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Interaction of Water Droplets in Air Flow at Different Degrees of Flow Turbulence

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Abstract—Presented are results of experiments on high-speed video recording of collisions of water droplets in a gas medium as part of aerosol. Parameters of the gas (air) flow and aerosol cloud were monitored using cross-correlation complexes and optical methods of Particle Image Velocimetry, Particle Tracking Velocimetry, Interferometric Particle Imagine, and Shadow Photography. Conditions at different degrees of gas flow turbulence were considered. The characteristic Reynolds numbers ranged from 1100 to 2800. The relative probabilities of coagulation, scattering, and fragmentation of water droplets upon their collisions were calculated. Experimental dependences of probabilistic criteria on parameters of droplets and flow have been obtained for subsequent mathematical modeling. It has been shown that fragmentation and complete breakup of droplets can enable several-fold increase in the relative area of the liquid. The effect of the degree of gas flow turbulence on parameters of recorded processes of interaction of droplets has been established. The results of the experiments were subjected to criterion processing, the Weber and Reynolds numbers taken into account.

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INTRODUCTION

Development of any scientific direction occurs in the form of periodic pulses of intensity in certain time intervals of progress in engineering and technology. This is due to the fact that each subsequent generation of researchers has more advanced equipment (with increased registration speed, resolution, and accuracy) for experimental research, as well as specialized software systems for numerical modeling (with parallelization of computations and high server performance). As a result, ideas about certain physical processes, effects, and phenomena are clarified. A similar conclusion can be made in the field of mechanics of multiphase and multicomponent media [1–11]. Every year, not only new knowledge about some local effects appears, but quite often hypotheses are put forward for development of early general ideas about a complex of processes and complicated systems.

Many effects in interaction of droplets in a gaseous medium are considered difficult to control and, as a result, unpredictable. These include rebound (i.e., approach, interaction through the gas envelope, and separation, integrity maintained), coagulation (coalescence), scattering (penetration), and fragmentation (breakup or reduction) of liquid droplets in gas, vapor-droplet, and vapor flows. It is reasonable to develop models for reliable prediction of characteristics of these processes. This will advance the concepts of the classical theory of collisions (flocculation) and coalescence (coagulation) of droplets [9–11], which rely on the well-known works by B.V. Deryagin, L.D. Landau, E. Verwey, and J.T. Overbeek. Conduction of relevant experimental studies will enable clarification of the known empirical and theoretical expressions from works by A.G. Girin, V.A. Arkhipov, V.P. Bushlanov, I.M. Vasenin, F. G. Gaponich, A. M. Podvysotskii, V.M. Trofimov, A.A. Shreiber, B.N. Maslov, K.Yu. Aref'eva, A.V. Voronetskii, etc., which are mainly based on an integral parameter of the mathematical expectation of the ratio of the target droplet mass change upon its collision with projectile droplets to the total mass of the latter, and generalization via criterion expressions using the Reynolds, Weber, and Laplace numbers [12–20]. It will also be possible to obtain dependences of characteristics of heat and mass transfer of target and projectile

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droplets in gaseous, multicomponent, and multiphase media. It is important to analyze the possibility of applying the modern mathematical theory of kinetics of coagulation and breakup to describing these processes in multicomponent and multiphase media (with different densities and velocities). Of particular interest are such processes when studying collisions of binary and multicomponent droplets, which are accompanied by different modes of dispersion, rebound, coagulation, and fragmentation, non-simultaneous evaporation of components, and other interrelated processes, the effect of which taken together has not been described mathematically so far.

The available results of experiments on collision of liquid droplets in gaseous media (for example, [17–20]) are not enough to describe the consequences of droplet interaction in flows with different degrees of turbulence. Such effects have not been analyzed because of the lack of reliable experimental data. This problem is extremely relevant since most gas-vapor-droplet applications involve flow turbulization for intensification of the heat and mass transfer processes [21–32]. Estimates are needed of how this process affects the consequences of interaction of colliding liquid droplets. Analysis of survey and specialized articles of recent years (for example, works [33–43] reflect the main results of experiments by M.E. Orme, K.D. Willis, C.E. Abbott, T.B. Low, J.W. Telford, D.N. Montgomery, J.R. Adam, K.V. Beard, S.G. Bradley, N. Ashgriz, G. Brenn, Y.J. Jiang, W. Rommel, K.G. Krishan, H. Zhang, S.K. Pawar, and others) shows that the factor of flow turbulization has not been studied in terms of intensification of rebounds, coagulation, scattering, or breakup. In the first approximation, it is enough to select frames with aerosol droplet collisions since it is extremely difficult and most likely impossible to create a stand to study the conditions and characteristics of collisions of two droplets in turbulent gas flows.

The purpose of this work is experimental study of conditions, patterns, and characteristics of the processes of rebound, coagulation, scattering, and fragmentation of water droplets when they collide in air flow when caused versus different degrees of turbulence of the latter.

