ATOMIZATION BY A ROTATING DISK OF LIQUIDS WHICH POORLY WET ITS SURFACE

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It is shown that when a rotating disk is used to atomize liquids which poorly wet its surface, it remains possible to atomize the liquid to uniform-sized drops, a feature characteristic of liquids which wet the disk surface well.

When a low-volatility liquid which wets the surface well is atomized by a rotating atomizer (for example, when mineral oil is atomized by a metal disk), a very thin film of liquid remains on the metal surface, and even at low liquid flow rates, the liquid forms a continuous film moving from the center to the circumference of the disk. This atomization condition has been studied fairly thoroughly, and a number of publications have been devoted to it (see, for example, [1-3]; a survey of a number of articles is given in the monographs [4, 5]). Much less attention has been paid to the case of the atomization by a rotating disk of liquids which poorly wet its surface [3, 6, 7].

Observations show that in this case, at low flow rates, the liquid (for example, water) forms a film whose shape is nearly that of a circle of radius R_f that does not reach the circumference of the disk, which has radius R ($R_f < R$). The liquid flows from the edge of the film toward the circumference of the disk in the form of one or more streams (Fig. 1 shows photographs obtained with a strobotachometer). As the liquid flow rate Q increases, the film radius R_f will increase and so will the number of streams. At the circumference of the disk the streams break up into drops. These drops are of different sizes, i.e., the atomization is polydisperse.* At some critical flow rate (Q_{cr}) the radius of the film becomes equal to the radius of the disk, $R_f = R$, i.e., the entire surface of the disk is wetted, and when $Q > Q_{cr}$, the wetting of the disk surface should no longer influence the atomization process: liquids, whether they wet the disk surface well or poorly, should be atomized equally if their physical properties (surface tension, viscosity, density, volatility) are identical.

It is of great practical importance to know whether the critical value Q_{cr} exceeds the flow-rate value Q_{tr} at which there is a transition from the first and second monodisperse atomization regimes to the third, polydisperse, regime. If $Q_{tr} > Q_{cr}$, then for the case of poor wetting of the disk by the liquid there is still a possibility of atomization of the liquid into drops of uniform size; if $Q_{tr} < Q_{cr}$, then for the given conditions only polydisperse atomization of the liquid is possible.

Thus, in order to estimate the quality of the atomization of a liquid which poorly wets the disk, we must have an estimate of the values of Q_{cr} which are characteristic of the boundary of the region $Q < Q_{cr}$, within the limits of which the wetting apparently has a substantial effect on the quality of the atomization.

To determine the film radius R_f and the values of Q_{cr} as functions of the parameters of the process, theoretical calculation methods have been proposed [6, 7]. In order to estimate the practical applicability of these methods, we conducted experiments on the atomization of two different liquids — water and a 7% solution of the surfactant OP-7 in water — by a smooth rotating disk. The densities of these two liquids were $\rho = 1.00$ g/cm^3 and $\rho = 1.03$ g/cm^3, respectively, the viscosity values were $\eta = 0.01$ and 0.022 g/cm·sec, the surface tension was $\sigma = 73$ and 37.6 g/sec^2, the boundary angle of wetting (contact angle) was $\Theta = 62°$ and 21° on a duralumin surface and 57° and 13° on a plastic surface.

*At very low flow rates Q it is possible to have monodisperse atomization even with poor wetting.

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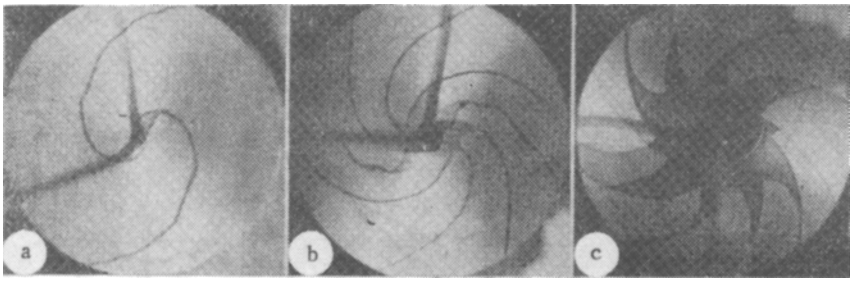

Fig. 1. Atomization of water by a duralumin disk with R = 3.5 cm (ω = 157 sec^{-1}, Θ = 62°): a) Q = 0.01 cm^3/sec; b) 0.1; c) 0.5 cm^3/sec.

