Automation of nephelometric measurements of mass concentration of submicron atmospheric aerosols

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A method for automation of nephelometric measurements of the submicron aerosol mass concentration in the atmosphere on the basis of commercially available photoelectric nephelometer (FAN-A) is suggested. The electric scheme of the device was modernized through design and installation of additional controller board, whose main function is analog-to-digital conversion, and program-computerized control for the controller operation. The key element of the board is the microcontroller, converting the analog data and storing them in the memory of the microchip included in the controller scheme. The operation of the device and data accumulation do not require the connection to a computer; this is important under field conditions.

Introduction

Nephelometers are widely used for study of characteristics of atmospheric aerosols (AA). Most frequently, they are used for study of optical properties of AA polluting the atmosphere. These studies revealed that the visibility deterioration in the atmosphere depends on the concentration, size spectrum, and chemical composition of AA.[1–8]

Theoretical studies in the field of atmospheric optics with the use of Mie theory have made it possible to obtain reliable semi-empirical formulas relating the results of the optical measurements with data on the AA mass concentration obtained by gravimetric and other methods. In particular, it was found that the scattering by AA particles is proportional to their mass concentration, and the proportionality coefficient depends on the particle size spectrum and chemical composition of AA.

Different variants of nephelometers are developed, and they are widely used not only for ground-based and aircraft measurements of spatio-temporal variations of AA mass concentration, but also for quantitative assessment of AA disperse and chemical composition. Different nephelometer types are commercially produced in industrially-developed countries for study and monitoring of the microphysical and optical AA characteristics. In Russia, analogous studies are conducted in the Institute of Atmospheric Physics RAS, Institute of Atmospheric Optics SB RAS, Institute of Experimental Meteorology, Main Geophysical Observatory, and the Saint-Petersburg University.[9–15]

It should be noted that the unique instrumentation created by the authors themselves of the above Institutes was used in the nephelometric studies of AA optical characteristics or atmospheric pollution level (excluding the Institute of Atmospheric Optics). Usually these instruments have quite large sizes and can be exploited only by their authors. The Institute of Atmospheric Optics SB RAS has developed ground-based and aircraft computer complexes using as the optical sensor the commercially available photoelectric nephelometer of FAN type.[14,15]

The commercial nephelometers for aerosol studies have been fabricated by Zagorsk Instrumental Plant since 1950s. These devices were designed primarily for determination of the efficiency of filtering materials, as well as for different aerosol studies under laboratory conditions. The optical characteristics of the optical scheme of the nephelometers allowed measuring the aerosol scattering in a few spectral intervals at different angles. In addition, they measured the polarization characteristics of the light scattered by aerosol. The characteristics of the nephelometers of KOL (visual variant) or FAN (photoelectric variant) types are described in more detail in Refs. 16 and 17, as well as methods of calibration and calculation of characteristics of light scattering by standard aerosols with known optical parameters.

The last-generation photoelectric nephelometers FAN-A, manufactured since 1970s, can automatically record the scattered radiation intensity to a logger or

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have a connector to old-generation computers. When such nephelometers are used under field conditions together with domestic computers fabricated in 1980s, there appear many difficulties due to large size, weight, and large energy consumption of the complex.

The FAN-A nephelometer is designed for relative measurement of the radiation flux scattered by aerosol. The device has a high sensitivity to the scattered intensity because of the use of photomultiplier tube (PMT) as the photosensitive element.

In our studies we measured the mass concentration of atmospheric aerosol.[18,19] We can work in laboratory conditions, at stationary stations, and mobile platforms (automobile, ship, and aircraft). A serious requirement to the measurements is their continuousness for a long period such as days and months, because the AA mass concentration depends on many factors and rapidly changes. Therefore, there appear problems, when transporting and mounting the measurement complex, controlling it, and storing data.

A solution of these problems is of concern in this paper, which describes the modernization of the nephelometer FAN-A through inclusion of the controller board, designed on the basis of modern electronic components and having a standard interface with computer.

Principle of the nephelometer operation

Measurements of the aerosol mass concentration with the nephelometer FAN-A are based on the linear conversion of radiation flux, scattered by aerosol particles, into the electric current. Figure 1 presents a simplified optical scheme of the photoelectric measurement.

