Experimental study of loss in stability of the drop shape in the approach air flow

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Abstract. A new experimental scheme of installation to study the deformation of drops by aerodynamic forces was described. Results of experimental studies of the deformation of drops in the air flow were shown. Video shoots of the deformation of the drops for different values of Weber numbers were obtained. Experimental dependence of the degree of deformation of the drop from Weber number was obtained and an approximating formula for determining the degree of deformation of the drop was obtained.

1 Introduction

The processes of loss in stability of drops in approach gas flow leading to their deformation and fragmentation play an important role in the hydrodynamics of two-phase flows [1]. These processes are of practical importance in meteorology (the formation of a spectrum of droplet sizes of atmospheric precipitation [2]), in engine building (the dispersion of fuel droplets in internal combustion engines and liquid rocket engines [3, 4]), in ecology problems (evolution of a cloud of droplets of toxic components Liquid rocket fuels, formed during depressurization in the atmosphere of fuel tanks of carrier rockets [5]) and in a number of other branches of engineering and technology. In this paper, we consider an experimental facility for studying the deformation of a stationary droplet in an air flow. The main criterion for determining the deformation of the droplets in the gas flow is the Weber number that characterizes the correlation of forces of the dynamic pressure of the gas (aerodynamic force) to the force of surface tension. With increasing Weber number the drops deformation increases, and with some critical value it is splitting due to the instability of Kelvin-Helmholtz [1].

2 The scheme of the test installation for studying the deformation of drops by aerodynamic forces

To improve the accuracy of measurement of the degree of drop deformation and of the parameters that is included in the Weber number a new test installation for studying the deformation of drops by aerodynamic forces was proposed [6]. The scheme of installation is shown in Fig. 1. The installation includes a vertically arranged dropper with the capillary

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1, the system of flow which directs drops vertically upwards and visualization system. The air supply system contains a battery of cylinders 2 with compressed air connected by tube through a reduction gear 3 with a control manometer 4 regulating valve 5 and a flowmeter 6 with the lower access of the cylindrical pipe 7, is located coaxially with dropper 1. A flow shaper 8 is in pipe 7, which is made in the form of at least six symmetrically arranged nozzle plates. The imaging system includes a video camera 9, which can check the original drop 10 in the cut of the capillary dropper 1, and two high-speed video camera 11, located with the possibility of registration of deformed drops 12 in perpendicular surfce in the output section of the nozzle 7.

For rgistration of original spherical drop 10 the digital video camera “the Panasonic HDC – SD60” was used, and for the registration of deformed drops 12 two high-speed cameras “Citius C 100” were also used. Video recording was performed with a spatial resolution of 384×790 pixels with a rate of 300 frames per second and exposure time (0.5÷2.0)MS. To control the distance made by the droplet, a scale with divisions of 1 mm was used. To measure the volumetric air flow a turbine flowmeter, calibrated with drum gasostatic GSB – 400 class was used, 1 [7] (measurement error rate of no more than 1%).

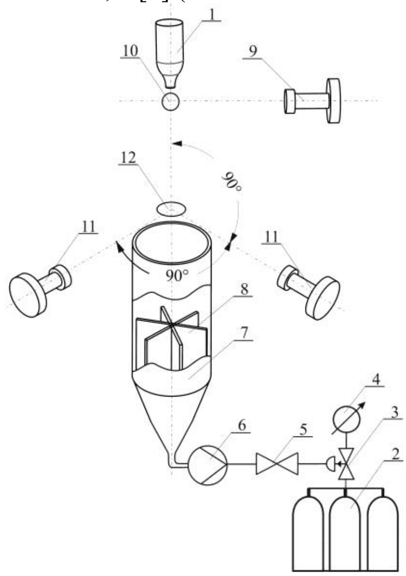

Fig. 1. The scheme of the test installation for studying the deformation of drops by aerodynamic forces.

