Experimental Estimation of Characteristic Times of the Existence of Liquid Drops in the Form of a Sphere and Ellipse upon their Movement in a Gas Environment under the Conditions of Moderate Weber Numbers

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Abstract—The experimental procedure has been developed and studies using high-speed (10^5 frames per second) system of cross-correlation video registration of a change in the shape of drops for the most typical liquids that are widely used in various chemical technologies (water, kerosene, and ethyl alcohol) have been carried out. The liquids move with significantly subsonic speeds (up to 5 m/s) in the air environment under the influence of gravitational forces. The initial sizes of drops varied in the range of 3–6 mm. The cyclic nature of the changes in the shapes of drops during movement has been established. Characteristic times of transitions from one shape of drop to another have been measured. Characteristic times of the existence of drops in the form of spheres and ellipses have been defined. Recommendations about the use of geometrical models of liquid drops for theoretical study of heat and mass transfer and hydrodynamics in the course of their movement through gas environments under the conditions of moderate Weber numbers have been formulated.

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INTRODUCTION

For theoretical study of heat and mass transfer and hydrodynamics in systems with gas-drop and vapor-drop streams, a key question is the choice of geometrical models of liquid drops. The drop shape significantly influences the value of the force of resistance to its movement and, correspondingly, the characteristic times of the hydrodynamic, thermal, diffusive, and chemical processes that take place during the application of chemical technologies [1]. Approaches that assume the use of modeling approximations, i.e., spheres, ellipses, cylinders, pancakes, cones, and other configurations, to describe the drop movement are known (see, e.g., [2–9]). Discrepancies between the modeled shapes of drops and those that actually occur are frequently [6–9] accepted as (sometimes rather significant) differences when comparing the results of theoretical studies of heat and mass transfer and hydrodynamics using such approaches and experimental data. A determining influence of real shapes of drops, particles, and bubbles was also established for processes of their movement in liquids (see, e.g., [10–13]).

Experiments have shown [14–17] that liquid drops continuously change their shape as they move through gas environments. At the same time, the oscillatory nature of the changing forms of drops has been established [14–17], and has been observed during movement in liquid, e.g., in water [18]. It is difficult when solving interfaced tasks of heat and mass transfer and hydrodynamics to consider deformation processes that take place rapidly because of objective restrictions in the digitization of time and space parameters for all methods of numerical modeling and computer systems. Therefore, it seems to be expedient to obtain experimental data using one of the typical geometrical drop models, e.g., sphere or ellipse, and enter corrections in expressions for resistance coefficients (analogously to [7–9]) to account for real changes in the latter in the course of theoretical studies of the considered processes. It is possible to determine the values of these corrections when experimentally defining the characteristic times in which a given form of a drop is during movement, as well as time intervals between the periods of steady existence of specific configurations, i.e., transitions from one shape to another. At the same time, it is rational to carry out experiments with several of the most typical liquids that are widely used in various applications, e.g., water, kerosene, and ethyl alcohol [22–32]. The definition of characteristic times for which drops of the allocated liquids exist in the most probable forms according to the data [5–8] (sphere and ellipse) during
their movement through a typical gas environment (air) with significantly subsonic speeds (for performance of terms of moderate Weber numbers [5–8]) is of interest.

The purpose of the present work is to experimentally estimate characteristic times of the existence of drops of the most typical liquids in the form of spheres and ellipses during their movement in the gas environment under the conditions of moderate Weber numbers.

**EXPERIMENTAL**

For carrying out the studies, an experimental stand (Fig. 1) similar to that applied in [32–34] for studying of regularities of evaporation of set of water drops moving through high-temperature (more than 1000 K) gases was used. The recording cross-correlation equipment included a cross-correlation camera with a format of the image of $2048 \times 2048$ pixels, the minimum delay between two consecutive shots was less than 5 μs; a double-pulse solid-state laser was used with a wavelength of 532 nm, the energy of the impulse was not less than 70 mJ, the duration of the impulse was no more than 12 ns, and the frequency of repetitions was no more than 15 Hz; a synchronizing processor was used with a digitization of signals of no more than 10 ns. Unlike experiments [32–34], a high-speed (10⁶ frames per second) video camera was added to the registering equipment. The air was used at moderated (about 300 K) temperatures in the experiments carried out instead of high-temperature gases as the gas environment.

Sizes, dispersion, and initial speeds of drops of three studied liquids (water, kerosene, and ethyl alcohol) were regulated by a dosimeter (Fig. 1), and it was used during the experiments [32–34]. The main characteristics of the deformation of single-liquid drops were studied when passing in air a distance of 1 m. Initial (at the moment of separation) relative diameters of drops and the speed of their movement changed in the ranges of $d_0 = 3–6$ mm and $u_0 = 0–3$ m/s, respectively.

The choice of these initial sizes and speeds of drops that leave the dosimeter is based on the requirement to provide moderate Weber numbers for the experiments [5–8]. At the greatest possible density of air under the considered conditions $\rho_a \sim 1.5$ kg/m³ and coefficient of surface tensions of water, ethyl alcohol, and kerosene [35–37] of $\sigma_w = 0.0618$ kg/s², $\sigma_a = 0.0228$ kg/s², and $\sigma_k = 0.0289$ kg/s², the maximal Weber numbers in the experiments were equal to $Wem_w = \frac{d_m^2 \rho_a}{\sigma_w} \sim 52 \times 6 \times 10^{-3} \times 1.5/0.0618 \sim 3.64$, $Wem_a = \frac{d_m^2 \rho_a}{\sigma_a} \sim 9.86$, and $Wem_k = \frac{d_m^2 \rho_a}{\sigma_k} \sim 7.78$. Limiting Weber numbers for studied liquids according to [5–8] (i.e., Weber numbers that characterize the transition from preservation conditions of solidity of drops until they are crushed) should be equal to $Wel \sim 9–11$. As a result, it can be concluded that, in the experiments, the requirement to ensure moderate Weber numbers was satisfied ($We < Wel$).

It has been experimentally determined [14–17] that the processes of the movement of liquid drops in a gas environment are characterized by cyclic deformation. According to the conclusions [14–17], the term deformation cycle is a time interval in which, in the course of the movement, the drop consistently assumes a form close to identical twice (Fig. 2). In the experiments carried out to control the times in which drops exist in a given form and times required to transition from one form to another, when processing the results of the studies, the main characteristics of the registered deformation cycles were calculated, includ-