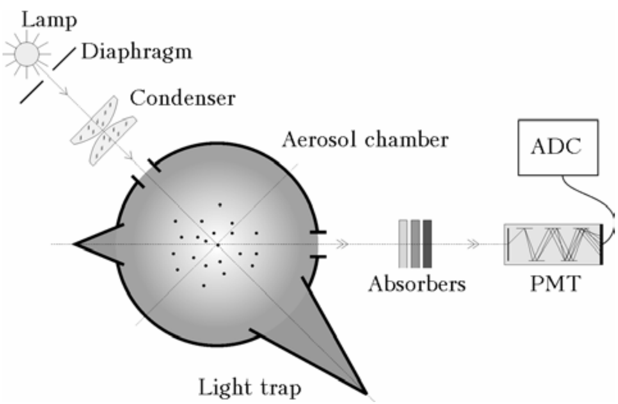


Fig. 1. Simplified optical scheme of photoelectric measurement of radiative flux, scattered by aerosol, with the nephelometer FAN-A.

The air with aerosol is pumped through the aerosol chamber, where it is illuminated by 40-W halogen incandescent lamp. The radiation flux, scattered at an angle 45°, whose intensity, if necessary, can be attenuated using calibrated non-selective light absorbers, is converted into electric signal by means of PMT. Any external recording device with current input such as a logger can be connected to the nephelometer output.

Controller board

The controller board was designed to replace the logger in order to eliminate the processing of huge paper rolls.

The heart of the controller board is microcontroller ATmega8 (http://atmel.com/dyn/products/product_card.asp?part_id=2004) of Atmel firm (http://atmel.com). This microcontroller was chosen because it already contains a 10-bit analog-to-digital converter (ADC) and a universal asynchronous receiver-transmitter (UART) for communication with computer via interface RS232 (COM port). To connect external devices of data accumulation, the nephelometer is provided with current signal output in the range 0–300 μA. Signal is matched to the input ADC level via operational amplifier, reading voltage across resistor of 100 Ω, which is wired to the current output. The UART of microcontroller requires CMOS-TTL-levels, i.e., 0–5 V, whereas COM port of computer uses –12 and +12 V levels; therefore, a special chip-adapter MAX3323E transforms the levels and protects the communication line from the high static voltage.

This scheme works at the automated acquisition of data. It was used in the first version of the microcontroller board. However, when the data were accumulated during 24 hours a day, the power supply failures took place over short time periods. This was followed by a loss of data; so the protection from such failures was required.

The second version of the controller board (Fig. 2) was improved through inclusion of the energy independent memory and the real time clock with separate supply from three clock batteries.

The microcontroller reads the input signal at a frequency of 10 samples per minute and marks the time of the last record. The memory is enough to store data recorded for 68 h (2 days and 20 h) in cyclic recording. The computer is not connected continuously to the controller board; it is sufficient to connect it periodically for reading the information from the memory. The microcontroller board also can control for the measurement subranges, when the signal varies within wide range and goes out the current measurement sensitivity limits.

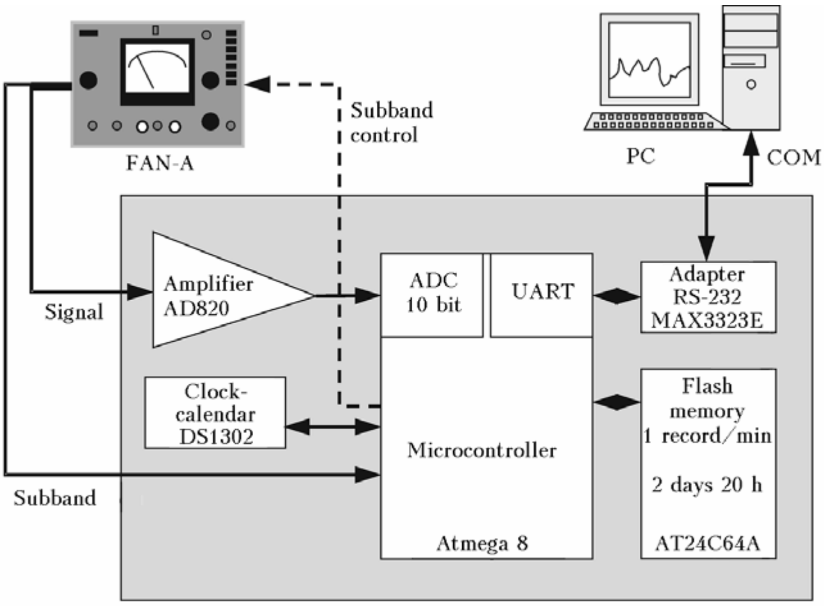


Рис. 2. Schematic view of the nephelometer microcontroller board.

