perature to 1250°C crystallization of the oxide once again results in analogous processes, which are significantly weaker owing to the fact that by this time almost the entire volume of the copper particle is oxidized.

The questions associated with high-temperature oxidation of copper particles moving in air are especially important in connection with the development of controllable systems for depositing coatings with prescribed electrophysical properties. In the study of the combustion of copper and other particles there opens up the possibility of controlling the phase composition and size of the particles and forming an oxide coating with different thickness, which substantially changes the surface and volume properties of the particles, by varying the conditions of combustion and the moment of extinguishment. A regulatable, high initial temperature of the drops makes it possible to achieve good adhesion to the substrate and to form, in air under normal conditions, unoxidized coatings, since an oxide layer starts to grow on copper particles at temperatures $T < 1800°C$, and in the process there is enough time for the particles to traverse a significant distance, which makes it possible to employ electrostatic control devices.

NOTATION

τ, width of the pulse making it possible to detach the drop; M, mass of the particle; v_0, velocity of emergence; F, force; Δt, time from the start of displacement at the center of mass of the drop up to detachment of the drop; F_σ, surface tension force; F_e, force due to the electronic pressure; I, current; U, voltage; m and e, electron mass and charge; r, radius of the drop; R_e, radius of the electrode; T, temperature; T_0, initial temperature of the drop; T_m, melting point of the metal; σ_m, surface tension of the metal at the melting point; and $(d\sigma/dT)_m$, derivative of the surface tension of the metal at the melting point.

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APPLICATION OF FLUORESCING SOLUTIONS FOR TEMPERATURE DIAGNOSTICS OF MONODISPERSED MACROPARTICLES

V. V. Blazhenkov, A. V. Klimenko,
and D. S. Lin

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A method for measuring the temperature of monodispersed particles is studied. The method is based on the fact that the fluorescence of water solutions of fluorochromes is temperature dependent. The employed method makes it possible to reduce significantly the instability of the excitation light flux and of the optoelectronic recording apparatus.

In order to study heat transfer of photodispersed macroparticles which are moving in a gas flow the temperature must be determined by a contact-free method, since existing methods of measurement with the help of thermocouples do not permit investigating drops smaller than 400 μm in size [1]. In [2] a method based on the temperature dependence of the fluorescence of water solutions of some substances was proposed. The character of this dependence for different substances and concentrations of the same substance is different, since it is determined by different physicochemical processes occurring in the solutions. We employed as temperature indicators water solutions of rhodamine 6G and riboflavin.

For low-concentration solutions of fluorochromes the fluorescence intensity is proportional to the intensity of the excitation light

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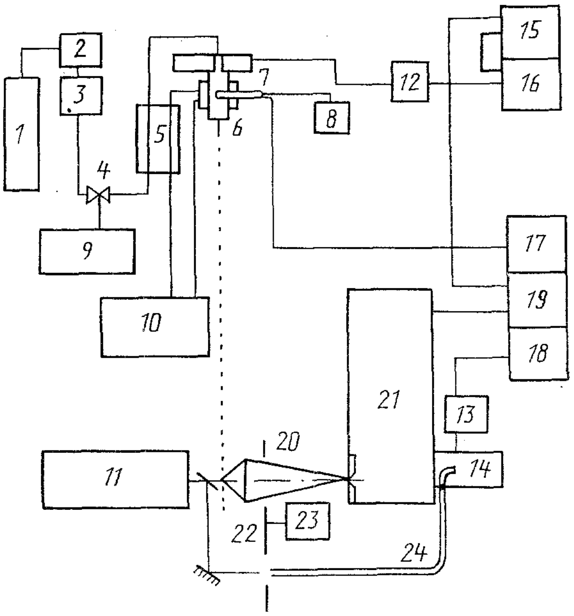

Fig. 1

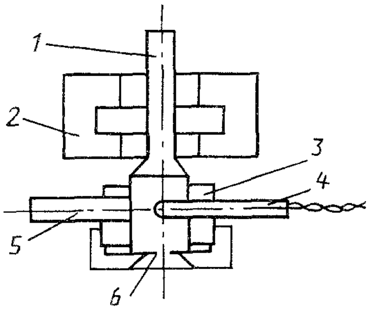

Fig. 2

Fig. 1. Line diagram of the apparatus: 1) tank with compressed gas; 2) reducer; 3) reservoir with fluorochrome; 4) controllable piezoelectric ceramic throttle valve; 5) countercurrent pipe exchanger; 6) generator of monodispersed drops; 7) thermistor; 8) current source; 9) high-voltage source; 10) thermostat; 11) argon ion laser; 12) high-voltage amplifier; 13) former; 14) FÉU-136 photomultiplier; 15) TTL generator; 16) programmable frequency divider; 17) ATsP-701A analog-to-digital converter; 18) 420 counter; 19) power supply for the stepping motor; 20) optical system; 21) MDR-23 monochromator; 22) obturator; 23) stepping motor; 24) fiber lightguide.

