PARAMETERS OF AUTONOMOUS ISOKINETIC AEROSOL SAMPLER IN A WIDE RANGE OF WIND VELOCITIES

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The isokinetic aerosol sampler (IAS) is an autonomous device for monitoring of atmospheric pollutions. Air is pumped into the device due to the velocity head of wind and rarefaction created by a two-blade propeller (windwheel) rotated by the wind flow. Aerosols are deposited on a filter. The study of the influence of filter drag on the value m (the ratio of velocities of the inflowing air mass and the flow in the air tube) was performed in N.E. Zhukovskii Institute by use of the wind tunnel T-30. Resistance of filter medium [ΔP] *was standard, from* 2.3 *to* 48 Pa. *The speed of air inflow was* 2–25 m/s. *Minimal air flow rates were recorded for media with* [ΔP] = 48 Pa. *In the range of wind velocity* 5–15 m/s, *the amount of air passed through the material was less by* 20–25% *as compared with the device without a filter, and by* 12–14% *as compared with the material FPP-15-1.6 for which* [ΔP] = 16 Pa. *Isokineticity* ($m = 1$) *is observed for the material FPP-15-1.6 at wind velocity* V = 10–25 m/s. *The value m decreases with the decrease of V. It reaches* 0.8 *for* $V = 5$ m/s. *For the material with* [ΔP] = 48 Pa, *we have* $m < 1$ *in the wind speed range* 3–15 m/s; *when* V = 2.5–7.5 m/s, *the value m coincides with those obtained for the filter medium with* [ΔP] = 16 Pa. *As for materials with* [ΔP] < 10 Pa, $m < 1$ *in the wind velocity range* 5–25 m/s.

The isokinetic aerosol sampler (IAS) has been designed for monitoring atmospheric air pollution by sampling aerosol (radionuclides, dust, chemical substances etc.) using a filter element with the subsequent determination of activity, qualitative and quantitative composition of the aerosols. Isokineticity (it means that the velocities of wind in the atmosphere and flow in the input IAS channel are equal) provides invariability of relative content of particles in the atmosphere studied and in the air entering the device (Fig. 1).

The IAS is an autonomous device that uses wind power to drive the propeller (windwheel) serving as a centrifugal pump. Its blades are made hollow, and their ends are cut. The mechanical counter of revolutions enables one to determine the volume of air pumped through the filter.

Air enters the device through the input channel with a diameter of 50 mm. Aerosols are captured by a filter fastened to the conical filter support with a base diameter of 100 mm and cone element of 270 mm. Purified air passes through the tunnel with the diameter of 35 mm and length of 1000 mm. Then it enters the hollow blades (500 mm long) of the windwheel with cut ends escapes into the atmosphere. The tunnel and windwheel are connected by the insert and a hub, both having five holes with a diameter of 18 mm. During rotation on the windwheel, air is thrown into atmosphere through the blade sections. To face the inflow channel (fastened to the support with a bearing) into the wind, a wind vane is placed on the tunnel. The cross section of the input channel is chosen so that the flow velocity is equal to wind (inflowing air) velocity, so the main condition of isokineticity[3] is fulfilled. In a more detail, the description of IAS is presented in Ref. 2.

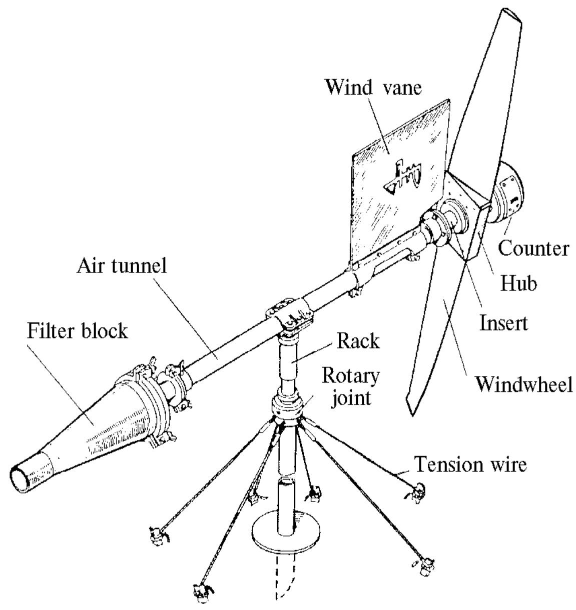

FIG. 1. The isokinetic aerosol sampler.