The microcontroller board is mounted inside the nephelometer casing (Fig. 3).

Fig. 3. FAN-A nephelometer. The microcontroller board is inside its casing.

Software

The program for the microcontroller was written in C language for AVR and incorporates the functions of sample extraction from ADC, receiving and transmitting messages through UART, setting and reading the current time, storing information into the memory and reading it, processing of interrupts from timer, and synchronizing data after supply failure.

The program for computer or user is written in programming language Delphi, compatible with Windows operating system, and has a graphical interface (Fig. 4).

The program allows adjusting the parameters of the COM port, selecting the directory for file storing, setting up the time on the microcontroller board, and reading data from the memory. Upon connection with controller board, the program begins to display the signal, scanned in time with a second renewal. Three types of signals are optional: at the blowing of the atmospheric air, at the blowing of filtered air, and of instrument zero. Recording of each signal is made by pressing the corresponding button in the program window when preliminary (manual) setting the necessary mechanical commutations. All three signals are required to obtain the calibrated data; noteworthy, the mass concentration of submicron AA fraction is linearly related with the ratio of the light scattering by aerosol to scattering by the clean air.

The pressing of the “Statistics” button opens the window, where signals over the entire observation period are seen, which can be preliminary processed. This means obtaining of the absolute value of AA mass concentration, as well as the tables for hourly means curve and diurnal cycle of the entire measurement period.

Disk data format

Every minute the one-minute average signal is recorded on hard disk. The signal is in relative units of ADC and can be converted to the absolute value provided the calibration is known. Data in the file are arranged into a few columns, where time is given in the first column, the signal value in the second, the measurement subrange in the third, and the mark indicating the signal type in the forth. The file is in the text format and can readily be imported into well