EXPERIMENTAL STAND AND RESEARCH METHODS

The experimental studies were planned with focus on reproducing the conditions of mixing of gas and droplet flows at different velocities (of 0 to 10 m/s) for the research results to be used in a wide range

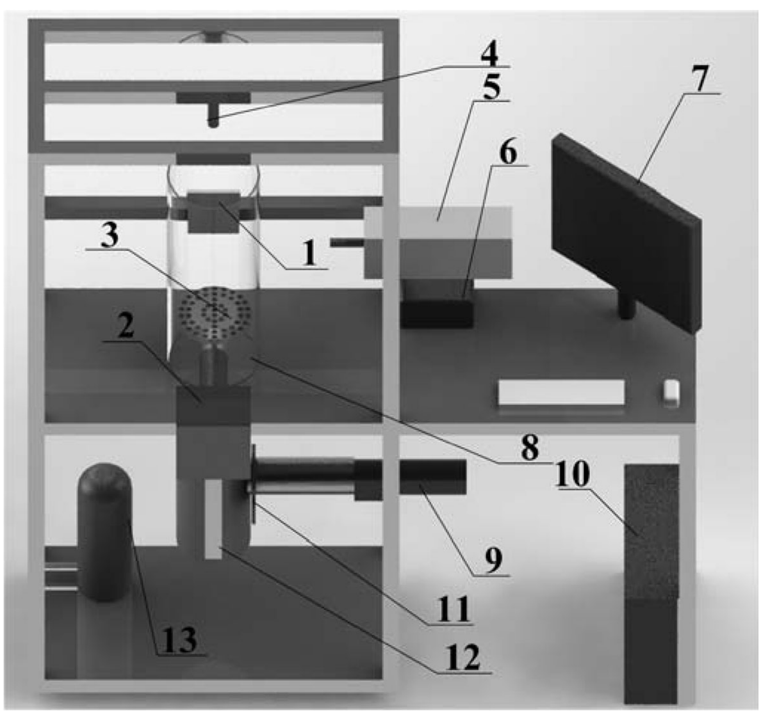


Fig. 1. Scheme of experimental stand: 1—projector; 2—high-speed video camera; 3—turbulizer; 4—spray; 5—laser radiation unit; 6—synchronizer; 7—data output device; 8—quartz glass cylinder; 9—air blower; 10—personal computer; 11—gate; 12—air duct; 13—water tank.

of applications: from heat and mass transfer systems and contact chambers for thermal purification of liquids to fuel technology. Therefore, it was reasonable to use several systems for spraying of liquid at an angle of 0, $\pi/4$, and $\pi/2$ to one another. The position of channel for air flow injection varied similarly. In contrast to experiments [19, 20], the temperature of gaseous medium was about 20°C. Figure 1 shows the scheme of the experimental stand with aerosol generators and air flow. The stand was designed with due account of previously used stands and devices presented in a large group of articles by researchers who worked on this problem in different years and at various scientific centers, see, for example, [12–32]. The specific conditions of experiments [12–32] and their possible effect on the planned ones were taken into account.

The parameters of the experiments and means of recording are as follows: sizes (radii) $R_d = 0.1$–1 mm (the methods of Interferometric Particle Imagine (IPI) [44–47] and Shadow Photography (SP) [48, 49]), phase velocities $U_d = 0$–10 m/s (the methods of Particle Image Velocimetry (PIV) [50–52] and Particle Tracking Velocimetry (PTV) [53]), relative concentration of $\gamma_d = 0.001$–0.002 m^3 of liquid droplets in 1 m^3 of gas (the Shadow Photography (SP) method); linear air velocity $U_g = 0$–10 m/s (the Particle Image Velocimetry (PIV) method); the degree of flow turbulence varied due to the use of two types of turbulizers and controlled change in the velocity of the inlet air. The typical Reynolds numbers of the channel (its inner radius of 0.05 m taken into account) and droplets were $\mathrm{Re}_c = 2U_d R_c/\nu_a$ and $\mathrm{Re}_d = 2U_d R_d/\nu_a$, respectively.

In the experiments, it was important to combine several optical techniques for recording parameters of gas flow and droplets in an aerosol cloud, which rely on the Actual Flow software. To this end, a specialized cross-correlation complex was used, typical results (fields and histograms of recorded parameters) of operation of which are shown in Fig. 2.

PIV is a well-known and widely used optical method for measuring instantaneous velocity fields of liquid and gas in a selected cross section of flow. A pulsed laser creates a thin light knife and illuminates small (tracer) particles suspended in the flow to study. In experiments, the tracers were titanium dioxide nanopowder particles with a size of about 100 nm and relative volume concentration in gas of about 0.1%. The positions of particles at the moments of two successive laser flashes are recorded in two frames of digital camera. The flow velocity is determined from calculation of particle displacement between the laser flashes. The registration of characteristics of the particle movement involves application of correlation methods to tracer pictures, as well as regular splitting into elementary areas. When recording the velocity and mode of gas flow prior to injection of droplet aerosol, particles of titanium dioxide were introduced into the flow. The velocities U_g (Fig. 2a) were calculated from the speed of their movement.

Upon aerosol injection, the tracers were liquid droplets. The velocities U_d were recorded by the velocities of the tracers. Special markers ensured implementation of algorithms for processing of videograms by the PTV method to record the velocity of each droplet. In contrast to the PIV method, in the PTV one, the velocity vector is measured from displacements of individual tracers in the flow (Fig. 2b). The measured vector field has a resolution higher than in the PIV method, and the vector mesh is irregular, with nodes at the points of tracer positions. The PTV method enables reliable control of the velocities and trajectories of various marked elements of multiphase and multicomponent media, as well as recording the velocities and trajectories of liquid fragments at collisions of droplets. The errors in determining the values of the velocities U_d and U_g were 2.3% and 1.9%, respectively.