Fig. 2. Generator of monodispersed drops: 1) drainage tube; 2) piezoelectric corrector; 3) temperature-controlling jacket; 4) thermistor; 5) input pipe; 6) draw plate.

$$I_f = AB_{en}(T)\,\alpha I_b, \tag{1}$$

where α is the absorptance of the dye solution.

Thus the quantity I_f/I_b can be used to measure the temperature of monodispersed macroparticles.

A line diagram of the apparatus is presented in Fig. 1. The flux of monodispersed macroparticles is formed as follows. The solution of the fluorochrome flows, driven by the excess gas pressure, from the reservoir 3 through the controllable piezoelectric ceramic throttle valve 4 and the countercurrent pipe exchanger 5 into the generator 6. The piezoelectric ceramic throttle valve makes it possible to regulate smoothly the pressure of the liquid at the inlet into the generator.

The generator of monodispersed drops with a temperature-controlled jacket, whose construction will be described below, undergoes axial oscillations. The oscillations of the generator excite surface waves in the emerging jet of liquid. Under the action of the Rayleigh instability this results in breakup of the jet into separate drops with rms deviation of the parameters not exceeding 0.1-0.01%.

The thermostat 10 makes it possible to heat the liquid solution up to the required temperature in the heat exchanger 5 and protects the generator from freezing when it operates at low temperatures of the surrounding gas. The fluorescence was excited with light from an argon ion laser 11 of the type LGN-502. The nominal radiation power of the laser was chosen to be equal to about 1 W. For drops with diameter greater than 50 μm and velocity 1-10 m/sec and the indicated radiation power, as estimates show, the maximum heating of the drops is less than 0.1 K. The fluorescence is recorded at an angle of 90° with respect to the excitation light with the help of an optical system 20, which forms an image, magnified approximately by a factor of 10, of the radiating drops on the input slit of MDR-23 monochromator

21. The monochromator is controlled with the help of the power supply of the stepping motor 19, which is configured in the CAMAC standard. The monochromator was tuned to the wavelength of maximum fluorescence. The light from the output slit of the monochromator strikes a FÉU-136 photomultiplier, which operates in the photon-counting mode. The voltage supplied to the photomultiplier (U_s = 1900 V) was chosen at the center of the plateau of the counting characteristic; this makes it possible to optimize quite well the signal-to-noise ratio.

The temporal instabiity of the photomultiplier employed was equal to 1-4% over several hours of operation. During one series of measurements, which lasted for about 1 h, the intensity of the LGN-502 laser radiation did not remain constant, but dropped by 20-30%. This made it necessary to find a measurement scheme which would be insensitive to the indicated instabilities. For the photon-counting method the number of recorded photons is proportional to the fluorescence intensity (if single-photon pulses do not overlap):

$$N_f = I_f \Omega \varkappa(t), \tag{2}$$

where $\varkappa(t)$ is the sensitivity of the photomultiplier, which is a random function of time. In order to take into account the instability of the optical system, an obturator, which periodically covers the light striking the monochromator and opened the fiber-optic channel along which part of the exciting light travelled to the photomultiplier, was introduced into the optical scheme. The time intervals during which the photomultiplier recorded the fluorescence and excitation light were equal, and the number of recorded photons of excitation light also is proportional to the intensity of the laser radiation, taking into account corrections for instability of the optical system:

$$N_b = I_b \xi \varkappa'(t). \tag{3}$$

The quantity $\varkappa'(t)$ has the same meaning as $\varkappa(t)$ in the preceding formula. It should be noted, however, that the fluorescence and excitation intensities are not measured simultaneously, but rather one after the other. The quantities $\varkappa(t)$ and $\varkappa'(t)$ can be assumed to be equal, if the time intervals over which the fluorescence and excitation are measured are short. In the experiments described, they were equal to about 600 msec, which is significantly shorter than the characteristic instability time of the optical system. Under these conditions, by combining the formulas (1)-(3) it is possible to find the dependence of $B_{en}(t)$ on the experimentally measured quantities N_f and N_b:

