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STUDY OF THE OPERATION OF A GAS-LIQUID ATOMIZER WITH A POROUS MIXING ELEMENT

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Experimental data for a gas-liquid atomizer with a porous mixing element are presented. Hydraulic characteristics of the atomizer at different mass flow rates of the air and liquid are obtained. Water and glycerin were used as the working fluids. The maximum diameter of the formed droplets was measured by the method of spark photography. A semiempirical relation for evaluating the droplet dimension is proposed.

At present, atomizers with porous elements are finding increasing use. A detailed review of their structures and ranges of application is given in [1]. The most efficient is the use of porous elements in small-drop (less than 0.1 MPa) gas-liquid atomizers. Porous inserts in such atomizers serve to provide a uniform mixing of the two-phase flow and gas saturation of the liquid, which facilitates its dispersion, and can enhance the efficiency of the atomizers. Thus, the continuous operation of centrifugal atomizers can be accompanied by a change in their flow-rate characteristics and atomization parameters because of their clogging and the formation of deposits. To obviate the formation of deposits on the walls of the swirl chamber and the nozzle, the latter are made of porous material and a header for feeding a low-viscosity working medium is placed on the periphery. In this case, the gas that infiltrates through the porous wall to the periphery of the liquid vortex impedes the formation of deposits on the inner surface of the atomizer walls and dissolves resin fractions. Experimental data for the operation of a centrifugal atomizer with porous inserts are presented in [2, 3].

It should be noted that gas-liquid atomizers with porous mixing elements have a drawback, which is their proneness to clogging. This is the case if the dimension of solid particles, which are contained in the liquid, is larger than the characteristic diameter of the pores; therefore, it is expedient to place a fine filter ahead of the atomizer in the liquid-supply main. Moreover, when a solution is atomized, it should not be supersaturated; otherwise the salt precipitation will also entail pore closure.

In atomizers, porous materials are most frequently used that are prepared by the method of sintering of bronze, stainless steel, titanium, and ceramic particles with dimensions ranging between 0.35 and 1.2 mm. However, it should be noted that the specimens that are produced by this method have a poor technological reproducibility of the basic characteristics. In this work, consideration was given to the atomizer with a mesh porous element devoid of this drawback.

Experimental Equipment. The subject of inquiry was a model atomizer (Fig. 1). In the frame, a 20-mm-diam.-sleeve is fixed, in which disks out of P24 mesh are arranged. The total thickness of the mesh package is 10 mm, and the porosity is 0.7.

A basic diagram of the experimental setup is shown in Fig. 2. It comprises the systems of liquid and gas supply. In a steady-state regime, the air flow rate was measured from the pressure drop on a measuring washer, and the liquid flow rate was measured from a change in its level in a measuring tank over the start-up time.

An objective evaluation of the droplet dimensions in the operation of gas-liquid atomizers is an involved task, since the presence of a high-velocity gas flow introduces appreciable errors into the measurement.

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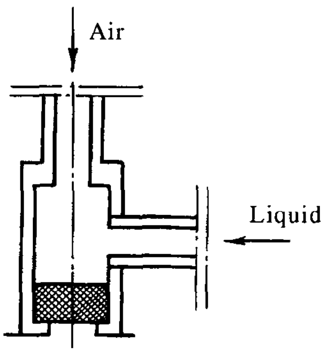


Fig. 1. Diagram of the atomizer.

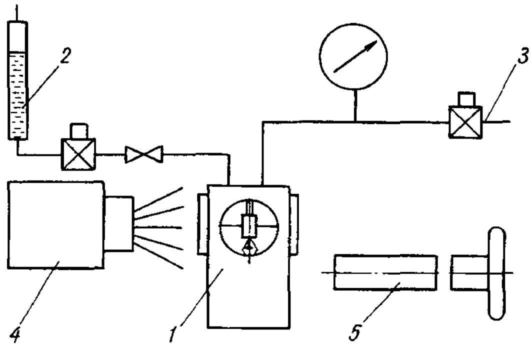
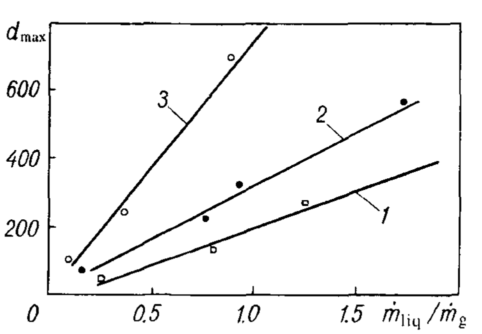


Fig. 2. Diagram of the setup: 1) atomizer; 2) tank with the liquid; 3) air-supply main; 4, 5) droplet photography system.