The droplet sizes (radii) R_d were recorded using the IPI and SP methods. The IPI method is designed to register instantaneous distributions of the diameters of droplets, bubbles, and spherical particles and droplets in a plane cross section of gas flow (Fig. 2c). The spherical drop size was calculated from the interference pattern observed in the defocused image when illuminated with a laser knife. Because different droplet forms (other than spheres: ellipsoids, pancakes, and parachutes) were recorded during movement and collisions, it was reasonable to use the SP method, which allows one to record the size and number of liquid droplets in gas flows. A specialized light source created the shadow of object under research. The errors in the determination of the droplet size R_d by the IPI and SP methods were 1.8% and 2.6%, respectively. The application of frame processing algorithms using the SP method enabled determination of the relative droplet concentration γ_d.

It should be noted that unlike earlier experiments [19, 20], high-speed (up to 10^5 frames per second) video cameras were used as part of cross-correlation software and hardware complexes. This

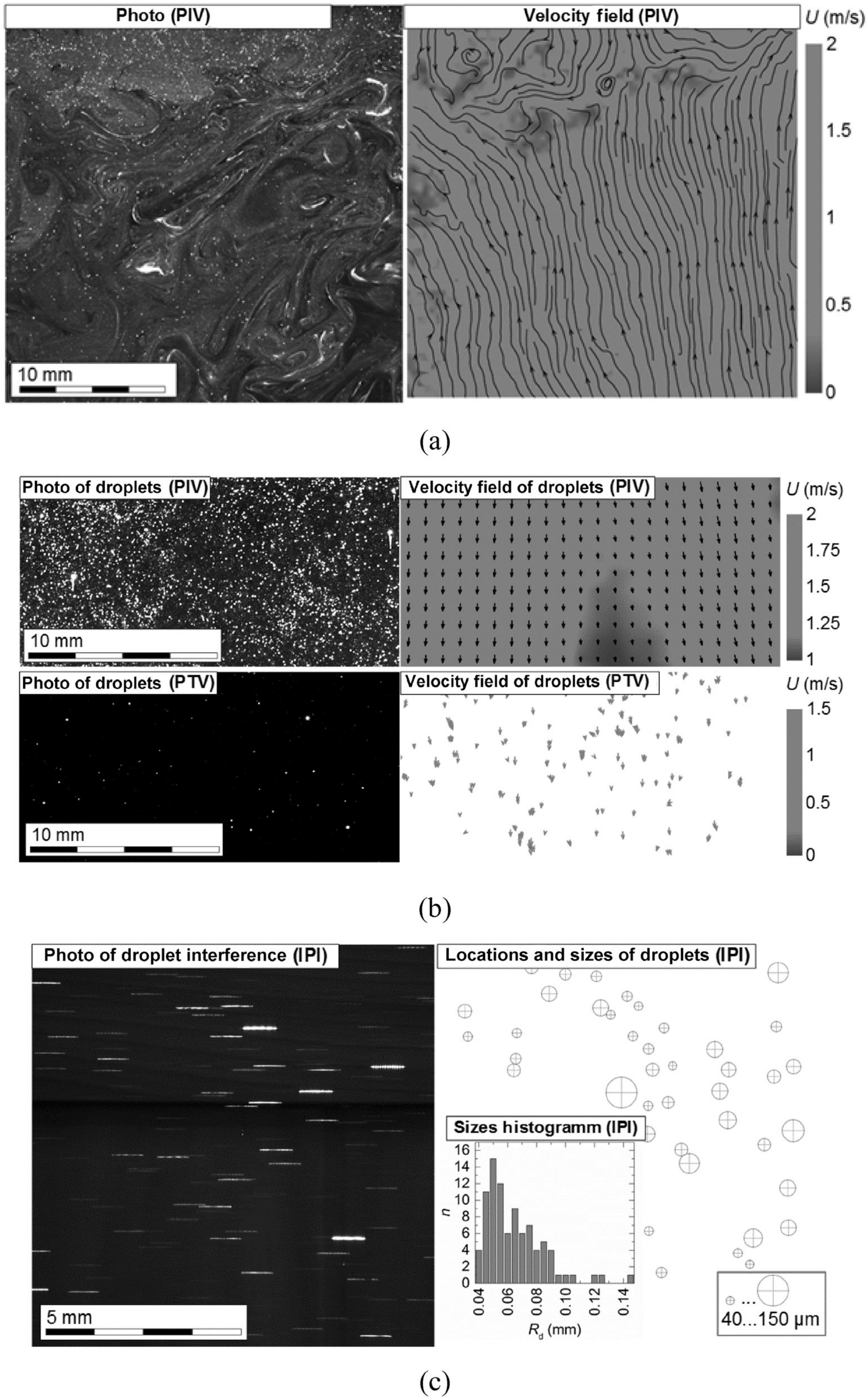
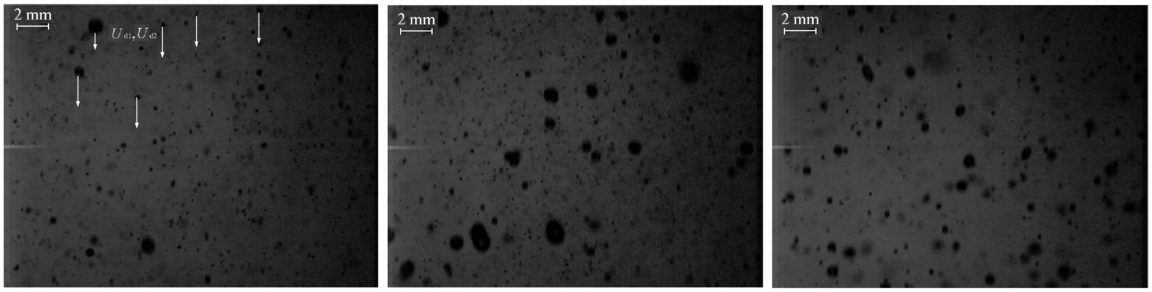


Fig. 2. Typical velocity fields for (a) gases and (b) droplets, as well as (c) histograms of dimensions for laminar and turbulent gas flows studied.