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The IAS devices were made at the Antonov aircraft plant ANTK. Flow rate characteristics were determined for the filter material FPP–15–1.5 placed in the form of a cone (area 0.04 m^2) on the filter support and fastened at the cone base with a rubber ring. During a long–duration sampling (sometimes, up to 1 month), under high dust content, fogs, rains, and snowfall, large quantities of liquid and solid aerosols are accumulated on the filter and increase its resistance. This can change the relations between the velocities of inflowing air and the flow in the tunnel part of the device, i.e., the isokinetic coefficient m.

The influence of filter resistance on the value m was studied in the wind tunnel T–30 in N.E. Zhukovskii Institute with open operating part and nozzle diameter of 1.2 m.

The hydrodynamic characteristics of IAS were determined on the ground for the inflow air velocities V = 2–25 m/s.

Air pressure in the tube depends on the atmospheric pressure and it is equal to 746 ± 5 mm Hg at a temperature of 315 ± 3 K. Operating time in one regime did not exceed 2 min. During a single tube actuation, IAS readings were taken in eight regimes of velocities V.

The volume air flow rate Q, isokinetic coefficient m, pressures in the channel, and their pulsations were determined as functions of the inflowing air velocity for six filters differing in hydraulic resistance and fiber diameter. We used materials FPP–15 with standard resistance (i.e., resistance to the air flow with the velocity 1 cm/s) of 1.6, 3.2, and 4.8 mm H_2O, and FPP–70 with the standard resistance 0.23, 0.53, and 1.06 mm H_2O. To estimate the maximum flow rate characteristics of IAS and isokinetic coefficients, the tube was blown without a filter.

The experimental results were processed in accordance with the data from Refs. 4–6. Analysis of the results presented in Fig. 2 demonstrates that the volume air flow rate through the IAS increases with the increase of the inflowing air velocity for all six filters. This function is practically linear in the velocity range 5–25 m/s. For similar V, the air flow rate decreases with the increase of the standard filter resistance.

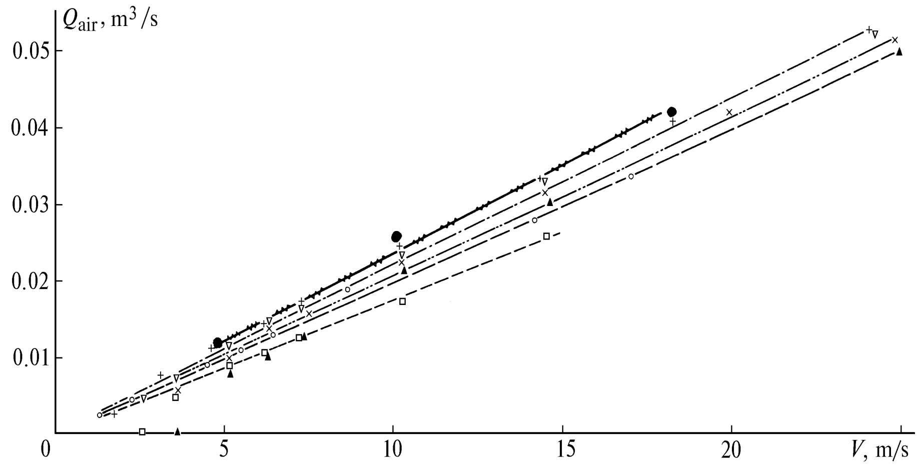

FIG. 2. Air flow rate Q_B in the input channel of the isokinetic aerosol sampler as a function of the inflowing air velocity V with different filter materials: without a filter (• and ∀∀), FPP–70–1.06 (× and –···–), FPP–70–0.23 (+ and –·–), FPP–70–0.53 (▿ and –·–), FPP–15–1.6 (▲ and – –), FPP–15–3.2 (○ and ——), and FPP–15–4.8 (□ and – –).

