MEASURING NATURAL OSCILLATION PERIODS FOR DROPLETS AND TWO-COMPONENT PARTICLES

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Measurements have been made on the natural oscillation periods for droplets forming freely in air, including ones containing solid particles.

Real time is often used in researching the dynamics of a gas droplet flow or the time, phase, and relaxation characteristics of the processes there. In [1-3], there are discussions on droplet deformation and break-up due to aerodynamic forces, and data were given on the time intervals in dimensional form (induction time, characteristic break-up time, and so on), which hinders extending the data to cases differing from the particular conditions as regards droplet size, physical properties, aerodynamic forces, and so on. Dimensionless time parameters should be used [1]. The characteristic time ranges for droplet break-up under aerodynamic forces or on droplet collision may be examined by reference to the natural oscillation periods τ, as may other microscopic phenomena. Determining τ is also of considerable independent interest. Theoretical and experimental results have been surveyed [2] on oscillations on drops immersed in water or other liquids, as well as oscillations under zero-gravity conditions, acoustic pressure, etc. The most detailed studies on natural oscillations in droplets have been described in [4].

We have determined oscillation periods for droplets alone or with solid inclusions (two-component particles) falling freely in air.

Figure 1 shows the apparatus. The water-glycerol mixture flowed from vessel 1 through the control valve 2 into the conical funnel 3, whence it passed through the flow-rate regulator 4 to the forming capillary 5. The solution level in funnel 3 was kept constant. Near the capillary, the pump 6 imposed pressure pulsations on th flowing liquid, so the jet broke up into a monodisperse flow, with the droplets detached at the pulsation frequency. The droplets were collected in the receiver 7. A two-component product was made by supplying quartz sand from the bunker 8 via the dispenser 9 to the funnel 3. The particles were prevented from sticking in the bunker by the electromagnetic vibrator 10. The suspension was prepared in funnel 3 with the stirrer 11, which mixed the sand continuously. The necessary particle concentration was provided by controlling the particle flow. As in the production of pure droplets, the suspension was broken up by the pressure pulsations acting on the jet from the capillary 5. The piston-type pump 6 was driven by the electromagnet 12, which was controlled by the generator 13, which produced square pulses at 4-30 Hz with mark-space ratio 0.5. The pump also provided for adjusting the amplitude. To prevent solid from entering the pump, the cavity was separated from the suspension by an elastic diaphragm. The cavity in the pump cylinder was filled with the pure water-glycerol mixture. The droplet generation mode was chosen such that there were appreciable oscillations with small amplitude in the measurement section.

Stroboscopic illumination was combined with photographic and video recording to examine the deformation phases. Particular attention was given to new methods of stroboscopic display. One of them was that the drops were observed with the simultaneous recording of several phases at very accurately controlled time intervals. The digital control unit 14 for the flash lamps (UMV display device) produced a train of pulses with intervals that were multiples of 1 msec, which synchronized the commercial stroboscope gave frozen images for the number of phases equal to the strobe pulse number during the drop generation period. The photographic recording was with pulsed illumination from several IFK-75 lamps operating in turn, which were powered by a high-voltage unit and striker, with the striking also provided by the

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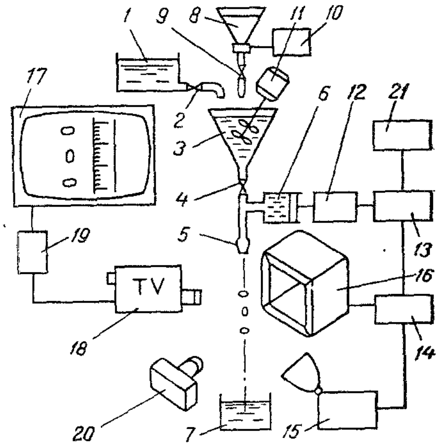

Fig. 1. The apparatus.

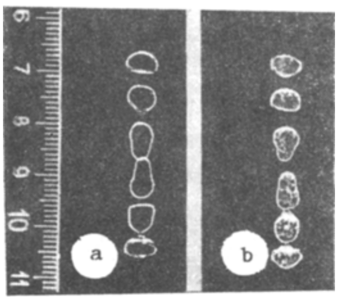

Fig. 2.

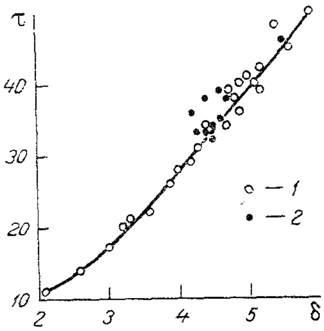

Fig. 3

Fig. 2. Photographs of an oscillating pure droplet (a) and a two-component particle (b); δ = 5.1 mm, C = 40%; V = 6%.

Fig. 3. Natural period as a function of size: 1) pure droplets; 2) two-component particles; τ in msec and δ in mm.