(a) (b) (c)

Fig. 3. Typical videogram frames with collisions of water droplets in gaseous medium in laminar and turbulent modes of gas flow: (a) Re $\approx$ 1100, (b) Re $\approx$ 2400, (c) Re $\approx$ 2800.

is because of the need to register not only the above parameters of droplet aerosol and gas flow but also characteristics of the processes of collision of droplets. In this case, videograms recorded by high-speed cameras were processed in two stages, using the Mathematica and Tema Automotive software packages. At the first stage, Mathematica filtered and selected frames with droplets moving toward one another. At the second stage, Tema Automotive performed automatic processing of frame data in the mode of tracking of a marked pair of approaching droplets (Fig. 3). That yielded more exact data on the velocities and sizes of colliding droplets (in each pair), as well as the number n_d, sizes R_d, and total surface areas (S_d) of forming droplets. That in turn enabled comparison with the initial S_{d0} value, corresponding to the sum of the surface areas of two interacting liquid droplets. For example, during coagulation, the tracking was carried out for one drop that formed during a collision; during scattering, the sizes of two droplets formed were recorded; during breakup of colliding parent droplets, the number and total free surface area of all liquid fragments were calculated. Such procedures are not possible with the optical methods described above. Therefore, it was necessary to separate these experiments. In addition, implementation of optical methods is linked with limitation in the frequency of laser flashes as per settings of cameras, laser, and synchronizer. The equipment used enabled a frequency of such frame pairs of 10 to 12 at most and thus recording the average velocities U_d and U_g and droplet sizes R_d.

Unlike the well-known approaches based on recording characteristics of interaction of two droplets, when, as a rule, one droplet is forcibly directed toward the other, the first called the projectile, and the other the target [18], in this paper we studied the interaction of water droplets as part of aerosol. This made it possible to take into account a group of factors corresponding to real aerosol clouds in gas-vapor-droplet applications. In this case, the registration of the characteristics of collisions of droplets is performed in the form of statistical analysis. Similarly to algorithms [19, 20], the numbers of collisions of droplets with coagulation, scattering, and breakup were calculated, and then dividing them by the total number of registered and processed collisions gave the probabilities of the three main outcomes: P_1, P_2, and P_3. For analysis of factors affecting the droplet interaction characteristics, the dependences of P_1, P_2, and P_3 on the droplet size R_d, velocity U_d, angles α_d, and thus the Weber number of the projectile droplet We_1 and of the target droplet We_2 were recorded. Their values between the motion trajectories in a pair varied in the wide range of 0 to 90° due to the use of different schemes of aerosol injection and air injection. In the general form, the expression $\mathrm{We} = 2\rho R_d|U_d|^2/\sigma$ was used. The droplet velocities were subtracted in the case of their co-directional movement and summed in the case of counter movement; in the case of side collision, the calculations were performed for the velocity of either the projectile or target.

RESULTS AND DISCUSSION

Figure 4 shows the calculated values of the relative probabilities of coagulation, scattering, and breakup of interacting water droplets at medium (for the investigated range of Reynolds numbers) parameters of gas (air) flow turbulence ($\mathrm{Re}_c \approx 2400$). Similarly to the techniques in [18–20], the typical Laplace ($\gg 1$) and Stokes ($\ll 1$) numbers have been estimated for illustration of the fact that in the experiments performed the main attention should be paid to the ratio of inertia forces and the surface tension of the liquid (the role of viscosity and dispersed phase is small). Therefore, the criterion processing of the results of the experiments can be carried out using the We parameter for both interacting droplets, other typical criteria omitted. For example, articles [33–43] present maps of interaction modes for liquid droplets with consideration of traditional criteria: the Ohnesorger, Laplace, Weber, and Reynolds numbers. Most likely, it is important to focus on the characteristics (sizes, velocities, and trajectories) of both colliding drops, i.e., the target and projectile. For clarity, Fig. 4 shows the respective dependences for both types of interacting droplets. It is important to have large statistics (at least 50 collisions) with identical consequences (in articles [33–43] they are called interaction modes: rebound, coagulation, scattering, and breakup) under the same conditions in order to form conclusions on the reliability and reproducibility of the results. In these experiments, such tasks were performed with focus on different conditions for injection of aerosols and air inlet, which ensured a large number of collisions of droplets with varying interaction parameters.

Analysis of Fig. 4 demonstrates generally satisfactory correlation of the results with the data of experiments with two droplets [18] and registration of collisions of the latter as part of aerosol [19, 20]. Good correlation has been achieved both in the Weber number ranges in which coagulation, breakup, and scattering conditions dominate and in the sequence of transitions between these variants of consequences (modes) of interaction of droplets. However, analysis of the transitional values of the Weber numbers (0–1.5: rebound, 1.5–15: coagulation, 15–50: scattering, 50–100: scattering and