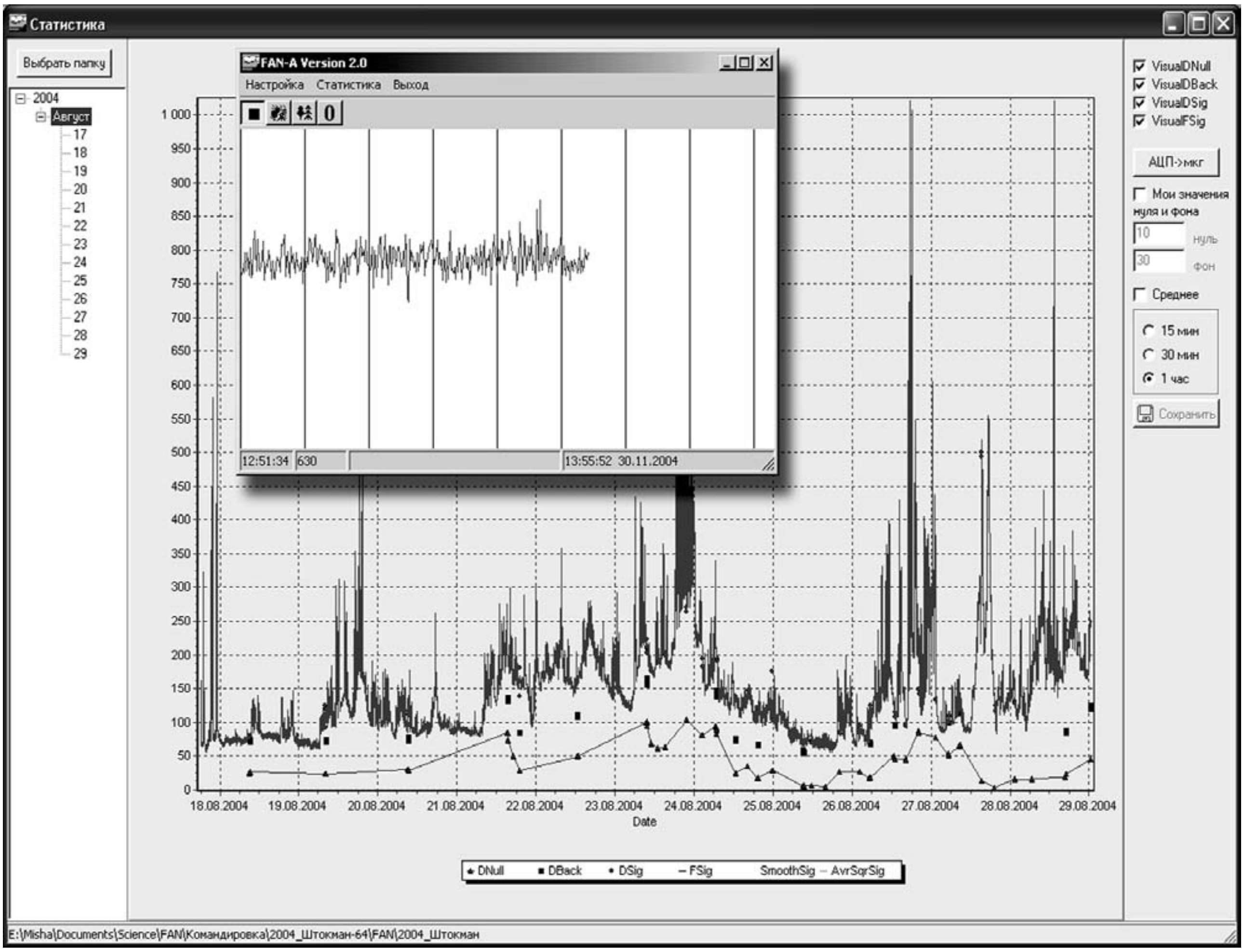


Fig. 4. Graphic interface of the program controlling the nephelometer controller. The controlling window with second-to second imaging of the signal is at the top to the left (the interval between vertical lines is 1 minute). The whole signal with a minute resolution is at the bottom.

known programs processing large data arrays (Excel, Origin, MatLab, etc.).

Experiments

A few expeditions were conducted with the use of the improved nephelometer, and all measurements turned to be successful. The worst measurement conditions were during the expedition of the Research Vessel *Professor Shtokman*. The nephelometer was placed in the direction-finding deck inside a specially construction, protecting the instruments from the rain and wind (Fig. 5).

In the process of operation there was one half-hour failure of power feeding due to external factors, after which the nephelometer operation was restarted. Figure 4 presents the data in the form they are read from the instrument, and Figure 6 gives the same data converted to the absolute values of mass concentration of AA submicron fraction.

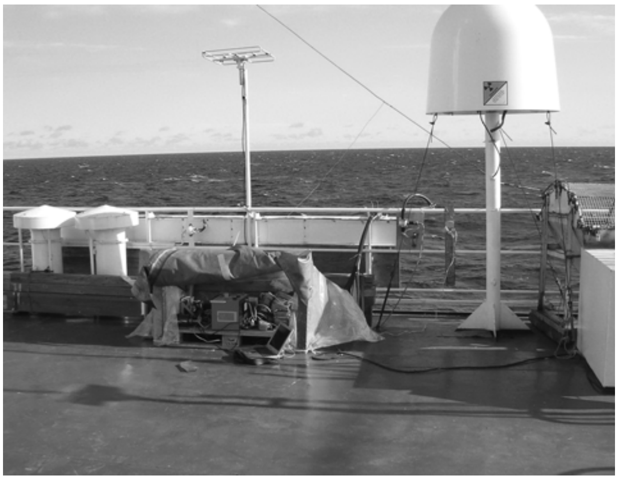
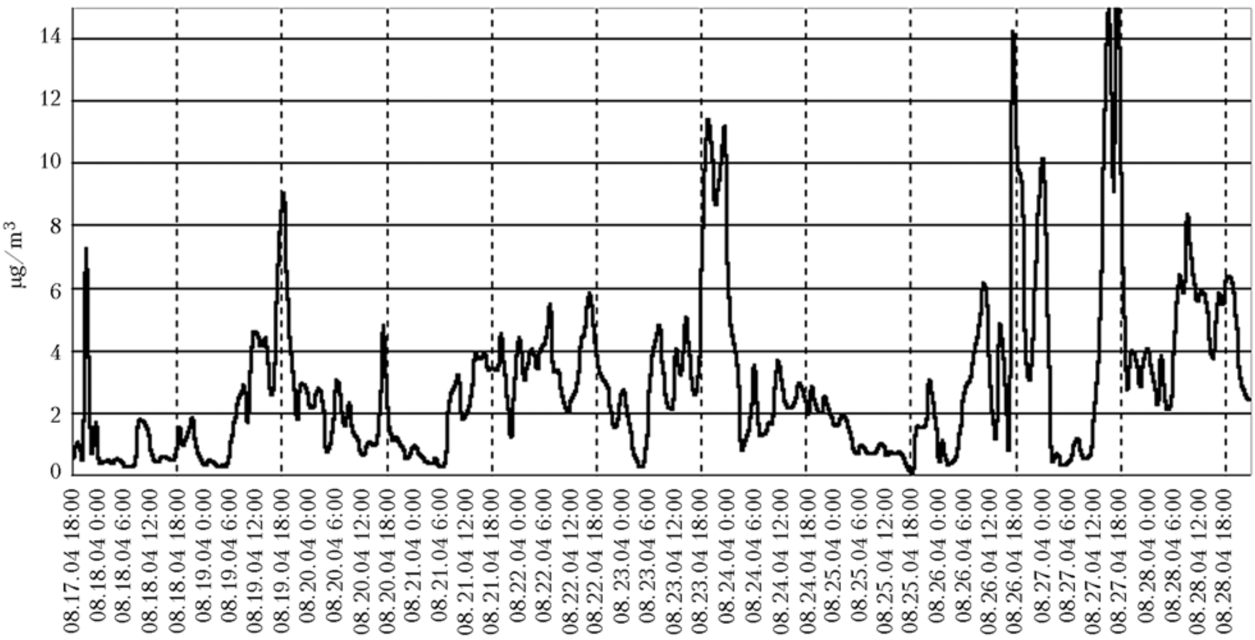


