MULTIFREQUENCY LASER COMPLEX FOR MONITORING ATMOSPHERIC AND INDUSTRIAL AEROSOLS

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We present here methodical grounds and establish the applicability limits of a modified method of the spectral transmission to the determination of the mean size of aerosol particles. Based on a specially designed three–wavelength He–Ne *laser and adaptive system for recording and regulating the laser power we have developed an automated laser–based complex for monitoring the industrial aerosol parameters. Thus obtained data on aerosol are then used for making analysis and forecasts of the ecological situation in the areas adjacent to the industrial objects.*

Investigation of the parameters of atmospheric aerosol formations and local aerodisperse systems of anthropogenic origin is based on the measurement of the extinction coefficients for radiation at different wavelengths. Normally multiwavelength laser systems (see Ref. 1) are used in such measurement systems.

Optical parameters of aerosols essentially depend on their microphysical parameters (density, size spectrum, shape and components of the complex refractive index). The latter can widely vary from one aerosol type to another and within the same type. All this makes the problem of developing methods for aerosol monitoring complicated.

In this study we used a modified method of spectral transmission (MMST) when determining optical parameters of aerosol particles. This method consists in measurements of the extinction coefficients at different wavelengths. This method does not enable one to determine the particle size distribution function $f(a)$. Nevertheless, the MMST suits the measurement of the mean particle size best of all, in particular, the mean volume-surface diameter a_{32} due to the following advantages: the method is simple for the instrumental performance and allows the aerosol media with high optical thickness τ to be investigated.

The principle of MMST consists in solving the inverse problem presented by the following integral equation:

$$\tau_\lambda = \frac{Nl}{4} \int_0^\infty \pi\, a^2\, Q(a, \lambda, m)\, f(a)\, \mathrm{d}a \;,$$

(here N is the concentration of particles, l is the sounding optical depth, a is the particle diameter, Q is the efficiency factor for radiation by a single particle, m is the complex refractive index of the particulate matter) and in transformation of the equation to the form:

$$\tau_\lambda = 1.5\, M l \bar{Q} \;/\; (a_{32}\, \rho) \;,$$

here ρ is the particulate matter density,

$M = \frac{\pi N \rho}{6} \int_0^\infty a^3 f(a)\, \mathrm{d}a$ is the mass concentration of aerosol particles,

$\bar{Q} = \int_0^\infty Q(a, \lambda, m)\, a^2 f(a)\, \mathrm{d}a \Big/ \left[\int_0^\infty a^2 f(a)\, \mathrm{d}a\right]$ is the averaged efficiency factor of the radiation extinction,

$a_{32} = \int_0^\infty a^3 f(a)\, \mathrm{d}a \Big/ \left[\int_0^\infty a^2 f(a)\, \mathrm{d}a\right]$ is the mean volume-surface diameter of the particles.

The physical model of the method is based on the interaction between radiation and a scattering medium according to the mechanism of Mie scattering and conservation of the invariance of the mean efficiency factor with respect to the form of $f(a)$. The correctness of this assumption is caused by the fact that Q is determined by the integrals of $f(a)$ and, hence, is low-sensitive to the peculiarities in $f(a)$ behavior in the range of particle size considered.

The problem of estimating the aerosol particle size by this method is reduced to the measurements of optical thickness at several wavelengths and calculations of the mean extinction for laser radiation at these same wavelengths.

Two variants of the MMST, one- and two-frequency, have been used in this paper.

In the first variant the optical thickness is measured, the mass concentration of the particles is *a priori* prescribed based on calculations or independent measurements while the mean particle diameter a_{32} is determined graphically using the following set of equations:

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$\bar{Q} = f(a_{32})$,

$\bar{Q} = \tau\rho a_{32} / (1.5\ Ml)$.

In this case the measurable particle size ranges from a_{32} = 1 to 30 μm.

