SPRAYING OF A LIQUID BY PNEUMATIC PUMPS

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Results are given from measurements on the size and distribution of the droplets in the spraying of a high-viscosity liquid by pneumatic pumps.

Various industrial spraying applications require restrictions of droplet size, production of a definite size spectrum, and a relationship to the various properties of the liquid. As regards highly viscous liquids, theoretical and experimental results do not permit a sufficiently complete account of the relation of the mean diameter and the size distribution to the spraying conditions.

The reason for this is partly the complexity of the process itself and also that there difficulties arise in making the measurements. The best method of determining drop size is to take samples from the jet onto glass slides coated with an immiscible liquid [1]. This method gives results comparatively rapidly, but it does not eliminate the possibility of droplet coalescence on the glass, distortion of droplet shape, or errors due to the particular sampling site.

We have estimated droplet size by using the polymerization of organic resins to give solid spherical particles as a freely flowing powder. The spraying liquid was thermosetting phenol–formaldehyde resin, which was prepared as an aqueous solution with values of viscosity more than 0.01 and rather less than 100 N-sec/m^2. These droplets rapidly solidify to spheres when heated by the gas, and these may contain bubbles that do not produce holes on the surface, the particle size and the gas temperature being the decisive factors here. These spheres do not dissolve in liquids and do not melt [2].

The spraying was performed in a laboratory spraying drier heated by fuel gases, with external mixing for the pneumatic pumps. The pump was placed outside the drying chamber. The diameter of the air nozzle was 3.5-5.0 mm, while that for the liquid was 1.3-1.5 mm. The solidified powder was collected in the chamber and in trapping devices, and from these samples we estimated the particle size. The powder was fractionated by sieving and washing with water jets on the sieve. The mean fraction size in the powder was then converted to droplet size with allowance for the density of the solid particles and the loss during polymerization.

In this way we recorded volume distribution curves for the droplet sizes for liquids with viscosities at 293°K from 0.02 to 6.00 N-sec/m^2.

Similar curves were recorded for air temperature ahead of the pump from 296 to 463°K (235-369°K when corrected for adiabatic expansion), and with ratios of the mass flow rates of air and liquid in the

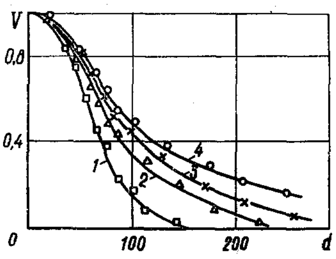

Fig. 1. Size distribution of drops in spraying liquids of various viscosities (293°K): 1) 0.03 N·sec/m^2; 2) 2.00 N·sec/m^2; 3) 2.50 N·sec/m^2; 4) 3.73 N·sec/m^2; for the following parameters: μ_{al} = 237-240 m/sec; ρ = 1120-1200 kg/m^3; σ = 0.031 N/m; G_a/G_l = 5.

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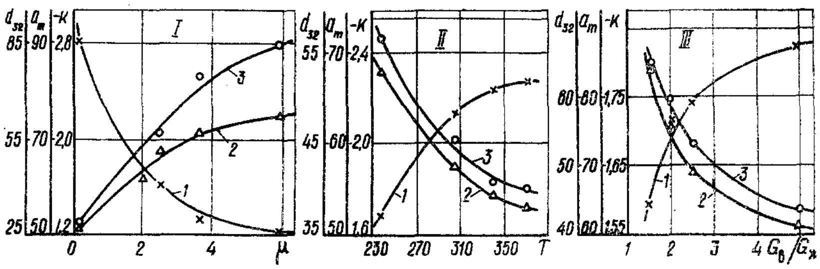

Fig. 2. Dependences of the coefficients k (1) and a_m (2) in the equation of total distribution of the drops (1) and of the mean volume–surface diameter of the drops d_{32} (3) on: I) liquid viscosity μ; II) the temperature of adiabatic expansion of the air T in spraying liquid of viscosity (293°K) 2.5 N·sec/m²; III) ratio of the weight flow rates of air and liquid G_a/G_l in spraying liquid of viscosity (293°K) 2.0 N·sec/m².

range 1.47-5.00. Figure 1 shows the volume distribution curves by size for various cases; the typical feature is that the curves move to smaller sizes as the viscosity decreases.

We also found that the parameters of the spraying process affect the coefficients in the equation describing the distribution. The literature has many equations for particular and some for more general distribution curves [1, 3], of which the Rosin–Rammler equation is simplest to use in calculations.

This equation gives an exponential relationship of the form

$$V = 1 - \frac{1}{\exp\left(\frac{d}{a_m}\right)^k}. \tag{1}$$

To find the coefficients k and a_m we use an expression obtained after taking logarithms twice:

$$\lg\lg\frac{1}{1-V} = k(\lg d - \lg a_m) - 0.3625. \tag{2}$$

In Fig. 2 results are given for k and a_m and also for the mean volume–surface diameter d_{32}: curve I shows the dependence on the viscosity at 293°K; curve II the dependence on the temperature of adiabatic expansion of the air; and curve III the weight ratios of the air and liquid flows. We found that k and a_m are largely independent of the viscosity above 2-3 N-sec/m², air temperatures above 300-320°K and ratios of air and liquid flows above 3. The trend in d_{32} is analogous to that in a_m for the same quantities. These curves enable us to determine the droplet distribution for any spraying conditions within the ranges employed. Figure 2 shows that it is not satisfactory to evaluate the sprayer performance merely in terms of the mean droplet diameter.

