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Abstract

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PHYSICS

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ON THE INFLUENCE OF THE SHAPE OF REGULAR PERTURBATIONS OF THE SURFACE OF A LIQUID JET ON ITS BREAKUP INTO DROPS

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The breakup of thin laminar or slightly turbulent jets of a low-viscosity liquid into drops is caused by the static instability of a liquid cylinder subjected to the action of surface tension and to random or regular perturbations imposed on the surface of the liquid jet (ˆ1).

In the natural breakup of a liquid jet, the random character of the perturbations leads to its breakup with the formation of a discrete series of drops (ˆ2). In this case, in accordance with Rayleigh' s theory, the maximum number of drops is formed whose volume is close to the volume of a segment of the unperturbed jet of length $4.51\,d_{\mathrm{str}}$. The imposition of regular perturbations on the jet surface leads to its breakup into uniform drops (ˆ1).

During drop formation, along with the formation of the main drops, a large number of drops considerably smaller in size are formed at the constrictions of the jet (ˆ2). These microdrops, also called satellites or Plateau spheres, are the main source of losses of valuable products and of harmful emissions of aerosol particles into the atmosphere during granulation of ammonium nitrate fertilizers, spraying of liquids, and a number of other technological processes.

As a result of earlier investigations it was established that the breakup of a jet of molten ammonium nitrate into drops, when regular perturbations of a definite frequency are imposed by pressure pulses from an oscillating membrane, can proceed with the production of strictly uniform granules (drops) (ˆ3).

In the present work the conditions for regular breakup of liquid jets into uniform drops without the formation of satellites were investigated when the surface of the jets was perturbed by a regular variation in the velocity of liquid outflow from orifices. The regular variation in the velocity of liquid outflow was produced by propagation in it of pressure pulses from an oscillating membrane (ˆ3). Outflow orifices with diameters from 0.5 to 1.2 mm were used at a liquid head

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Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

from 0.08 to 1.2 m. The frequency of membrane oscillations was from 80 to 1200 Hz.

Water at 16° and molten ammonium nitrate at 174° were used as working liquids. In the investigations, the previously established limits of effective frequencies of membrane oscillation were used,

$$\nu = V/(3.5 \div 8)d_{\text{or}},$$

and the diameter of the drops obtained corresponded to the diameter calculated from equation (⌒4)

$$d = \sqrt[3]{3d_{\text{or}}^2\,\varepsilon V/2\nu},$$

where ν is the frequency of membrane oscillations; V is the velocity of outflow of the liquid jet; d_{or} is the diameter of the outflow orifice; ε is the coefficient of contraction of the jet; d is the diameter of the drops formed.

The outflow of liquid from openings in a thin wall and from glass nozzles was investigated. Observations were made visually with the aid of an ST-5 stroboscope; all especially interesting cases were photographed. In addition, the resulting drops of ammonium nitrate were crystallized on a rotating aluminum disk, after which their diameter and the presence of satellites were determined.

Fig. 1. Regular breakup of a horizontal liquid jet with the formation of satellites under symmetric surface disturbances. Pressure-pulse frequency 1285 Hz; head 1.22 m; orifice diameter $1 \cdot 10^{-3}$ m

Fig. 2. Regular breakup of a horizontal liquid jet without the formation of satellites under asymmetric surface disturbances. Pressure-pulse frequency 584 Hz; head 0.54 m; orifice diameter $1.2 \cdot 10^{-3}$ m

As a result of the investigations it was established that, in the regular breakup of liquid jets into drops using regular pressure pulses, uniform drops can be obtained both without satellites and with satellites.

At a specific power of the pressure-pulse radiator (an electrodynamic membrane radiator was used) of the order of 50 W per 1 m^2 of perforated surface, barely noticeable initial neckings form on the jet, which then narrow while symmetry is almost completely preserved. In this case, microdrops—satellites—form at the

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Fig. 3. Natural breakup of a liquid jet into drops. Head 0.54 m; orifice diameter $1 \cdot 10^{-3}$ m

Figure 3: Fig. 3. Natural breakup of a liquid jet into drops. Head 0.54 m; orifice diameter $1 \cdot 10^{-3}$ m

sites of the neckings (Fig. 1). The size of the satellites increases with increasing wavelength of the initial disturbances.

When the specific power of the pressure-pulse radiator is increased to a value of the order of 360 W per 1 m^2 of perforated surface, the configuration of the initial neckings changes. They acquire a clearly pronounced asymmetric shape relative to a plane perpendicular to the axis of the jet. At the moment of jet breakup, the drops have a pear-shaped form, with the sharp end directed toward the outflow orifice. After the jet breaks up into drops, within a time of the order of 1/500 s the pointed end is drawn into the drop by the force of the liquid' s surface tension. If the membrane emits regular acoustic oscillations without superposed noise, the jet breaks up into uniform drops without the formation of satellites (see Fig. 2).

The presence of noise (because of poor-quality fastening of the membrane or for other reasons) promotes the formation of satellites. Satellites are also formed almost regularly during the natural breakup of liquid jets into drops (Fig. 3).

In observing the motion of satellites formed during the regular breakup of jets into drops, three variants of their move-

In the first variant, the satellites formed at the necking points immediately moved away from the main drops at a speed of 0.5–1.5 m/sec, following approximately the same trajectory. In the second variant, the satellites that formed approach the main drops and are absorbed by them. No micro-splashing occurs. In the third variant, the satellites that form strike the main drop and, after the impact, do not coalesce with it but rebound from it, without changing their size.

Fig. 3. Natural breakup of a liquid jet into drops. Head 0.54 m; orifice diameter $1 \cdot 10^{-3}$ m

The removal of satellites from the main drops and their coalescence can be explained by electrical phenomena. When a drop and a satellite have unlike charges, they coalesce.

The absence of satellites for the indicated pear-shaped form of breakup of the liquid jet into drops can be explained by the proximity of the place where the satellite forms to the main drop, which strengthens the electrostatic interaction between the satellite and the drop and promotes their coalescence. In addition, with a pear-shaped drop the conditions for the formation of a satellite are generally made more difficult.

The formation of the pear-shaped drop at the moment of its detachment from the jet is due to the difference in the velocities of the liquid particles inside the jet, and then inside the drop, as a consequence of the periodic change in the velocity of liquid outflow from the orifice or nozzle.

This process is most easily controlled when regular disturbances are imposed on the surface of the jet by means of a periodic change in the pressure before the outflow orifice. By changing the law of the periodic variation of pressure, one can increase or decrease the pear-shaped character and thereby control the process of drop formation.

Regular breakup of a liquid jet into drops can be achieved by imposing disturbances on the liquid jet by other means, for example by torsional oscillations of an axisymmetric perforated surface. However, in this case as well, the number of satellites will be minimal when the drop has a pear-shaped form at the moment of its detachment, for the reasons indicated above.

The rebound of satellites after impact with the main drop can be explained by surface phenomena resulting from the presence of impurities in the liquids or from impurities entering from the surrounding atmosphere.

The use of the established regularities of the controlled breakup of a liquid jet into drops makes it possible to eliminate or sharply reduce losses of valuable products and aerosol emissions into the atmosphere in a number of industrial processes.

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