ISOKINETIC AEROSOL COLLECTOR FOR ECOLOGICAL MONITORING SYSTEMS

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We describe in this paper the construction of a collector capable of isokinetic aerosol sampling and by that to reduce measurement errors. When determining the mass concentration of suspended substances the error can decrease by 3–20 *times.*

Atmospheric aerosol, or suspended substances, is one of the basic air polluting components. Usually there are such toxic substances, as benzapyrene, heavy metals, sulfates, nitrates etc. in the composition of atmospheric aerosol particles, especially those of the anthropogenic origin. Therefore, permanent control of these air components is performed in the ecological monitoring systems. A wide variety of methods and tools is applied for measuring the aerosol properties. A detailed list of these is presented in Ref. 1. However, a key moment in the study of aerosol properties is correct sampling of particles from air (aspiration), to which N.A. Fuks paid special attention.[2] The matter is, that particles, depending on their size, are differently involved in air flows and consequently can escape the measuring volume of the device or to bypass a plate or filter. The comparison of the readings of 17 simultaneously operated devices[3] has shown, that because of the wrong aerosol aspiration their readings differed by up to 25 times. Hence, without a correct sampling it is useless to speak about the reliability of the data on aerosol concentration.

The problem of aerosol aspiration was studied in a number of papers. So, it was pointed out in Ref. 2 that the isokinetic condition must be fulfilled when sampling aerosol from air, namely the speed of flux, flowing on a sampler, should be equal to the speed in its section. For the sampler not to disturb the flow around it, there are some requirements to its construction.[4] They are the following[5]: The sampler section should be perpendicular to a flow; a thin-walled pipe, the ratio of the external diameter of which to the internal one does not exceed 1.1, should be used for collecting aerosol; if a thick pipe is applied, it should be sharpened at an angle of 15°, and the thickness of its front edge should be less than 5% of the internal diameter; the aspiration aperture should be not less than 1.5 calibre far from the device shell in the device middle section.

If the isokinetic condition is not fulfilled, the distortion of the sample can be adjusted by formula proposed in Ref. 6:

$$A_1 = C/C_0 = 1 + (V_0/V - 1)\,\frac{(2 + 0.65V/V_0)St}{[1 + (2 + 0.62V/V_0)]St}\,,$$

where C and C_0 are the measured and actual aerosol concentrations, respectively; V and V_0 are the wind speed and the speed in the sampler section, respectively; $St = V_0 V_s/dg$, V_s is the sedimentation rate of particles; d is the internal diameter of the pipe; and g is the acceleration of gravity. This formula was tested experimentally,[7] and holds within the limits $0.2 < V/V_0 < 10$, if the sampler satisfying the aforementioned conditions has been used.

In addition to the errors related to the collection of particles from air, there are the errors, caused by sedimentation of particles in the transportation channels. The following formula for taking it into account was derived in Ref. 8:

$$M/M_0 = (1 - \alpha)\,(V/V_0) + \alpha\,.$$

Here M and M_0 are the masses of particles, entering the sampler at the speeds V and V_0, respectively; and α is determined by the expression

$$\alpha = [1 - \exp\,(L/d)]\;/\;(L/d_1)\,.$$

In this formula L is the distance from the end of the sampler to the place, where the curvatures of the air flow appear because of nonisokinetic sampling; d_1 is the distance at which the particle stops determined by the expression $d_1 = \rho V_0 D^2/18\mu$, where ρ is the density of particle; D is its diameter; and μ is the gas viscosity.

However, the requirements stated are not fulfilled in the systems available for monitoring of the suspended substances.[9] Thus, for example, in the principal measuring complexes of Russian Hydrometeorological Service POST and POST-2 the correctness of aerosol sampling consists in a choice of an inlet aperture from the windward side of a pavilion and rather a rough selection of the sampler nozzle section, depending on the wind speed. It is easy to come to a conclusion, that the change of the wind speed and direction during sampling is not compensated far. Then there are no instructions in the manuals[10] on updating the isokineticity. Therefore the errors in

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determining the aerosol mass concentration from these data[11,12] can exceed 100%, that contradicts the State Standard,[13] establishing a threshold error to be not higher than 25%.

All the above-stated has served as the reason for development of the device free of these disadvantages. This device is described in the given paper.

DESIGN AND OPERATION OF THE AEROSOL SAMPLER

The diagram of the isokinetic sampler is shown in Fig. 1. It is seen from Fig. 1 that the sampler consists of the nozzle *1* of variable section, the area of which is changed from 30 to 1.5 cm^2 with a movable shutter *2*. The shutter position is determined by means of the sensor *9*, and its movement is performed with the electric drive *7* through the reducer *8*. The nozzle is connected with the rotatable console *3*, which simultaneously is the air flue. The console *3* provides the perpendicularity of the nozzle *1* section to the air flow by means of the electric drive *4* and the reducer *5*. The direction, along which the aerosol is sampled, is determined with the angular sensor *6*. The measurement volume *10* is arranged in the form of a joint, into which the measuring device or a filter may be inserted. The air flow rate through the measuring device is checked by means of the rotameter *11*. The vacuum at the device outlet is provided by the air flow stimulator *12*, which most often is an ordinary vacuum cleaner.[9,10]