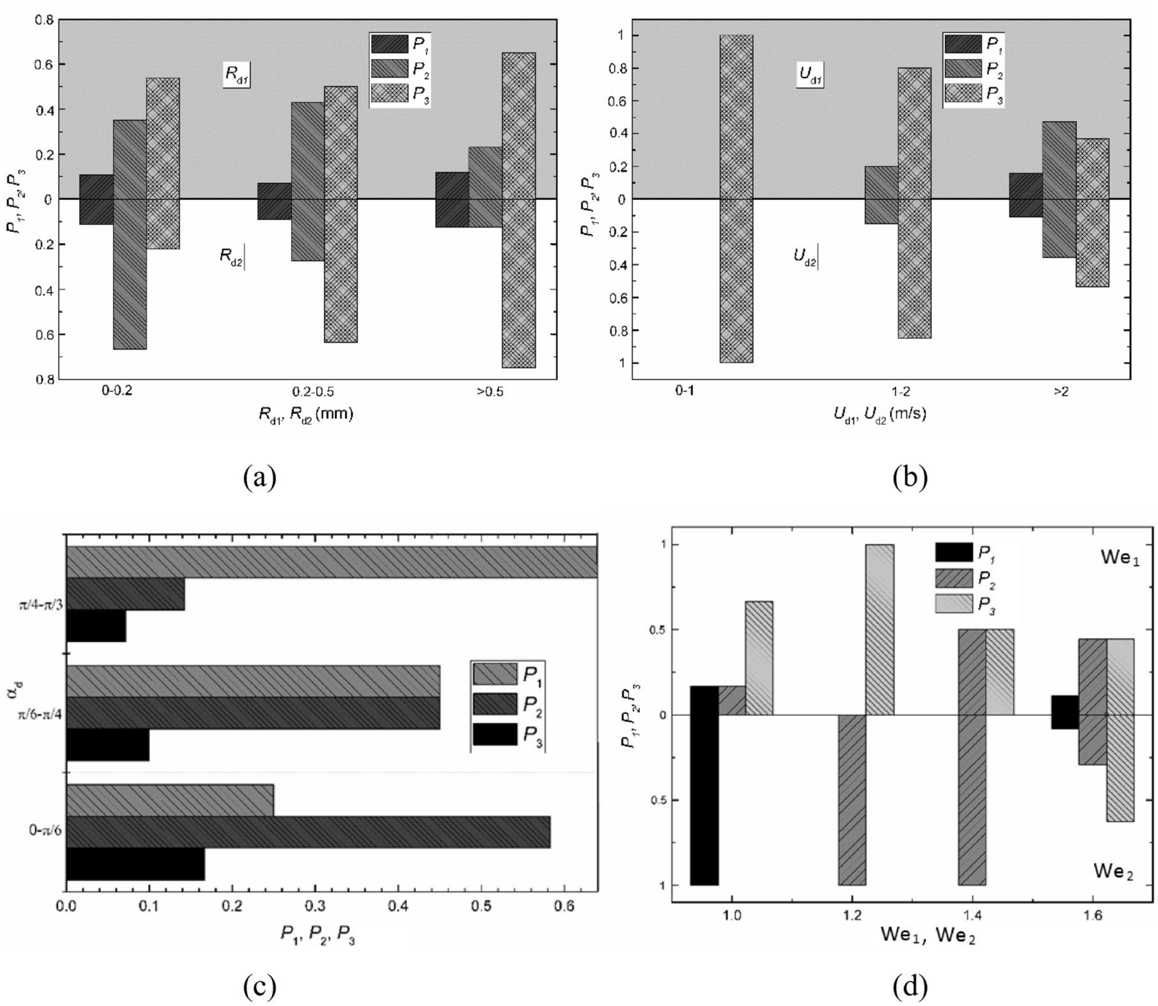


Fig. 4. Effect of main factors on probability of consequences of droplet collisions in gaseous media (sizes, velocities, and angles of attack for targets and projectiles) at $Re_c \approx 2400$: (a) sizes; (b) velocities; (c) angles of attack; (d) Weber numbers.

breakup, above 100: breakup in the explosive decay mode with formation of cloud of small liquid fragments), for example, from coagulation to scattering or from scattering to breakup, shows that the experiments yielded values that differ by 25–35% from the data in [18–20]. In idealized conditions of experiments with two droplets [18], slightly smaller values of ultimate Weber numbers were established; in fact, one drop struck the other. Experiments with mixing of aerosol and combustion products [19, 20] resulted in a rather large amount of statistics (samples from at least 50 collisions under identical conditions were considered). However, results of experiments in [18] and [19, 20] were not divided with respect to the angles of attack. In real conditions, the angle of interaction and the droplet surface configuration affect the consequences of collisions (in particular, Fig. 4 shows fundamental differences in the P_1, P_2, and P_3 values for the angle of interaction varying from 0 to $\pi/2$).

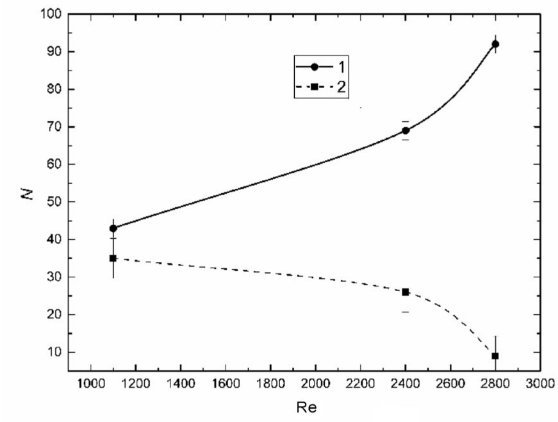
If one compares the effect of the sizes, velocities, and angles of attack on the droplet interaction modes, the influence of the velocities is the largest (this conclusion agrees well with the results of numerous experiments performed over the past 50 years, summarized in [33–43]). This trend is especially noticeable with velocities varying from 3–4 to 7–8 m/s. Up to 3 m/s, the effect is rather weak, whereas above 8 m/s, almost all collisions lead to breakup of droplets (the We values exceed 100).