The installation works like this. By means of gear 3 a predetermined volumetric flow rate of air Q is set, measured by the flowmeter 6. Using dropper with capillary 1 the original spherical droplet of the working fluid is formed (water-glycerol solutions, silicone oil, castor oil, etc.). At the time when a drop 10 separates its shape and diameter is determined by the processing of the video shoots, obtained by camera 9.

After separation of the original drop 10 from the capillary its gravitational sedimentation under the action of gravity happens. The counter equal flow of air from the nozzle 7 affects the drop, under which the drop is deformed. The size and the speed of the deformed drop 12 is recorded by two high speed video cameras 11, situated near the outlet section of the nozzle 7. The speed of movement of the drop is determined by frame-by-frame video processing.

Thus, this installation provides improved accuracy measurement of the degree of deformation of the drop and parameters that is included in the Weber number due to providing the well-controlled conditions of blowing the original spherical drop with a significant simplification of the experimental equipment of the installation and the alignment of the measuring apparatus.

3 Experimental study of the drop deformation in an air flow

Let`s consider the deformation of drops of glycerin in an air flow in conditions of indoor temperature. Let`s carry out the calculations of the parameters of the installation.

The diameter of the capillary is determined from the relation [8]:

$$d_c \le \frac{1}{6}\sqrt{\frac{\sigma \cdot \mathrm{Bo}_{cr}^3}{\rho_p \cdot g}}, \tag{1}$$

where σ is a surface tension coefficient of the liquid; Bo_{cr} the critical value of Bond number; ρ_p is the fluid density; g is the gravitational acceleration.

The maximum value of the diameter of the initial drop is determined from the relation:

$$D_0 \le \sqrt{\frac{\sigma \cdot \mathrm{Bo}_{cr}}{\rho_p \cdot g}}. \tag{2}$$

The diameter of the nozzle is calculated from the relation:

$$d_n \ge 5D_0. \tag{3}$$

The length of the pipe is determined from the relation:

$$l_n \ge 10 d_n. \tag{4}$$

The number of Weber is the main criterion for determining the deformation of the drop in the gas flow [1]:

$$\mathrm{We} = \frac{\rho_g u^2 D_0}{\sigma}, \tag{5}$$

where ρ_g is the air density; u is the speed of the blowing of drops.

The rate of the blowing of drops is calculated by the formula:

$$u = u_p + u_g, \tag{6}$$

where u_p the speed of the drop in the outlet section of the nozzle, determined by a specific frame-by-frame processing of results of high-speed photography; u_g is speed of air flow in the outlet section of the nozzle.

The speed of air flow in the outlet section of the nozzle is calculated by the formula

$$u_g = \frac{4Q}{\pi d_n^2} = \frac{Q}{S_n}, \tag{7}$$

where Q is the volumetric consumption of air; S_n is the square of the sectional area of the pipe.

The Reynolds number is calculated by the formula

$$\mathrm{Re} = \frac{\rho_g u D_0}{\mu_g}, \tag{8}$$

where μ_g - is the dynamic viscosity of the air.

The Bond number is calculated by the formula:

$$\mathrm{Bo} = \frac{\rho_p D_0^2 g}{\sigma}. \tag{9}$$

The value of the degree of deformation is determined by the formula:

$$\varepsilon = \frac{D_m}{D_0}, \tag{10}$$

where Dm - is the diameter Miteleva cross-section of the deformed drop, which defined by the formula:

$$D_m = \frac{D_{m1} + D_{m2}}{2}, \tag{11}$$

where, D_{m1}, D_{m2} - are the diameters of Miteleva section of the drop, measured by the results of high-speed video shooting in two perpendicular surfaces.

Calculations, required for physical characteristics of air and glycerol at a temperature of 20 ° C, required for calculations, are shown in table 1.

Table 1. The physical properties of air and glycerol.

Parameter	**Air**	**Glycerol**
ρ, kg/m^3	1.205	1260
μ, Pa·s	$1.808 \cdot 10^{-5}$	–
σ, N/m	–	$63 \cdot 10^{-3}$

Parameters of a installation are shown in table 2.

Table 2. Parameters of a installation.