These distributions are better characterized by the coefficients in the distribution equations. Thus it is desirable to obtain mathematical relationships relating the complex of process parameters to the coefficients in the distribution.

As such equations have not yet been introduced into the theory and practice of spraying, we examined the performance of sprayers with highly viscous liquids by means of the mean volume–surface drop diameter, using the widely known equation of Nukiame and Tanasawa [4]:

$$d_{32} = 585\cdot 10^3\,\frac{\sqrt{\sigma}}{u_{al}\sqrt{\rho}} + 1683\left(\frac{\mu}{\sqrt{\sigma\rho}}\right)^{0.45}\left(1000\,\frac{V_l}{V_a}\right)^{1.5}. \tag{3}$$

This empirical equation was deduced from experiments with viscosities down to 0.03 N-sec/m². Our results showed that for μ = 0.02-0.03, N·sec/m²; σ = 0.026-0.051 N/m; ρ = 1120-1160 kg/m³; u_{al} = 200-237 m/sec; 1000 V_l/V_a = 0.19-0.26 the value of d_{32} obtained experimentally agrees satisfactorily with that calculated from (3), whereas at higher viscosities there were considerable discrepancies, as has been noted before [1].

TABLE 1. Numerical Values of the Coefficients of Eq. (4)

Coefficient	No. 1	No. 2	No. 3
$A \cdot 10^{-3}$	−3017,8	−293,3	−1650,5
B	+381,9	+36,9	+168,3
m	+0,032	+1,714	+0,488
n	+0,165	+0,485	+0,168

TABLE 2. Values of the Mean Volume–Surface Diameter of the Drops d_{32} in Spraying Liquids of Various Viscosities

μ, N-sec/m² at 293°K	d_{32}^{p}, μ				d_{32}^{e}, μ
	equ. (3)	No. 1	No. 2	No. 3	
2,20	101,9	42,3	45,0	48,4	43,4
3,37	54,0	—	76,7	62,2	78,2
1,10	65,0	—	—	30,7	38,8
0,03	27,9	—	—	—	27,4

Therefore we determined the coefficients in (3) from the experimental data obtained so as to be able to extend its range of application to highly viscous liquids; we write (3) in the form

$$d_{32} = A\,\frac{\sqrt{\sigma}}{u_{al}\sqrt{\rho}} + B\left(\frac{\mu}{\sqrt{\sigma\rho}}\right)^{m}\left(1000\,\frac{V_l}{V_a}\right)^{n}. \tag{4}$$

Moving the first term on the right of Eq. (4) to the left and taking logarithms we get

$$\ln\left(d_{32} - A\,\frac{\sqrt{\sigma}}{u_{al}\sqrt{\rho}}\right) = \ln B + m\ln\left(\frac{\mu}{\sqrt{\sigma\rho}}\right) + n\ln\left(1000\,\frac{V_l}{V_a}\right), \tag{5}$$

where the coefficients A, lnB, m, and n are found from the condition of minimal deviation of the experimental values of d_{32} from those calculated from (4) or (5) in accordance with

$$S = \sum\left[\ln B + m\ln\left(\frac{\mu}{\sqrt{\sigma\rho}}\right) + n\ln\left(1000\,\frac{V_l}{V_a}\right) - \ln\left(d_{32} - A\,\frac{\sqrt{\sigma}}{u_{al}\sqrt{\rho}}\right)\right]^2, \tag{6}$$

where lnB, m, and n were calculated by least squares for a given A. The maximum of S was found by the method of dichonomyns [5].

All the calculations were done by computer; Table 1 gives the results of A, B, m and n for highly viscous liquids. The numbers denote the following ranges of the parameters: the other parameters were analogous to No. 1; μ = 2.20–2.28 H·sec/m²; σ = 0.031–0.041 N/m; ρ = 1200 kg/m³; u_{al} = 237–276 m/sec; $V_l/V_a \cdot 1000$ = 0.19–0.66; No. 2 μ = 2.20–3.37 N·sec/m²; u_{al} = 237–300 m/sec; No. 3 μ = 0.82–3.37 N·sec/m²; $V_l/V_a \cdot 1000$ = 0.14–0.66 the other parameters being analogous to No. 2.

Table 2 indicates the discrepancies between the experimental values of d_{32} and those calculated from (3) and (4) using the results found for the coefficients. The numbers in Table 2 correspond to the ranges of the parameters and the coefficients of Table 1; as seen from Table 2, the deviation of d_{32} calculated from the coefficients for the viscous liquids is the less the narrower the viscosity range used in determining the coefficients.

Thus Equation (3) may be used to calculate the mean diameter of liquid droplets for higher viscosities if the appropriate corrections are introduced into the coefficients in this equation.

NOTATION

V	is the number, by volume, of drops of larger size (dimensionless);
d	is the diameter of drops, μ;
d_{32}	is the mean volume–surface diameter of drops, μ;
μ	is the dynamic viscosity of liquid, N·sec/m²;
σ	is the surface tension of liquid, N/m;

ρ is the density of liquid, kg/m^3;
G_a/G_l is the ratio weight flow rate of air and liquid (dimensionless);
V_l/V_a is the ratio of volume flow rate of air and liquid (dimensionless);
μ_{al} is the velocity of air relative to liquid, m/sec;
T is the temperature of adiabatic expansion of air, °K.

Subscripts

e is the experimental value;
p is the predicted value.

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