The material FPP–15–4.8 has the highest standard resistance (4.8 mm H_2O) among the filters tested. Figure 2 demonstrates that the material provides the lowest air flow rates in the IAS: in the range 5–15 m/s, the volumes of air passed through the IAS were less by 20–25% as compared with the device without a filter. However, the decrease was not so considerable as compared with FPP–15–1.6; it did not exceed 12–14%. Pressure losses at the filter make up only a small fraction of the total hydraulic resistance of the channel, regardless of the standard resistance of the material placed in the IAS.

If dust, fog, and snow accumulation on the material FPP–15–1.5 during IAS operating in flied conditions leads to three-fold increase of standard resistance, then the air flow rate, in the first approximation, decreases to the end of sampling, as it was obtained in blows with the filter FPP–15–4.8.

According to aerosol mechanics,[3] the isokinetic coefficient of IAS or an aspiration device is the ratio of the air flow velocity in the input plane of the air intake to the velocity of inflowing air $m = V_{in}/V$. The equality m = 1 corresponds to the isokinetic aerosol sampling. In this case, aspiration errors are negligible.

Figure 3 presents the values m calculated using the results obtained at blowing IAS with different filter materials and without a filter. The maximum value m = 1.28 is obtained for the inflowing air velocity of 10 m/s without a filter. The use of any of tested filters, even with minimum standard resistance, leads to a decrease of m as compared with the case of blowing without a filter.

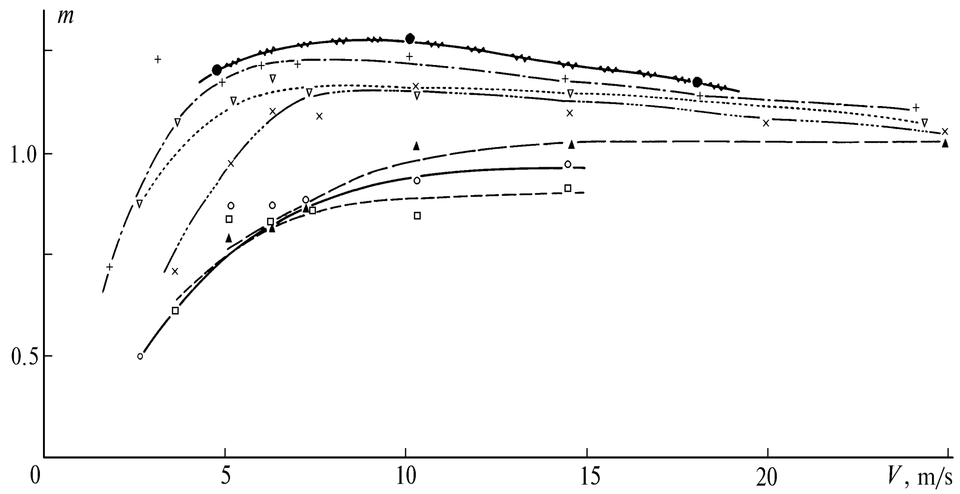

FIG. 3. Isokineticity coefficient m as a function of the inflowing air velocity V with different filter materials: without a filter (• and VV), FPP–70–1.06 (× and –····–), FPP–70–0.23 (+ and –·–), FPP–70–0.53 (▿ and ----), FPP–15–1.6 (▲ and — —), FPP–15–3.2 (○ and ——), and FPP–15–4.8 (□ and – –).