$$B_{en} = \frac{\Omega}{A\xi\alpha} \frac{N_f}{N_b}. \tag{4}$$

In the photon-counting process not only the useful radiation but also the dark photons are recorded. If the signal-to-noise ratio is close to optimal, then their number is comparable to N_f and N_b. For this reason the formula (4) must be refined, subtracting from N_f and N_b the dark counts N_d:

$$B_{en} = \frac{\Omega}{A\xi\alpha} \frac{N_f - N_d}{N_b - N_d}. \tag{5}$$

To measure N_d a phase in which dark photons were counted and during which the obturator covered simultaneously both channels along which light reaches the photomultiplier – the fluorescence light and the excitation light – was inserted into the measurement cycle.

The formula (5) contains the absorptance of the dye solution, which in the general case is also a function of the temperature. For water solutions of rhodamine 6G and riboflavin the temperature dependence $\alpha(T)$ is insignificant [3], and this makes it possible in this work to talk about using the temperature dependence of fluorescence and not absorption.

A diagram of the generator producing the flow of monodispersed macroparticles is presented in Fig. 2. The difference between this generator and the generators described in [4] lies in the following: First, the generator is used for dispersing liquids into a medium whose temperature is lower than the temperature of the freezing liquids, so that in order to prevent the liquid in the cavity of the generator from freezing and in order to maintain its temperature at a constant value a temperature-controlling jacket 3 was introduced. Second, the temperature in the generator was measured with an STZ-18 thermistor 4, since the signal from the thermocouple which lies adjacent to the piezoelectric element is too weak compared with the electromagnetic interferences. The voltage on the thermistor was varied with the help of the ATsP 701A. Instability of the jet was excited with a piezoelectric corrector 2, which could move freely up to 100 μm (at U = 1000 V). A signal in the form of a meander with an amplitude

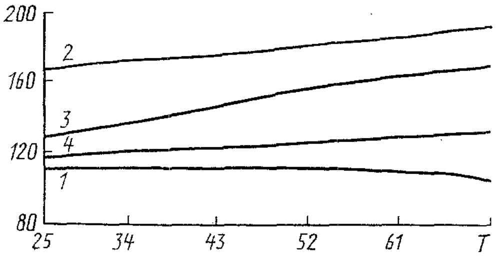

Fig. 3. Dependence of the photomultiplier signal (arbitrary units) on the temperature of the solution of fluorochrome, °C, in the generator: 1) riboflavin solution, $c = 1.5 \cdot 10^{-3}$ m; 2) same, $c = 1.5 \cdot 10^{-6}$ m; 3) rhodamine 6G solution, $c = 5 \cdot 10^{-6}$ m; 4) same, $c = 5 \cdot 10^{-6}$ m.

of about 100 V was applied to the piezoelectric corrector. A draw plate with a 150 μm in diameter opening was used for dispersing.

The method for measuring the temperature was tested for the above-indicated conditions on solutions of rhodamine 6G and riboflavin with different concentrations. The dispersing was performed in air at a temperature of 22°C. The diameter of the drops was equal to about 300 μm, and the velocity was equal to 1 m/sec. The fluorescence light was recorded immediately after the jet was broken up into a flux of monodispersed particles 10 mm from the opening of the draw plate. Figure 3 shows the dependence of the photomultiplier signal on the temperature in the generator.

The result obtained confirms that the method is workable and its sensitivity is adequate for heat-exchange problems (up to 1%/deg). The temperature range indicated in the figure was determined by the technical possibilities and can be extended in the direction of both higher and lower temperatures. The use of this method at temperatures below 0°C is complicated by the fact that the fluorochromes which we employed no longer fluoresce at these temperatures. In this temerature range we propose using solutions of dyes which fluoresce well in the frozen state.

NOTATION

I_f, intensity of the fluorescence light; I_b, intensity of the laser radiation; A, fraction of the laser radiation that is absorbed by the molecules of the fluorochrome; V_{en}, energy yield of fluorescence; T, temperature of the liquid; N_f, number of fluorescence quanta recorded by the photon-counting system; Ω, a coefficient that takes into account the geometry of the optical system and the losses of light in it; $\varkappa$, sensitivity of the photomultiplier; t, time; ξ, fraction of the laser radiation reaching the photomultiplier; N_d, number of dark counts of the photomultiplier; λ, wavelength; and c, concentration.

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