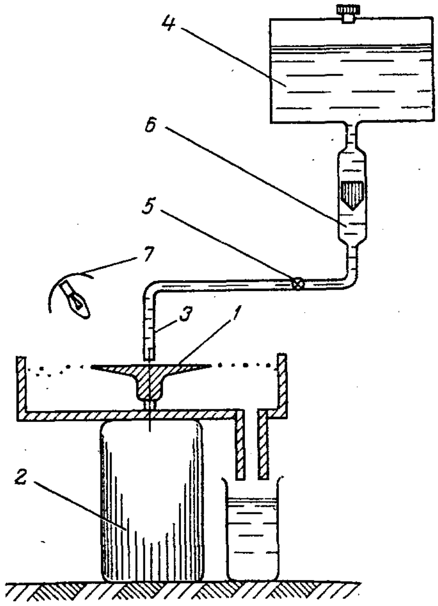

Fig. 2. Schematic of the experimental apparatus.

In the experiments, we used an apparatus shown schematically in Fig. 2. The disk 1 was brought into rotary motion by an electric motor 2. The liquid was fed to the center of the rotating disk from a nozzle 3 to which the liquid flowed by gravity from a tank 4 as a continuous stream; the flow rate of the liquid was regulated by a faucet 5 and measured by a rotameter 6. Visual observation of the motion of the liquid on the surface and circumference of the disk was carried out by means of a strobotachometer 7. Before each experiment the disk was dried and wiped with alcohol. We observed visually the onset of complete wetting of the disk (flow rate Q_{cr}), the beginning of the second monodisperse regime (the scattering of the liquid from the circumference of the disk in the form of liquid threads and their orderly disintegration into uniform-sized drops, flow rate Q_1), and the transition from the second monodisperse regime of atomization to the third, polydisperse, regime, in which the liquid film disintegrated beyond the circumference of the disk into drops of different sizes (see [2-5]; flow rate Q_{tr}).

The results of the experiments with water and with a 7% aqueous solution of OP-7 (measured values of Q_{cr}, Q_1, and Q_{tr}) are shown in Table 1.

A comparison of the experimental results with the results calculated according to [6] showed that in the investigated range of variation of parameters the calculated values of the critical liquid flow rate Q_{cr} for R_f = R were several orders of magnitude greater than the measured ones.

The results of calculations carried out by the method of [7], adapted to the case of a rotating disk [3], were found to be closer to the experimental data than those of calculations carried out according to [6]. According to [3], the critical liquid flow rate Q_{crt},

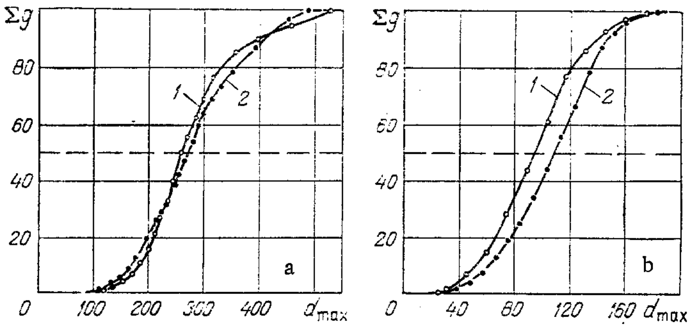

Fig. 3. Integral curves of the distribution of drop dimensions: a) $Q = 1.25$ cm³/sec, $\omega = 157$ sec⁻¹; b) $Q = 1.45$ cm³/sec; $\omega = 628$ sec⁻¹; 1) diesel fuel; 2) 7% aqueous solution of OP-7.