In the second variant the ratio between the experimentally measured optical thicknesses at two wavelengths equal to the ratio between the averaged extinction efficiency factors is used. The latter represents the particle size function

$$\frac{\tau_{\lambda_2}}{\tau_{\lambda_1}} = \frac{\bar{Q}_2(a_{32}, m, \lambda_2)}{\bar{Q}_1(a_{32}, m, \lambda_1)} = \Phi(a_{32}) .$$

Traditionally, when performing the MMST additional information on optical constants and the particle size distribution are used. To study the effect of uncertainty of the complex refractive index of particles ($m = n + i\varkappa$, where n is the refractive index and $\varkappa$ is the absorption factor of the particles) due to different origin of the aerosol particles we have calculated dependences of $\bar{Q}$ on a_{32} in the following ranges of n and $\varkappa$: $n = 1.6, \dots 2.0$ and $\varkappa = 3.5 \cdot 10^{-3}, \dots 3.0 \cdot 10^{-2}$. As a result we found that the probable variance of m introduces an error in a_{32} estimation which is equal to 4% for the particle size below 1 μm and decreases with the decreasing size.

The majority of single-mode particle distributions occurring in the physics of aerosols are mainly described by the generalized gamma-distribution of the following form:

$$f(a) = A\ a^{\alpha} \exp(-\ ba^{\beta}).$$

This distribution is primarily a function of α and β. For estimating the relationship between $\bar{Q}$ and $f(a)$ the calculations using parameters α = 0.3, ..., 2.0 and β = 0.5, ..., 2.0 have been made. In this case the distribution functions cover a wide range of the particle size and have modal diameters in the range from 0.1 to 5.0 μm. The *a priori* incorrectness of $f(a)$ introduces additional errors in a_{32} making it to be 8 – 9% (see Ref. 2).

Typical relationship between the mean extinction efficiency factor and a_{32} is shown in Fig. 1, while Fig. 2 depicts the averaged extinction efficiency factors as functions of a_{32} at different wavelengths. The figures near the curves present the wavelength in micrometer. Since $\bar{Q}$ depends on a_{32} only within some range of the particle size, one can introduce the concept of active fraction of particles in the distribution $f(a)$.

Thus, when performing laser control of aerosol the mean size of particles is determined in a single-frequency MMST variant, whereas in the case of a double frequency variant the mean size of the active fraction of particles whose size fall in the range between zero and some value determined by the radiation wavelength used is measured.

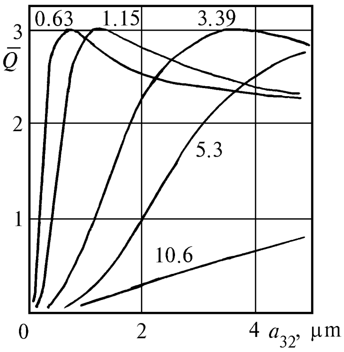

FIG. 1. Q as a function of a_{32} at different wavelengths.

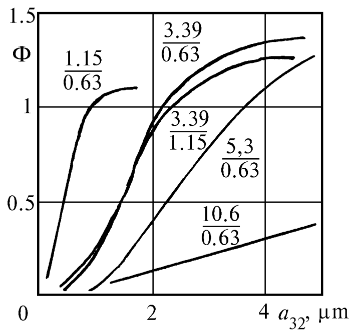

FIG. 2. $\bar{Q}_2 / \bar{Q}_1$ as a function of a_{32} at different wavelengths.

The laser measuring complex includes a laser radiation source, a means for measurement and control of the radiation power, a console, specialized photodetectors with a system for selection of the laser radiation to be measured, multichannel amplifying and recording devices operating in a wide dynamic range of input signal and a means for processing of the measurement data. Schematic diagram of the complex is presented in Fig. 3.

Specially designed three-wavelength He–Ne laser was used as a radiation source. The laser operation is based on the physical principle of normal and anomalous competition of the laser transitions from the same excited level (see Ref. 4).

As shown in Fig. 4, the laser consists of an LG–53 laser with three-mirror resonator (*3*) and optical-mechanical adapter (*1*) which includes aluminized spherical mirror and a modulator with a perforated disk. The resonator of LG–75 tuned at λ_1 = 0.63 μm is placed inside the resonator tuned at λ_2 = 1.15 μm and λ_3 = 3.39 μm. The modulator closes and opens mirror *3* from the side of the LG–75 active element which provides external resonator formed by the mirror *3* and the output mirror of LG–75 and tuned at λ_2 and λ_3 to be switched on or off. As a result modulated laser radiation at three wavelengths is generated simultaneously along the same optical path.