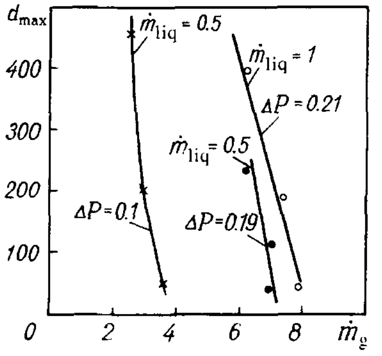


Fig. 3. (Maximum) droplet diameter vs. relative flow rate of the water and air: 1) $\Delta P_* = 0.1$ MPa; 2) 0.05; 3) 0.02. d_{max}, μm; $\dot{m}_{liq}$; $\dot{m}_g$, g/sec.

Fig. 4. (Maximum) diameter of glycerin droplets vs. mass rate of the air flow through the atomizer. ΔP, MPa.

In this case, the method of determining the dimensions of the droplets by trapping them in a tank with oil [4] is practically inapplicable.

The droplet dimensions were determined using the optical method of spark photography. The source of the light pulse was a spark facility, which comprised a pulse discharger based on an ISSh-15 stroboscopic scheme, batteries of FGTN high-voltage pulse capacitors, a unit for delay of the light pulse, a VS-23 high-voltage source, and an autorelease of the recording camera.

The measurement procedure was based on the fact that, in a specified region of the spray flare, a scale element (a wire 0.03 mm in diameter) was placed, on which the optical system was focused. The selected section of the spray flare was photographed in a steady-state operating regime of the atomizer. The experimental conditions and procedure permitted a determination of the droplets with dimensions of 10 μm and higher. Smaller droplets were not visible on the photograph.

Experimental Data. In the experiments, the droplet diameter was measured. Figure 3 presents the experimental data for water used as a working fluid. With increase in the parameter $\dot{m}_1/\dot{m}_2$, the droplet diameter increased. At a fixed value of the parameter $\dot{m}_1/\dot{m}_2$, a decrease in the pressure drop on the atomizer also led to an increase in d_{max}. The pressure drop ranged between 0.02 and 0.1 MPa. With small pressure drops, the dependence of the droplet diameter on the parameter $\dot{m}_1/\dot{m}_2$ became stronger.

Figure 4 presents the testing results for glycerin used as a working fluid. It is seen from the figure that the glycerin atomization to an assigned droplet dimension requires much higher air flow rates than does the water atomization.

As follows from the experimental data, a low flow rate of the viscous fluid produces a significant resistance for the gas in the porous insert; therefore, it is of interest to assess the effect of the basic process parameters on the pressure drop in the operation of the gas-liquid atomizer.

Hydraulic Characteristics of the Atomizer. The filtration of the gas-liquid flow in a porous medium is described by Darcy's law in generalized form:

$$u_i = \frac{kK_i}{\mu_i} \frac{dP}{dz} . \tag{1}$$

The coefficient of relative phase permeability is adopted in linearized form:

$$K_1 = 1 - \varphi , \quad K_2 = \varphi . \tag{2}$$

The gas and liquid mixing in the atomizer (see Fig. 1) occurs ahead of the porous element; therefore, φ = const across the entire thickness of the porous element.

The gas and the liquid in the porous matrix each move at its own mean velocity. The pressure in both phases is assumed to be the same. The latter assumption implies that the Laplace pressure drop is small.

Proceeding from expression (1) and taking into account that φ = const, we represent the mass rate of the gas and liquid flow through the atomizer as

$$\dot{m}_1 = \frac{Sk (1 - \varphi) \Delta P}{\nu_1 L} , \tag{3}$$

$$\dot{m}_2 = \frac{Sk \varphi \Delta P}{\nu_2 L} , \tag{4}$$

whence the expression for the void fraction takes the form

$$\varphi = \left[1 + \frac{\nu_1}{\nu_2} \frac{\dot{m}_1}{\dot{m}_2} \right]^{-1} . \tag{5}$$

Since $\nu_1/\nu_2 \approx 0.01$ for the water–air system, from expression (5) for the same mass flow rates of the liquid and gas follows $\varphi \to 1$, i.e., a major part of the flow area of the porous matrix is taken up by the gas. Taking into account this fact and the estimate $\mu_1 >> \mu_2$, we see from expression (1) that the velocity of the gas phase is markedly higher than the liquid velocity. From expressions (4) and (5) we have

$$\Delta P = \frac{\dot{m}_2 \nu_2 L}{Sk} \left[1 + \frac{\nu_1}{\nu_2} \frac{\dot{m}_1}{\dot{m}_2} \right] . \tag{6}$$

With the filtration of the liquid alone through the porous atomizer, according to expression (3),

$$\Delta P_* = \frac{\dot{m}_1 \nu_1 L}{Sk} . \tag{7}$$

The division of expression (6) by expression (7) results in

$$\frac{\Delta P}{\Delta P_*} = \frac{\nu_2}{\nu_1} \frac{\dot{m}_2}{\dot{m}_1} \left[1 + \frac{\nu_1}{\nu_2} \frac{\dot{m}_1}{\dot{m}_2} \right] . \tag{8}$$

In conformity with expression (8), the filtration of the two-phase flow in comparison with the filtration of the liquid alone is accompanied by a sharp increase in pressure loss. In the case where $\dot{m}_1/\dot{m}_2 \sim 1$, the ratio $\Delta P/\Delta P_* \sim \nu_2/\nu_1 >> 1$.