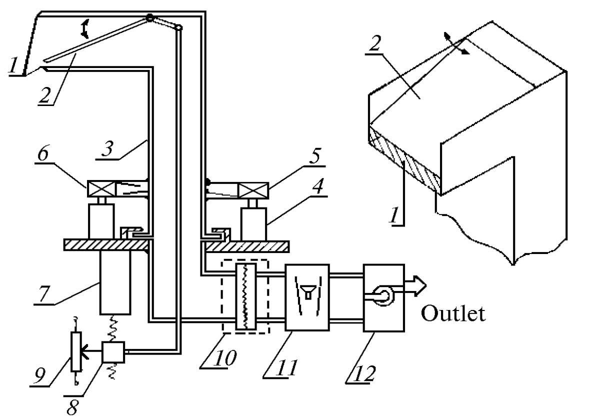

FIG. 1. Design of the sampler. The scheme of the nozzle is shown in the upper right corner. 1) variable area; 2) movable damper.

Let us consider the operation of the sampler using the block-diagrams shown in Fig. 2. Depending on the problem to be solved (collection of samples on the filters, measurement of the aerosol number density or its disperse composition, etc.) the air flow rate through the sample can vary[10] from 0.1 to 25 m^3/hour. So one should have the air flow stimulators with the air flow rate that may be varied. In our case, we set the fixed air flow rate at 10 m^3/hour, the most practical value. This rate is provided by means of the autoregulation scheme shown in Fig. 2*a*, when the shutter is completely open.

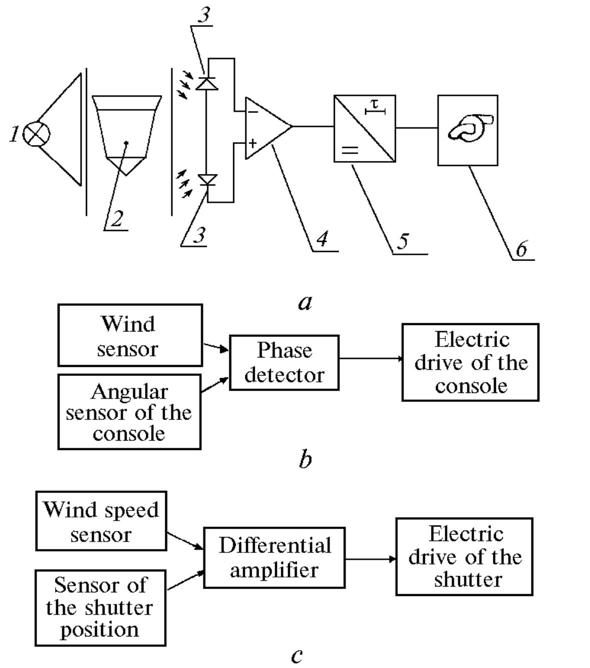

FIG. 2. Block-diagram of the air flow regulator (a), block-diagrams of the sampling console (b) and shutter (c) control.

It is seen from the figure that the light flux from a source *1* is directed to the control float of the rotameter *2*. The float position is recorded with the photodetectors *3*, the signal from which is fed to the air flow rate regulator *5* and air flow stimulator *6* through a differential amplifier *4*. The scheme is trivial, and no additional comments are needed.

The data on the wind speed and direction at the sampling site are necessary for operation of the sampler. The M-47 anemometer[14] is usually used in the monitoring systems available. A selsyn is its sensor of direction, and a tachogenerator is the speed sensor. So for the sampler we have chosen a selsyn as the angular position sensor, and a dc. motor as an electric drive.

It is seen from Fig. 2*b* that the signals from the wind direction and angular position sensors are fed to the phase detector, which controls the console electric drive by the value of their mismatch.

Since the wind velocity in real conditions vary in a wide range, and the constant air flow rate is necessary for the majority of techniques, we have chosen the scheme of the nozzle of a variable cross section. In such an approach the wind velocity variation is compensated for by varying the section area. The air flow rate through the device is constant. This approach is realized using the circuitry whose the block-diagram is shown in Fig. 2*b*. The signals from the wind velocity and the shutter position sensors are fed to the differential amplifier having the reversed polarity, because the amplification should correspond to the decrease of the nozzle section area. The differential amplifier produces the signal proportional to the discrepancy and sends it to the electric drive of the shutter, which moves on a predetermined scale.

Specifications of the sampler

Air flow rate, constant in the range	1 ... 25 m^3/hour
Range of the wind velocity, at which the isokinetic condition is fulfilled	1 ... 20 m/sec
Wind direction	0 ... 360°
Time constant on the angle and air flow rate	1 minute
Hysteresis:	
speed	± 0.5 m/(sec·%)
direction	± 10°

Thus, the sampler described is capable of isokinetically collecting aerosol at a constant air flow rate.

CONCLUSION

The isokinetic aerosol sampler described can be used in the monitoring systems available by means of connecting it to the existing communications. New developed complexes can be equipped with it. The use of it in experiments is also possible. It is not needed to acquire the wind sensor for equipping the operating systems, because it already exists in these systems. The sampler is quite simple for production. Its only disadvantage is the absence of the anti-ice system. However, such cases rarely occur.

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