In practice, perfect isokineticity ($m = 1$) is observed only for the material FPP–15–1.6 in the range V = 10–25 m/s. At lower velocities, the value m decreases for this material. It reaches 0.8 at 5 m/s. For two other materials FPP–15 with standard resistance of 3.2 and 4.8 mm H_2O, the values were less than 1 in the whole range of velocities 3–15 m/s. For the velocities 2.5–7.5 m/s, the values m practically coincide with those obtained for the material FPP–15–1.6.

For three materials FPP–70 whose standard resistance is significantly less as compared with the FPP–15–1.6, material the values of the isokinetic coefficient are less than 1 in the velocity range 5–25 m/s. Maximum m is observed at the velocities ~ 10 m/s, as during the blows of the channel without a filter. For maximum velocity of 25 m/s, the values m differ from 1 not more than by 5–8%, i.e., they correspond to isokinetic conditions of aerosol sampling. The same regime of aerosol sampling is observed at the velocities of 3–5 m/s; for lower velocities, the isokinetic coefficient is less than 1 and rapidly decreases with the decrease of the flow velocity.

During sampling, deviations of the isokinetic coefficient toward higher values must lead to distortions in the spectrum of aerosols falling into the air intake channel and, further, onto the filter. The results of calculations of the aspiration coefficients for aerosols A are presented in Fig. 4 for different values m. The coefficient A is the ratio of concentration of particles of a certain size at the input of the channel C_{in} to that of the same particles in the free flow (inflowing air) C. The calculations were performed in accordance with the data from Ref. 7. As follows from the curves presented in Fig. 4, for the range of values m obtained when blowing IAS, most significant losses (two-fold and higher) are observed for $m = 0.5$ for particles whose aerodynamic radius exceeds 10 μm.

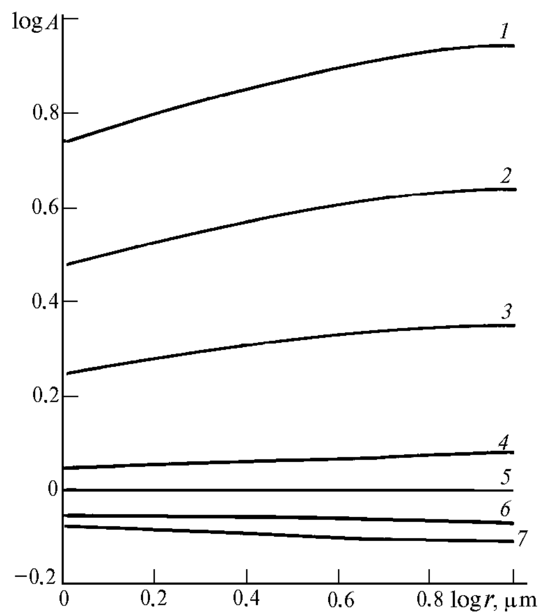

FIG. 4. Coefficient of aerosol aspiration A as a function of particle radius r for different values of the isokinetic coefficient m: 0.1 *(1);* 0.2 *(2);* 0.4 *(3);* 0.8 *(4);* 1.0 *(5);* 1.2 *(6);* 1.3 *(7).*

In the beginning of 1987, 72 aspiration-free samplers PB–1 designed in L.Ya. Karpov Scientific Research Physicochemical Institute were deployed in the 30 km zone around Chernobyl nuclear power plant for monitoring the composition and concentration of radioactive gas aerosol products of the accident in the 4th block. Later, on specialists of the USSR Ministry of Defence developed one more net of autonomous devices. They used about a hundred of isokinetic aerosol samplers (IAS).[2] The use of devices PB–1 and IAS in continuous sampling made it possible to monitor radioactive products from the near-ground atmospheric layer in the 30 km zone at about 200 strategic points. Some of them are at a distance of many kilometers from power supply sources. Operation simplicity of the sampler (removal and installation of filters, determining the quantity of filtered air) makes it unnecessary to employ a lot of experienced persons. In addition to a stationary net, the devices PB–1 and IAS were placed on cars what made it possible to use them for monitoring radioactive aerosols at the main roads of the 30 km zone around the Chernobyl power plant, in Pripyat and Chernobyl towns.

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