VIBRATING-CAPILLARY GENERATOR FOR OBTAINING TEST AEROSOLS WITH A DIAMETER OF LESS THAN 2 MICRONS

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Methods are considered for obtaining test aerosols of particle diameter less than 2 μm by means of a generator with a vibrating capillary, and subsequently using them to provide metrological assurance of photoelectric particle counters.

The manufacture and operation of instruments and systems for monitoring the purity of air in an industrial environment and for ecological monitoring are inseparably linked with their metrological assurance. In particular, in the case of aerosol particle counters the use of test monodisperse aerosols having different fixed particle parameters is most promising. One relatively simple and reliable method for generating test monodisperse aerosols is based on the principle of atomizing a solution of a nonvolatile liquid or solid in a volatile solvent. Under certain conditions an intense evaporation of the solvent occurs from the surface of droplets of the solution and consequently solid or liquid particles are formed whose size and concentration depend on the concentration of the nonvolatile substance in the solution and on the atomizing regime. Clearly, one must utilize a principle for atomizing the solution which leads to the production of uniform liquid droplets in order to obtain monodisperse aerosol particles. This is possible by means of forced capillary disintegration of a liquid. The theoretical requirements for such a method were developed by Rayleigh at the end of the last century [1]. The method is based on the instability of a liquid jet flowing from a capillary under pressure. If any sort of periodic perturbation is created in the jet it will disintegrate into droplets of uniform diameter. This happens only when the wavelength \( \lambda \) of the perturbation and the diameter \( D_j \) of the jet satisfy the condition

\[ \lambda = nD_j, \]

If this is not the case the jet exists in a stable state and it can be destroyed only as a result of random factors, and this disturbs the monodisperse nature, i.e., it causes droplets of different diameters to be formed. It follows from the theory of Rayleigh that the greatest instability of a jet is caused by a periodic perturbation of wavelength \( \lambda = 4.508D_j \). Schneider and Hendricks [2] determined experimentally that a jet disintegrates into droplets of identical diameter when

\[ 3.5D_j < \lambda < 7D_j, \]

which does not, in general, contradict the theory of Rayleigh.

For \( \lambda > 7D_j \) smaller-scale satellite droplets can appear at the same time as those of the principal diameter. For \( \lambda < 3.5D_j \) the liquid jet becomes stable with respect to periodic perturbations and its disintegration is governed by random factors (such as pressure fluctuations caused by the jet flowing out of the capillary). Consequently polydisperse droplets are formed having an unpredictable size distribution.

It was shown in [3] that for the purposes of the metrological assurance of aerosol particle counters it is best to employ aerosol generators having a vibrating capillary. Theoretically such a generator makes it possible to obtain monodisperse aerosols with aerosol particle diameters in the range 1-50 μm, although in practice the lower limit for the aerosol particle diameter is 2 μm. At the same time, Russian counters for aerosol particles have a threshold of 0.3-0.4 μm for the measured aerosol particles. It is therefore necessary to obtain aerosols with particle diameters below 2 μm in order to check them.

A regime with \( \lambda > D_j \) may be a possible way of solving this problem. The results of a number of experimental and theoretical investigations [4] have shown that for low perturbation frequencies (\( \lambda > 7D_j \)) satellites of smaller diameter can be

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formed at the same time as droplets of the principal diameter. The formation of satellite droplets when a harmonic perturbation interacts with a liquid jet is due to the nonlinear effect of the generation of higher harmonics. A constriction appears between the crests of the fundamental harmonic, as the capillary instability develops, and this grows very thin with time in the regions where it contacts a crest. The fundamental possibility of generating small diameter satellites is of considerable interest as a means of obtaining a submicron aerosol for testing ultrafine decontamination filters and checking aerosol counters.

Unfortunately no complete theory of forced capillary disintegration of a liquid has yet been developed which would allow one to calculate precisely the diameters and concentrations of the satellites as a function of the amplitude and frequency of the perturbations, and the diameter and flow velocity of the liquid jet. Investigations of forced capillary disintegration of a liquid beyond the limits of stable monodisperse disintegration were made at the Scientific-Research Laboratory of the Theory and Technology of Disperse Systems at the St. Petersburg State Academy of Aerodynamic Instrument Engineering, using an aerosol test rig similar to that described in [5]. During these investigations qualitative and quantitative estimates were made of the nature of the jet fragmentation.

A qualitative estimate of the fragmentation process was made by visually monitoring the nature of the deflection of particles created by a generator when an air stream acts on a jet (see Fig. 1).

It was established that monodisperse decay (Fig. 1a) occurs when the condition (1) is satisfied and the voltages on the electrodes of the piezoelectric vibrator are between 2 and 10 volts. A reduction in the frequency of the perturbations led to the formation of satellites (Fig. 1b), the number of the fractions in certain regimes being between three and five.

According to a quantitative estimate, the atomizing regime had the following parameters: solution concentration 1/8000, forced oscillation frequency $f' = 49$ Hz, jet diameter $D_j = 22 \mu m$, air flow rate for dispersion 3.9 liters/min, air flow rate for drying 44 liters/min, liquid flow rate 0.38 cm$^3$/min. Test samples of the aerosol formed were selected by a continuous-flow sedimentator, deposited on cover glasses, and were then analyzed under a microscope. It was established that by suitably choosing the frequency and amplitude of the perturbations it was possible to ensure the generation of an aerosol containing satellites whose diameters were smaller than those of the principal fraction by a factor of 4-8. It is therefore possible in principle to obtain a monodisperse aerosol with particle diameters in the range between hundredths of microns and tens of microns on the basis of forced capillary disintegration of a liquid. The aerosols obtained for the satellite fraction were monodisperse to within a factor of 0.7.

The extent to which the liquid flow is not in a steady state during forced capillary disintegration can be estimated using the Strouhal number Sh. This number is used in aerodynamics for the characteristics of nonsteady-state flows having a velocity $v_j$ which changes discretely with time at a frequency $f$, i.e., the number Sh is the dimensionless frequency of changes in the physical phenomena:

$$Sh = D_j f / v_j.$$