then $100 \times (C_{\text{sampler}} / C_{\text{actual}})$. When the test aerosol particle diameter is only a few micrometers or less, the aspirated sampler efficiency approaches 100% and these samplers can be used directly to confirm laser measurements of aerosol mass concentration as was reported previously for smoke aerosols.⁸

V. CONCLUSIONS.

The discussion in this paper has been limited to the determination of aspirated aerosol sampling efficiencies using laser reference techniques. These techniques, of course, are not limited to sampler efficiency measurements but can be used wherever it is desirable to continuously monitor the mass concentration of a test aerosol of spherical droplets; e.g., in studies of the human respiratory system. By using a He:Ne laser in the visible wavelengths ($\lambda = 0.63 \mu\text{m}$), aerosol measurements are made in the geometric scattering regime ($D_{\mu} \gg \lambda$) using materials for which many simplifications and precise approximations are possible from the Mie theory. The method is fast and accurate, and it eliminates the need for precalibration of "standard" samplers against which candidate samplers must be compared.

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