Fig. 5. Expedition of the Research Vessel *Professor Shtokman* in White Sea. Nephelometer was placed in a special shelter (at the center of photograph), protecting from rain, wind, and spray during storms.

Signal for entire measurement period (Research Vessel *Professor Shtokman*, cruise 64, White Sea, August 17–28, 2004)



Diurnal cycle (Research Vessel *Professor Shtokman*, cruise 64, White Sea, August 17–28, 2004)

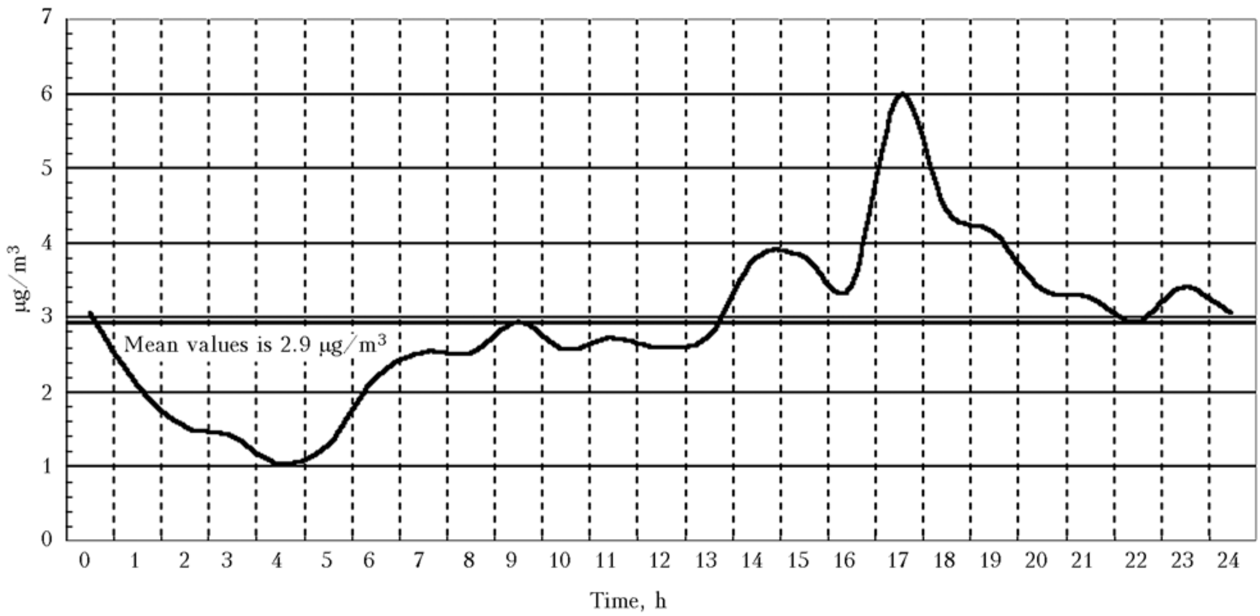


Fig. 6. Results obtained during continuous measurements. The top diagram presents the hourly mean mass concentration of the submicron fraction of AA for entire measurement period. The bottom diagram presents the diurnal cycle for this measurement period.