Droplet Diameter. The droplet dimension is intimately bound up with the specific regime of liquid atomization [4, 5]. There is no rigorous formulation of the problem on the liquid breakdown into droplets to date; therefore, empirical relations are prevalent in the literature. In [6], a detailed review of the correlations is given that permits an evaluation of the droplet diameter in atomization by compressed-air atomizers.

To generalize experimental data for the atomization by a gas-liquid atomizer with a porous insert, a relation is suggested in [7] that is based on the Nukiyama and Tanasawa equation:

$$d \approx A u_2^{-1} + B \nu_2^{0.45} (\dot{m}_1/\dot{m}_2)^{1.5} , \tag{9}$$

where A and B are the empirical constants for fixed densities of the liquid and gas.

There are a few objections to the use of this type of equation. First, the presence of two components in Eq. (9), each of which has the dimensions of length (or a part of the droplet diameter), does not represent any conceivable physical process; second, from the analysis of the equation it is impossible to ascertain the effect of structural parameters of the atomizer on the atomization characteristics.

In this study, to estimate the maximum droplet diameter it is suggested to use a semiempirical relation based on a specific physical model.

When the liquid flows out of the porous matrix, a part of the outlet section is occupied by the liquid and the other part is occupied by the gas. The characteristic dimension of the liquid jet, issuing from a pore, is related to the void fraction as

$$1 - \varphi \approx \frac{\delta^2}{d_p^2} . \tag{10}$$

It was noted above that the velocities in the liquid phase are much lower than in the gas phase, $u_1 < u_2$. In this case, the characteristic wavelength on the surface of a liquid jet, which arises from the development of instability, can be evaluated in the form

$$\lambda \approx \frac{\sigma}{\rho_2 u_2^2} . \tag{11}$$

Presumably, the measured maximum droplet dimension is proportional to the diameter of a droplet resulting from the primary disintegration of the liquid jet:

$$\lambda \delta^2 \approx d_{\max}^3 . \tag{12}$$

Substituting expressions (10) and (11) into expression (12), we obtain

$$d_{\max} \approx (1 - \varphi)^{1/3} \frac{d_p^{2/3} \sigma^{1/3}}{\rho_2^{1/3} u_2^{2/3}} . \tag{13}$$

With account for expressions (1) and (5), considering that $\varphi \to 1$, Eq. (13) is represented as

$$d_{\max} \approx \left[1 - \left(\frac{\nu_1}{\nu_2} \frac{\dot{m}_1}{\dot{m}_2} + 1 \right)^{-1} \right]^{1/3} \frac{d_p^{2/3} \sigma^{1/3} \mu_2^{2/3} L^{2/3}}{\rho_2^{1/3} k^{2/3} \Delta P^{2/3}} . \tag{14}$$

According to Eq. (14), with the parameter $\dot{m}_1/\dot{m}_2$ specified, the droplet diameter depends on the pressure drop on the atomizer as $d_{\max} \sim \Delta P^{-2/3}$. This conclusion is verified by experimental data (see Fig. 3). At fixed ΔP = const, $d_{\max}$ increases with $\dot{m}_1/\dot{m}_2$, which also agrees with experimental data (Fig. 3). In conformity with Eq. (14), at fixed ΔP = const and $\dot{m}_1/\dot{m}_2$ = const, an increase in the kinematic viscosity of the liquid leads to an increase in $d_{\max}$. Substituting expression (6) into Eq. (14), we obtain

$$d_{\max} \approx \left[1 - \left(\frac{\nu_1}{\nu_2}\frac{\dot{m}_1}{\dot{m}_2} + 1\right)^{-1}\right]^{1/3} \frac{d_p^{2/3}\sigma^{1/3}\rho_2^{1/3}S^{2/3}}{\dot{m}_2^{2/3}} \left(1 + \frac{\nu_1}{\nu_2}\frac{\dot{m}_1}{\dot{m}_2}\right)^{-2/3} . \tag{15}$$

According to expression (15), at fixed mass flow rates of the gas and liquid $d_{\max} \sim d_p^{2/3}$, i.e., with increase in the diameter of pores of the porous matrix, the maximum droplet diameter becomes larger.

Relations (14) and (15) are written with an accuracy to empirical constants that, generally speaking, depend on the conditions of the medium where the atomization is carried out.

NOTATION

d, droplet diameter; $d_{\max}$, maximum droplet diameter; d_p, pore diameter; k, coefficient of absolute permeability of a porous matrix; K_i, coefficient of relative phase permeability; L, length of porous insert; $\dot{m}_i$, mass flow rate of the ith phase; P, pressure; ΔP, ΔP_*, pressure drop on porous insert in filtration of gas-liquid flow and liquid; S, cross-sectional area of porous insert; u_i, velocity of the ith phase; φ, void fraction; λ, wavelength; μ, dynamic viscosity; ν, kinematic viscosity; ρ, density; σ, surface tension. Subscripts: 1, liquid; 2, gas.

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