Analysis of frames of videograms showed that under intense turbulence of gas flow ($\mathrm{Re}_c > 2500$), interaction of two droplets was accompanied by their substantial rotation around the center of mass. This leads to frequent collisions of rotating droplets in the mode of tangential interactions. As a result, scattering of droplets with partial fragmentation of colliding liquid fragments was observed quite often, i.e., in contrast to the traditional concept of scattering [13–18], there appeared not two drops with sizes corresponding to the initial sizes of the parent drops, but 2 to 5–7 small fragments. At high velocities of linear movement and rotation of droplets, the sizes of flying off fragments increased, and, as a result, the scattering mode turned into breakup (several-fold reduction) of initial droplets. Under such conditions, the probability of coagulation and rebound of droplets is extremely small.

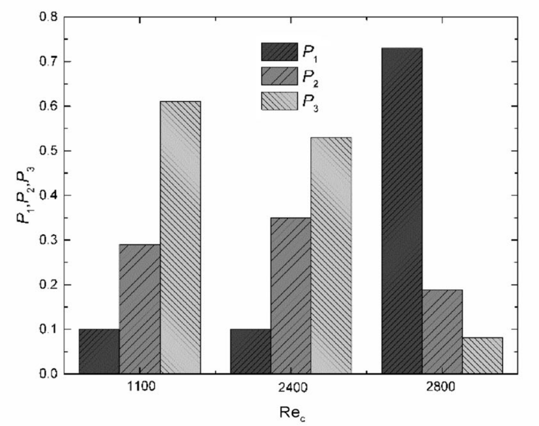
From Fig. 5, one can note that the dependences of the P_1, P_2, and P_3 values on the size R_d, velocities U_d, angles α_d, and We differ significantly for projectiles and targets. This result illustrates the importance of taking into account the parameters of both droplets in criterion processing and generalization of results of experiments. Traditionally, as in [13–18], they focus mainly on the parameters of the projectile droplet since it has the larger velocity and size; in addition, the main parameters in the system of interacting droplets are changed via variation in the projectile parameters.

The degree of turbulence of gas-droplet flow significantly affects the total number of interactions of droplets in the mode of collisions (coagulation, scattering, or breakup) and rebounds (Fig. 5a). This result seems quite obvious since liquid fragments rotate in different directions, and swirl patterns appear in the flow. Some droplets are caught by respective gas flows and get into so-called swirl holes. The trajectories of newly arriving droplets differ significantly from those of the first ones. As a consequence, the probability of their intersection increases significantly. One could assume that in such conditions almost all collisions will lead to breakup of the droplets. However, statistical analysis of the recorded results of droplet interactions yielded somewhat different dependences (Fig. 5). Their nature is contingent on the form of droplet collisions: head-on, side-wise, or co-directed. It can be concluded that the angle of attack is a decisive factor. Thus, even under conditions of intense turbulence of gas flow, arrangement of spraying devices can ensure stable coagulation. With co-directed injection of aerosols, almost every third to fourth collision led to coagulation, despite difference in parameters and turbulence of single flow. In the case of side-wise interaction of droplets, agreement with the results of experiments [18] with rotational and vibrational capillaries was observed (both in the physics of the processes and in the ranges of the Weber numbers). If one considers head-on collisions of droplets, the number of such interactions is significantly less at turbulization of gas flows because of their swirl.

One can use the obtained results to predict changes in the structure and composition of gas-vapor-droplet flows via implementation of droplet interaction processes (within wide ranges of the key parameters: $R_d = 0.1$–1 mm, $U_d = 0$–10 m/s, $\gamma_d = 0.001$–0.002 m^3 of droplets of liquid in 1 m^3 of gas, and $U_g = 0$–10 m/s). In particular, from the results of processing of videograms by optical methods, taking into account the established velocities and average sizes of droplets, one can predict the probabilities of collisions of droplets and thus the size and concentration of new droplets appearing during coagulation, scattering, or breakup (Figs. 6 and 7). With due account of the data of early experiments, in particular, [18–20], it is possible to supplement the prognostic apparatus with consideration of conditions of heating of droplets or gas flow, as well as dissimilar compositions of droplets.



(a)



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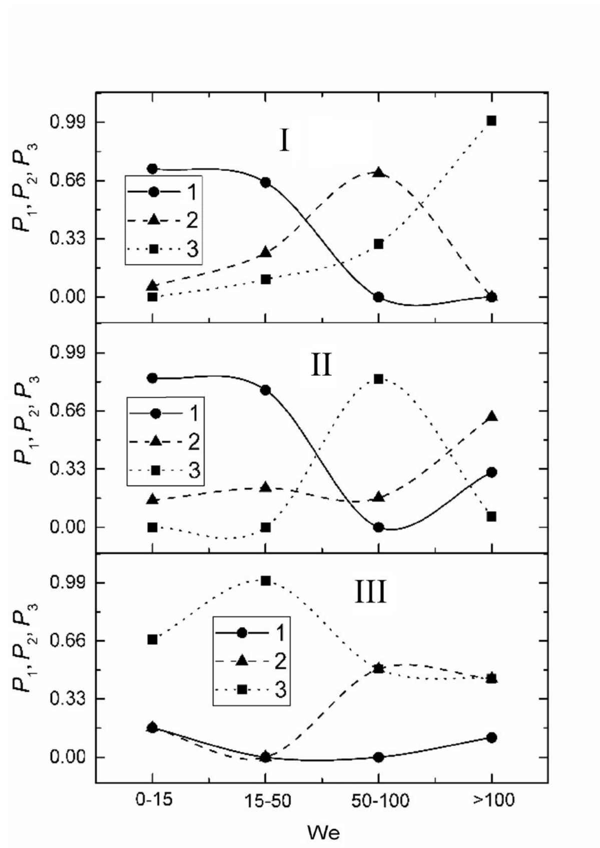

(c)

Fig. 5. Effect of gas flow turbulence degree (I—$Re_c \approx 1100$, II—$Re_c \approx 2400$, III—$Re_c \approx 2800$) on total number of (a) collisions (1) and rebounds (2), as well as on (b) and (c) relative probabilities of effects of interaction of droplets ($1—P_1, 2—P_2, 3—P_3$).