UMV. The lamps were mounted in the illuminator 16, which enabled one to record several phases in centre-jour illumination against a dark background (blackness of background about 0.95). This gave the time intervals between the phases with the accuracy of the digital devices, which were crystal stabilized. The enlarged images were viewed on the TV monitor 17 connected to the TV camera 18 via the matching unit 19. The video recordings were analyzed with the TV display in frame stop mode. The photographic recording was with KN-4 A-2 film (sensitivity 350-500 units GOST) with a Praktika camera 20.

The drop diameter was determined from the number of drops and mass, while the diameters of the two-component particles were determined from the number and the total suspension volume. The F5007 counter 21 recorded the numbers of drops and particles. The volume concentration V of the inclusions was determined from a previously constructed V = f(h/H) calibration curve, in which H is the suspension column height and h the height of the column of deposited particles in the cylindrical vessel.

The multiple display gave the intervals between adjacent phases. We used mixtures giving droplets with diameters δ of 2.1-5.9 mm at a glycerol concentration C of 0-91%, where the dynamic viscosity varied by more than two orders of magnitude. The two component experiments were performed with sand having fraction sizes of 100...160, 160...315, 315...400 μm and particle density ρ_s of 2774 kg/m^3, which was measured to reduce the experimental error. The volume concentration of the solid in the drops varied from 0 to 21%.

Figure 2 shows the photographs, which indicate six phases. The first and sixth (from the top downwards) are similar. The intervals between them were 38 msec for the pure drop and 40 msec for the two-component particle. At low and medium viscosities, our measurements

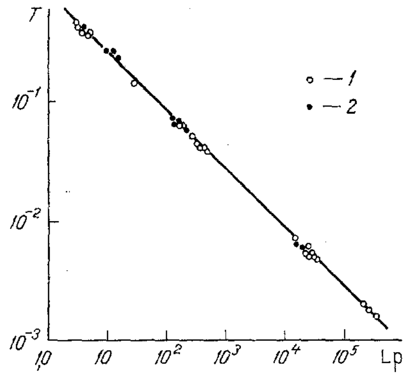

Fig. 4. Dependence of dimensionless time T on Laplace number: 1) pure droplets; 2) two-component particles.

$$\tau = \frac{\pi}{4}\frac{\rho\delta^2}{\eta}\frac{1}{\sqrt{\mathrm{Lp} - 6.25}}. \quad (1)$$

One cannot determmine the period from (1) at high viscosities, as the formula is restricted to Lp > 6.25. In the range LP $\leq$ 6.25, the damping is aperiodic [4], so τ becomes meaningless. However, we observed oscillations down to Lp = 3.

Figure 3 shows how the size affects the period for ρ = 1000...1550 kg/m^3, σ = 0.0618... 0.074 kg/sec^2, η = 0.001023...0.352 kg/(m·sec).

We proposed the measurements on a formula analogous to (1):

$$T = A(\mathrm{Lp} - \mathrm{Lp_{cr}})^{\alpha}, \quad (2)$$

in which $T = \tau\eta/(\rho\delta^2)$ is the dimensionless oscillation time and $\mathrm{Lp_{cr}}$ the Laplace number corresponding to the boundary between the periodic and aperiodic forms of damping. With the inclusions, T and Lp were calculated on the basis of the dynamic viscosity η_s of the suspension found by the use of Einstein's correction [5] for spherical inclusions: $\eta_s = \eta_\ell (1 + 2.5 V\cdot 10^{-2})$. The suspension density ρ_s was defined by $\rho_s = \rho_\ell + V\cdot 10^{-2} (\rho_{so} - \rho_\ell)$.

The inclusion affect the period only because the density is altered; there was no appreciable effect from the inclusion size on the period.

Figure 4 shows the dimensionless period T as a function of the Laplace number for pure drops and particles. T and viscosity decrease together, while τ is independent of the viscosity.

Computer processing by least squares showed the best fit to

$$T = 0.83/\sqrt{\mathrm{Lp}} \quad (3)$$

for $3 \leq \mathrm{Lp} \leq 3.7\cdot 10^5$. The minimum standard deviation (0.059) of the measurements from (2) occurred for $\mathrm{Lp_{cr}} = 0$, but nevertheless, the applicability of (3) is restricted to Lp $\geq$ 3.

Formula (3) agrees apart from a coefficient (0.785 instead of 0.83) with the classical Rayleigh formula for an ideal liquid.

NOTATION

δ, diameter, m; C, glycerol concentration, %; V, volume concentration of solid inclusions, %; ρ, density, kg/m^3; η, dynamic viscosity, kg/m·sec; $\mathrm{Lp} = \sigma\rho\delta/\eta^2$, Laplace number; σ, surface tension, kg/sec^2; τ, natural period, sec; T, dimensionless time. Subscripts: ℓ, liquid; so, solid inclusions; s, suspension.

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