TABLE 1. Experimental and Calculated Results

Expt. No.	Liquid	Material of disk	Disk radius R, cm	Disk rotation rate ω, sec⁻¹	Liquid flow rate, cm³/sec					Q_{trt}/Q_{crt}	Q_{trt}/Q_{cr}	Q_{tr}/Q_{cr}
					Q_{cr}	Q_1	Q_{tr}	Q_{crt}	Q_{trt}			
1	Water	Duralumin	5,0	73	8,0	13,5	24,5	24,8	46,2	3,11	7,15	3,06
2	»	»	8,0	73	9,0	15,0	44,6	36,4	63,4	4,04	6,7	4,95
3	»	»	2,5	157	3,8	3,8	12,5	10,6	18,1	2,78	6,56	3,29
4	»	»	5,0	157	4,4	7,0	19,8	18,4	29,2	4,17	6,1	4,5
5	»	»	8,0	157	7,0	10,0	37,5	26,9	40,1	3,84	5,74	5,35
6	»	»	1,25	314	1,6	2,0	5,6	4,55	7,41	2,84	6,27	3,5
7	»	»	2,5	314	1,6	3,2	5,9	7,97	12,0	4,97	5,77	3,68
8	»	»	5,0	314	3,0	4,9	26,0	13,9	19,9	4,62	5,35	8,65
9	»	»	8,0	314	3,3	7,0	31,5	20,3	26,5	6,15	5,03	9,85
10	»	Plastic	5,0	73	8,0	13,0	28,5	22,5	46,2	2,81	7,9	3,56
11	»	»	»	157	2,5	3,7	24,0	16,7	29,2	6,69	6,72	9,6
12	»	»	»	314	1,9	2,0	18,5	12,6	19,3	6,62	5,9	9,75
13	Water	Duralumin	2,5	73	1,6	2,1	12,5	3,68	13,2	2,3	13,8	7,8
14	+ OP-7	»	5,0	73	3,25	3,25	17,55	5,51	21,3	1,69	14,9	5,4
15	»	»	1,25	314	0,5	1,1	3,7	1,01	3,42	2,02	13,0	7,4
16	»	»	2,5	314	0,6	0,7	4,5	1,77	5,44	2,95	11,8	7,5
17	»	»	5,0	314	1,85	1,85	8,5	3,08	8,88	1,67	11,1	4,59

corresponding to complete wetting of the disk by the liquid (film radius R_f is equal to the disk radius R), is determined by the formula

$$Q_{crt} = 10.7 \left\{ \frac{\eta R^4 \sigma^3 (1 - \cos \Theta)}{\omega^2 \rho^4} \right\}^{1/5}. \qquad (1)$$

The values of Q_{crt} calculated by this formula for the conditions existing in the experiments are shown in Table 1; the table also gives the ratios Q_{crt}/Q_{cr}. The calculated data exceeded the measured ones by a factor of 1.67–6.69, the average factor being 3.9. To take account of this difference, we can introduce a correction factor of 0.26 into the right side of formula (1).

According to [2], for liquids which completely wet a rotating cone (or disk) the transition from the second monodisperse regime of atomization to the third, polydisperse, regime is determined by the empirical formula

$$Q_{trt} = 2.12 \frac{\sigma^{0.885} R^{0.685}}{\rho^{0.72} \omega^{0.6} \eta^{0.165}}. \qquad (2)$$

The values of Q_{trt} calculated by this formula are given in Table 1; it also shows the the ratios Q_{trt}/Q_{crt} when we used the correction factor 0.26 on the right side of formula (1), as well as the ratios of the corresponding experimental values, Q_{tr}/Q_{cr}.