***D₀*, mm**	***d_c*, mm**	***d_n*, mm**	***l_n*, mm**
4.24	2.5	24	240

A series of experiments for different values of air flow consumption in the range Q=(1.11 to 2.78) dm^3/s is carried out and shown on a installation. The results of measurements and calculations are shown in table 3.

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Table 3. Conditions and results of the experiment (Bo = 3).

Q, dm^3/s	u_p, m/s	u_g, m/s	u, m/s	We	ε	Re
0	2.98	0	2.98	0.66	1.01	777
1.11	2.76	2.46	5.22	2.03	1.07	1360
1.67	2.68	3.69	6.37	3.02	1.08	1657
2.22	2.44	4.91	7.35	4.02	1.15	1915
2.78	1.87	6.15	8.02	4.79	1.43	2087

Video shoots of deformed drops are shown in Fig. 2 for different values of Weber numbers.

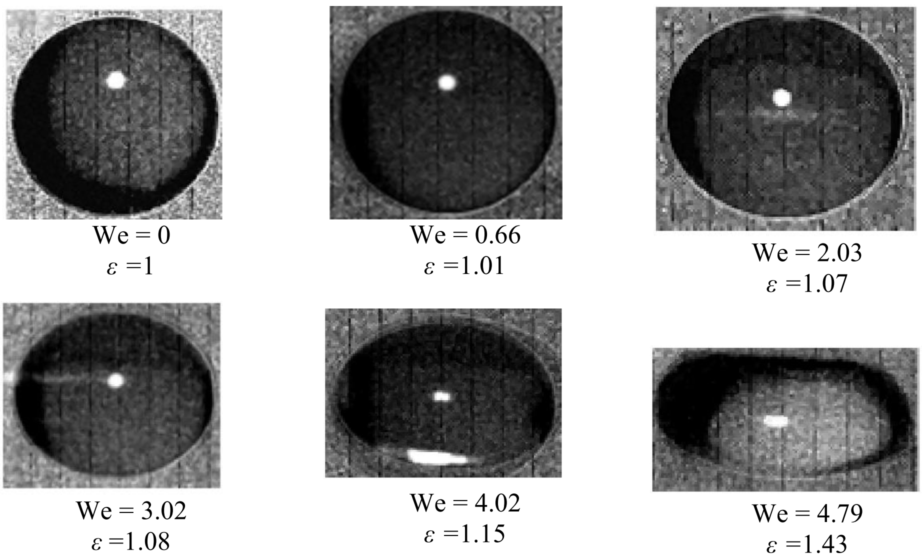

Fig. 2 Video shoots of deformed drops for different values of Weber numbers.

Experimentally obtained dependence of deformation degree of drops on Weber number (We) is shown in Fig. 3. From the above graph it follows that with increasing speed a blowing flow (or Weber number) the degree of deformation of drops monotonically increases.

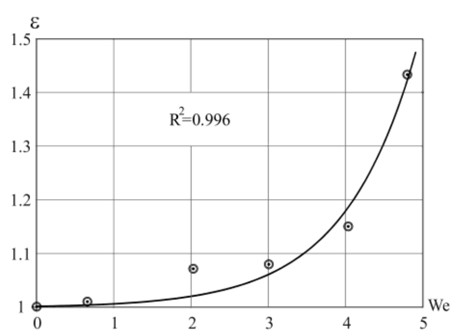

Fig. 3. The dependence of the degree of drop deformation of the number of Weber.

Approximation of the experimental data allowed to obtain the analytical formula (the coefficient of determination R2 =0.996):

$$\varepsilon = 1 + 2.5 \cdot 10^{-3} \cdot \exp(1.07 \cdot \mathrm{We})\,. \qquad (12)$$

4 Conclusion

- A modified scheme of installation for studying the deformation of drops by aerodynamic forces was presented.
- Video shoots of deformed drops for different values of Weber numbers were obtained.
- It was determined that by increasing the speed of a blowing flow (or Weber number) the degree of drop deformation monotonically increases.
- On the approximation of the experimental data, an analytical formula for calculating of the degree of drop deformation was obtained.

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