Figure 6 shows that when both the angular and linear relative interaction parameter is taken into account, the conventional boundaries of transitions between the studied modes (coagulation, scattering, and breakup) shift significantly. It is difficult to reveal any strict dependence of these effects on the range of the Reynolds number, which characterizes the laminar or turbulent regime. In general, it was noted that with intensification of gas flow turbulence, the number of collisions increased significantly and the

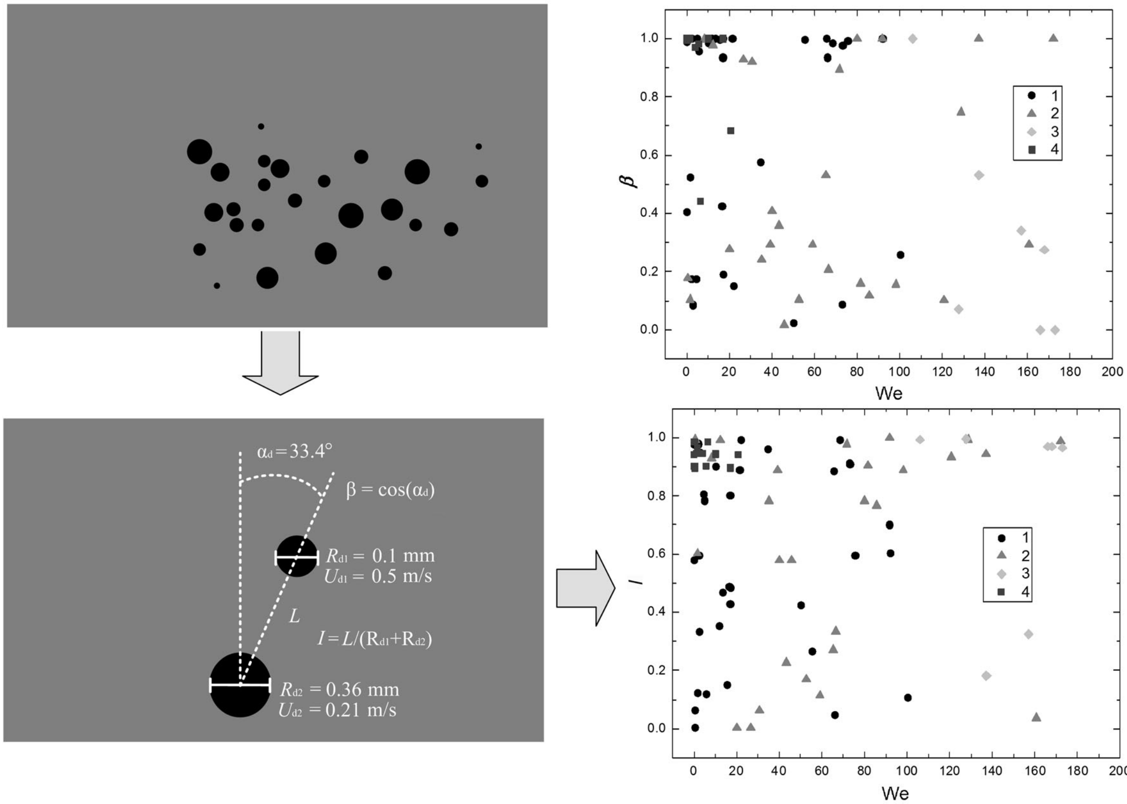

Fig. 6. Videograms and results of their processing (within modern approaches [33–43] based on mapping of droplet interaction modes in coordinate system including Weber numbers and linear and angular interaction parameters) with typical changes in structure and composition of gas-vapor-droplet flow upon droplet collisions (for $\mathrm{Re}_c = 1100–2800$): 1—coagulation; 2—scattering; 3—breakup; 4—rebound.

number of droplet rebounds decreased (Fig. 5). The maximum number of collisions in the coagulation and breakup modes corresponded to the medium range of We, Re_c and Re_d values.

If one draws parallels with reduction of inhomogeneous liquid droplets (suspensions, emulsions, solutions, and immiscible liquids) because of overheating to temperatures of intense vaporization of low-boiling component (for example, [54–57]), then a significant and especially several-fold increase in the liquid surface area in a gaseous medium due to droplet reduction can be provided only in a system with substantially inhomogeneous liquid compositions. In this case, the components of droplets must have considerably different boiling points and concentrations of components. For example, in [54–57] it was shown that for breakup of droplets containing water and oil or water and diesel it was necessary to heat non-uniform droplets to temperatures of 350 to 600 K. At maximum temperatures of convective, conductive, or radiative heating, it is possible to realize explosive (in a time less than 1 s) disintegration of a droplet with formation of a cloud of small fragments of liquid, and then the surface area of the liquid (S_d with respect to the initial value S_0) increases 30–120 times. Counter spraying of aerosols will not ensure such a significant growth of this parameter, but it can increase the respective surface areas of liquid 5–10 times, which is quite enough for a number of real technologies. Such approach to reduction is significantly less expensive than boiling-up of components of liquids, which was studied in [54–57].