From Table 1 it can be seen that the theoretical values of Q_{trt}/Q_{crt} are in all cases much higher than unity and vary (for all experiments) from 5.03 to 14.9, while the experimental values of Q_{tr}/Q_{cr} are much higher than unity and vary from 3.06 to 9.75. The average value of Q_{trt}/Q_{crt} is equal to 8.09, and the average value of Q_{tr}/Q_{cr} is 6.36. The table indicates that the second monodisperse regime of atomization was realized in practice in all 17 experiments conducted with liquids which poorly wet the disk.

For an additional check of these results, we determined experimentally the distributions of the dimensions of the drops for two liquids with similar physical properties but differing in the degree to which they wetted the duralumin disk: diesel fuel (ρ = 0.892 g/cm³, η = 0.047 g/cm·sec, σ = 30.6 g/sec², complete wetting of the disk) and a 7% aqueous solution of OP-7 (ρ = 1.63 g/cm³; η = 0.022 g/cm·sec, σ = 37.6 g/cm², Θ = 21°). The measurements were carried out at liquid flow rates Q which were higher than the critical value Q_{cr} but lower than the transition value Q_{tr}, i.e., under conditions such that the atomization of the two liquids should be identical irrespective of the difference in how well they wetted the disk.

In the experiments with diesel fuel the drops were deposited on slides which had first been coated with a thin layer of silicone (dispersion coefficient K = 1.9), and in those using an aqueous solution of OP-7 they were deposited on slides first coated with collargol (K = 3). The drops were measured and counted under the microscope and broken down into size classes [4].

Typical experimental results are shown in Fig. 3. It can be seen that the curves of drop size distribution for the cases in which the wetting was good and those in which the wetting was poor were in fact fairly close to each other, provided that the condition $Q_{cr} < Q < Q_{tr}$ was satisfied.

Thus, the calculations and the experiments showed that in the investigated range of variation of the parameters, when a rotating smooth disk was used for atomizing liquids which poorly wet its surface, there was fairly reliable realization of the second monodisperse regime of atomization and that for an approximate estimate of the range of liquid flow rates corresponding to this regime, we can use formula (1) with the correction factor 0.26 and formula (2).

NOTATION

R, disk radius; R_f, radius of the liquid film on the disk; Q, liquid flow rate; Q_{cr} and Q_{crt}, measured and calculated flow rates at which R_f = R; Q_1, measured flow rate at which the second monodisperse regime of atomization begins; Q_{tr} and Q_{trt}, measured and calculated flow rates at which the transition from the second regime to the third, polydisperse, regime takes place; ω, angular velocity of rotation of the disk; ρ, η, σ, Θ, density, viscosity, and surface tension of the liquid and boundary angle of wetting, respectively.

LITERATURE CITED

1. W. H. Walton and W. C. Prewett, "The production of sprays and mists of uniform droplet size," Proc. Phys. Soc. (London), 62B, 341-350 (1949).
2. J. O. Hinze and H. Milborn, "Atomization of liquids by means of a rotating cup," J. Appl. Mech., 17, No. 2, 145-153 (1950).
3. P. Theissig. Erzeugung von Flüssigkeitsfilmen, Flüssigkeitslamellen und Tropfen durch rotierend Scheiben, VDI, Forschungsheft, No. 574 (1976).
4. V. F. Dunskii, N. V. Nikitin, and M. S. Sokolov, Monodisperse Aerosols [in Russian], Nauka, Moscow (1975).
5. V. F. Dunskii, N. V. Nikitin, and M. S. Sokolov, Pesticide Aerosols [in Russian], Nauka, Moscow (1982).
6. I. M. Nafikov and N. Kh. Zinnatullin, "Discontinuity of a film of an anomalously viscous liquid in a centrifugal force field," Inzh.-Fiz. Zh., 39, No. 1, 51-56 (1980).
7. D. E. Hartley and W. Murtgatroyd, "Criteria for the breakup of thin liquid layers flowing isothermally over solid surfaces," Int. J. Heat Mass Transfer, 7, No. 9, 1003-1015 (1964).