When sounding industrial aerosols along an extended path whose optical thickness may vary in a wide range we use an adaptive system for laser power recording which includes an amplifier with an automated selection of the amplification coefficient depending on the input signal power and a block of optical filters with an automated adjustment of the laser power to provide linear mode of operation of the block of selective photodetectors.

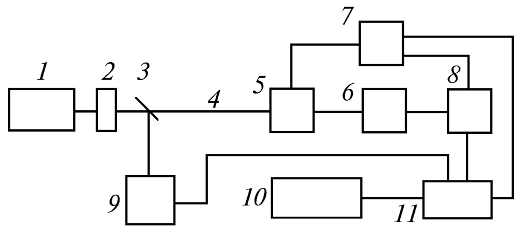

FIG. 3. Block–diagram of the laser complex. 1 is a three-wavelength He–Ne *laser; 2 is the calibration facility; 3 is a beam–splitting plate; 4 is the aerosol; 5 is the block of optical filters; 6 is the block of photodetectors; 7 is the controlling block; 8 is an amplifier with an automated adjustment of amplification coefficient; 9 is the block of radiation power control; 10 is a calculating system; 11 is a magnetic recorder.*

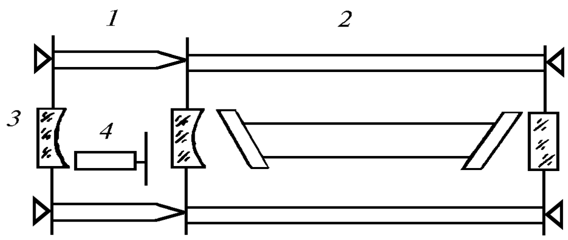

FIG. 4. The three–wavelength He–Ne *laser. 1 is an optical–mechanical adapter; 2 is a laser (LG–75); 3 is the aluminized spherical mirror; 4 is the modulator.*

The amplifier enables recording of a signal within the voltage range from 0.001 to 2 V and maintains output voltage in the range from 0 to 6 V. It has four discrete amplification coefficients (3, 20, 80 and 200) which can automatically change with the input signal power. Corresponding operation thresholds are 25, 100 and 650 mV, respectively.

The block of optical filters is remotely controlled with an electronic block which comes into action when the signal from the photodetector is maximal or minimal. Minimal signal provides condition for the optical filters to be removed in turn from the optical scheme until a signal appears at the amplifier input. At a certain signal at the output of the photodetector considered as the maximum one the filters are introduced into the optical scheme in the reverse order.

The measuring and recording system of the complex is developed on the base of 14-channel magnetic tape recorder of SR–50 type and a system for the measurement data processing using a computing complex of DL–1277 type. The latter consists of DL–1208PG programmed device with high resolution and DL–1277 computer for the data control and processing. All devices described are connected by means of a bus common. The signals are reproduced by the magnetic recorder, then interrecorded at DL–12088DL and processed by a controller of DL–1277 type.

Owing to the use of this adaptive system for signal recording and control of the sounding radiation power the range of recording signals up to 60 dB was achieved while the ultimate optical thickness measured, according to the measuring channel calibration, was found to be 10.5; 9.5 and 4.2 at the wavelengths $\lambda_1 = 0.63$ μm, $\lambda_2 = 1.15$ μm, and $\lambda_3 = 3.39$ μm, respectively.

The multiwavelength automated laser measuring complex was used for determining the mean size and concentration of aerosol particles which are formed, for instance, during destruction of wastes of explosives production. From optical thickness of a cloud of the combustion products measured at different wavelengths the particle parameters were determined using single and double frequency MMST variants. The mean size a_{32} falls within 2.6 – 3.7 μm and depends on the composition of the matter to be destructed. The mean size of particles from fractions with size from the following intervals: 0 – 1.5 μm, 0 – 4 μm, and 0.1 – 4 μm were equal to 0.5 μm, 1 μm, and 1.2 μm, respectively.

Disperse parameters of the aerosol formations arising from destruction of industrial wastes are used for analysis and forecast of ecological situation in the adjacent regions.

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