Conclusion

Data reading from nephelometer to computer memory via standard interface of serial data transfer (COM port) is automated.

Back-up data collection is performed into built-in energy-independent memory of the controller board.

Data accumulation in autonomous regime (without computer) during 2 days and 20 h is maintained, being protected from failure of power feeding.

Programs of computer control /interaction with controller board have been written.

The modernized nephelometer successfully operated in expeditions, as well as at the stationary station in Klyuchi village.

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References

1. R.J. Charlson, Rev. Environ. Sci. Technol. **3**, No. 10, 913–918 (1969).
2. I. Tombach and D. Allard, J. Air Pollution Control Assoc. **30**, No. 2, 134–142 (1980).
3. R.J. Charlson, D.S. Covert, Y. Tokiwa, and P.K. Muller, in: *Aerosols and Atmospheric Chemistry*, Edited by G.M. Hidy (Academic Press, N.Y., 1972), pp. 333–338.
4. R.J. Charlson, N.C. Ahlquists, and H. Horvath, Atmos. Environ. **2**, 455–464 (1968).
5. J.S. Kretzshmar, Atmos. Environ. **9**, No. 10, 931–934 (1975).
6. R.E. Lee, J.S. Caldwell, and G.B. Morgan, Atmos. Environ. **6**, No. 9, 593–622 (1972).
7. P.A. Scheff and R.A. Wadden, Atmos. Environ. **13**, No. 5, 639–643 (1979).
8. D. Ensor, R. Charlson, N. Ahlqust, K. Whitby, R. Husar, and B. Liu, *Aerosols and Atmospheric Chemistry*, Edited by G.M. Hidy (Academic Press, N.Y., 1972), pp. 315–324.
9. G.I. Gorchakov and G.V. Rozenberg, Izv. Akad. Nauk SSSR, Ser. Fiz. Atmos. Okeana **III**, No. 6, 611–620 (1967).
10. G.I. Gorchakov, A.S. Emilenko, A.A. Isakov, M.A. Sviridenko, and V.N. Sidorov, Izv. Akad. Nauk SSSR, Ser. Fiz Atmos. Okeana **19**, No. 11, 1226–1231 (1983).
11. A.S. Emilenko and V.N. Sidorov, "*Control of the state of air basin of Moscow.*" Preprint No. 9, Institute of Atmospheric Physics of RAS, Moscow (1992), Part II, pp. 93–104.
12. V.N. Sidorov, Ibid, pp. 105–115.
13. L.S. Ivlev, *Chemical Composition and Structure of Atmospheric Aerosols* (Publishing House of Leningrad State University, Leningrad, 1982), 364 pp.
14. M.V. Kabanov, M.V. Panchenko, Yu.A. Pkhalagov, V.V. Veretennikov, V.N. Uzhegov, and V.Ya. Fadeev, *Optical Properties of Coastal Atmospheric Hazes* (Nauka, Novosibirsk,1988), 201 pp.
15. M.V. Panchenko, "*Nephelometry in complex studies of the atmospheric aerosol*," Doct. Phys. Math. Sci. Dissert., Tomsk (1994), 513 pp.
16. Ya.P. Kogan, Pribory i Tekhnika Laboratornoy Raboty, No. 2, 215–219 (1958).
17. Ya.I. Kogan and M.E. Pankratova, Kolloidalnyi Zh. **XXXI**, No. 4, 623–626 (1969).
18. P.K. Kutsenogii, N.S. Bufetov, E.I. Kirov, and S.I. Shuiskii, Atmos. Oceanic Opt. **8**, No. 9, 725–731 (1995).
19. P.K. Kutsenogii, Khimiya v Interesakh Ustoychivogo Razvitiya **10**, No. 5, 627–635 (2002).