The results obtained (Fig. 6) are in general in satisfactory agreement with experiments [33–43] on the effect of the velocity and size of colliding droplets (expressed in terms of the Weber number), as well as the interaction parameters I and β, which introduce the distance between droplets in comparison with the sum of their sizes (radii) and the angle of attack. The main difference is that in the present work, for the first time, the effect of Re_c on the relative probabilities of consequences of droplet collisions has been established for an incident flow.

Prediction of parameters of gas-vapor-droplet flows (Figs. 6 and 7) is of great interest speaking of increasing the efficiency of gas-vapor-droplet technologies since a required component composition

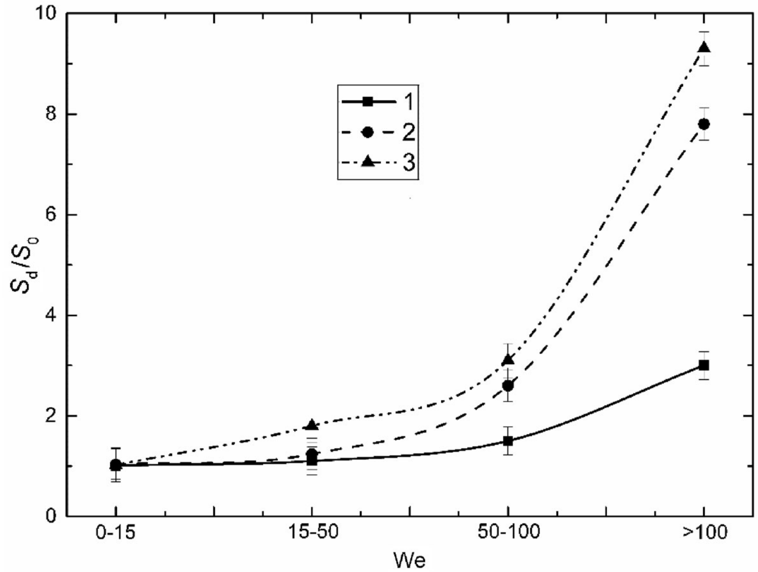

Fig. 7. Values of total surface area of liquid, calculated from results of droplet collisions at different degrees of flow turbulization: 1—$Re_c \approx 1100$, 2—$Re_c \approx 2400$, 3—$Re_c \approx 2800$.

of flows can be ensured (due to controlled coagulation, scattering, and breakup). The most promising applications [54–57] may be thermal and flame purification of water and other liquids from unregulated impurities; heat-transfer technologies of evaporation and condensation in heat-and-power paths and units; making heat carriers from smoke fumes, vapors, and water droplets; ignition of composite fuels without blocking of nozzles and extinction of flame in combustion chambers. For development of these applications it is important to proceed to experiments with multicomponent droplet aerosols and reproduction of conditions of intense phase transformations and chemical reaction.

CONCLUSIONS

1. The results of processing of experimental statistical data with characteristics of collisions of droplets as part of aerosol showed that among all the main factors studied (size, velocity, and trajectories of droplets, and angles of attack), velocities and angles of attack are most significant. The velocities can be introduced using two criterion expressions (the Weber and Reynolds numbers); description of the influence of the angle of interaction requires detailed study with due account of real configurations of droplet surfaces (papers [33–43] suggested typical calculation schemes, as shown in Fig. 6).

2. Increase in the degree of turbulence of gas flow intensifies the interaction of droplets, but these collisions do not always lead to breakup of droplets, i.e., significant fragmentation (Fig. 5 shows increase in collisions in the modes of coagulation, scattering, and breakup, as well as decrease in the number of registered rebounds). A detailed study of videograms showed that varying the location of spray devices, one could create conditions for intense coagulation and scattering.

3. The results of the experiments complement the current understanding of conditions and characteristics of interaction of water droplets in gaseous medium, which relies on experiments with registration of collisions of projectile and target droplets in idealized conditions [13–18] and registration of similar processes via selection of frames with mixing of droplet aerosols [19, 20]. In particular, possible variations in the probabilities P_1, P_2, and P_3 versus the Weber and Reynolds numbers have been shown for the first time. Using these values, one can predict the structure and composition of gas-vapor-droplet flows in promising heat-and-mass transfer and fuel aerosol applications.

NOTATIONS

I—relative linear parameter of interaction of droplets, $L/(R_{d1} + R_{d2})$

L—distance between droplets, mm

P_1—relative probability of droplet coagulation
P_2—relative probability of droplet scattering
P_3—relative probability of droplet breakup
R_{d1} and R_{d2}—radii of first and second droplets, mm
Re_c and Re_d—the Reynolds number for channel and fixed droplet
S_0—total area of droplets before interaction, m^2
S_d—total area of droplets arising after interaction of initial droplets, m^2
U_{d1} and U_{d2}—velocity of first and second droplets, m/s
U_g—air flow velocity, m/s
We_1 and We_2—the Weber numbers for first and second droplets
α_d—angle of attack
β—angle parameter of interaction of droplets, equal to $\cos(\alpha_d)$
η—relative share of combustible component in two-fluid droplet, %
ρ—density, kg/m^3
σ—surface tension, kg/s^2
γ_d—relative concentration, m^3 of liquid droplets in 1 m^3 of gas

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