NOZZLE WEAR IN TWO-PHASE FLOW

N. V. Pashatskii, N. I. Syromyatnikov, and B. A. Letnitskii

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The results of an investigation of the erosive properties of two-phase nozzle flows are presented. Recommendations are made concerning the design of wear-resistant nozzles.

Two-phase flows have numerous industrial applications, for example, in sand and shot blasting, coating technology, etc. The most critical component of the equipment employed is generally the nozzle, which is usually cylindrical (less frequently conical) in shape [1-4]. The solid particles suspended in the gas rapidly abrade the nozzle. Though nozzle life can be considerably extended by using erosion-resistant materials (ceramics, cermets, hard alloys, etc.) [3, 4], the erosion problem can by no means be considered solved.

We have investigated the effect of various parameters of the two-phase flow (particle concentration, nozzle inlet pressure, flow duration) on nozzle wear. This investigation has led to the development of an improved nozzle geometry.

The experimental setup comprised (Fig. 1) a compressor 1, a hopper containing the abrasive particles 2, a screw feed 3, and aeration chamber 4 for mixing the gas and solid phases, a hopper with a filter 5 for trapping the particles for reuse, and a nozzle chamber 6. As the abrasive material we used synthetic corundum (mean particle diameter 130 μ).

In the experiments we recorded the air and particle flow rates, the mixture pressure at the nozzle inlet, the initial and final nozzle dimensions, and the flow time. The flow temperature at the nozzle inlet was 25-30°C.

The effect of particle concentration ($\mu = G_s/G_g$) on wear was investigated on cylindrical nozzles made of 40Kh steel hardened to 40-45 HRC. The nozzle dimensions and the effects of wear are shown in Fig. 2. The convergent part of the nozzle 2 was made of 2Kh13 steel. The nozzles were tested at an air flow rate of $9 \cdot 10^{-3}$ kg/sec on the particle concentration range from 0.8 to 4.6. The flow time was 25 min.

As the wear parameter we took the relative increase in outlet diameter

$$\Delta_\mu = \frac{d_f - d_0}{d_0}.$$

On the investigated range of particle concentrations the Δ_μ dependence is almost linear (Fig. 3).

The flow time effect was investigated on nozzles made of acrylic plastic with a convergent section composed of 2Kh13 steel. The nozzle was 50 mm long and the diameter of the cylindrical channel was 3 mm. The test conditions were as follows: air flow rate $9 \cdot 10^{-3}$ kg/sec, particle concentration 1.6.

The tests showed that with time the wear decreases (Fig. 3). After 80 min the exit diameter of the acrylic nozzle remains practically constant.

The effect of inlet pressure was also studied on acrylic plastic specimens. The nozzle length was 30 mm, the channel diameter 3 mm. The inlet pressure was varied on the range 2-5 atm abs. at a particle concentration of 1.6. The duration of the test was 30 min. The greatest wear corresponded to an inlet pressure of 5 atm abs. (Fig. 3).

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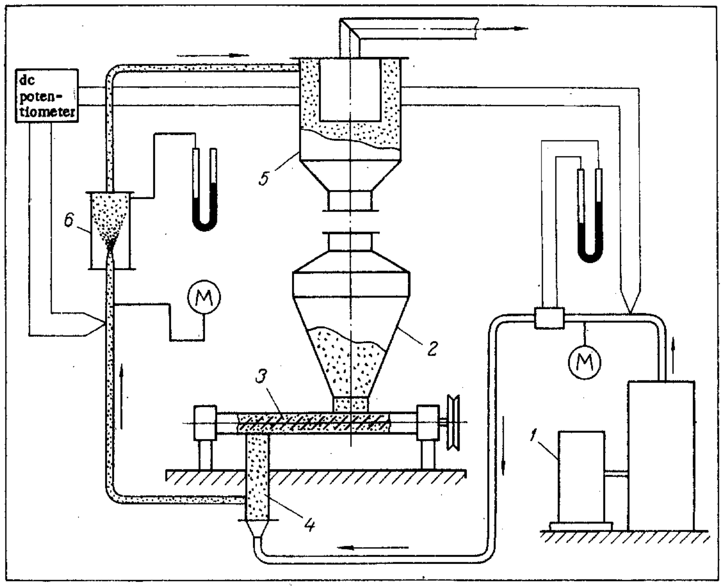

Fig. 1. Experimental setup for investigating nozzle wear.

The results of the experiments showed that the throat diameter changed only slightly. Thus, after five hours the relative change was 5%, whereas the diameter of the outlet section increased by approximately a factor of three (nozzle material 40Kh steel).

A study of the eroded nozzle profiles also revealed that the shape beyond the throat was similar to that of ideal nozzles for a pure gas constructed, for example, by the Rao method, except that in the throat region the experimental nozzle has a greater radius of curvature (Fig. 4).

In addition, it is necessary to note the exponential dependence of the nozzle wear on operating time (Fig. 3).

These observations may be explained as follows.

The throat diameter remains almost the same because of the low particle content in the boundary zone. This is a result of the inclination of the particle trajectories to the axis in the convergent part of the nozzle

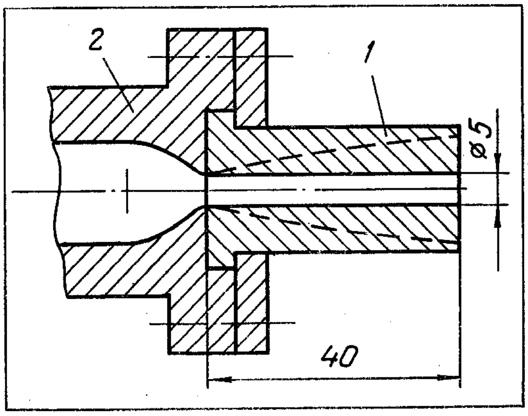

Fig. 2

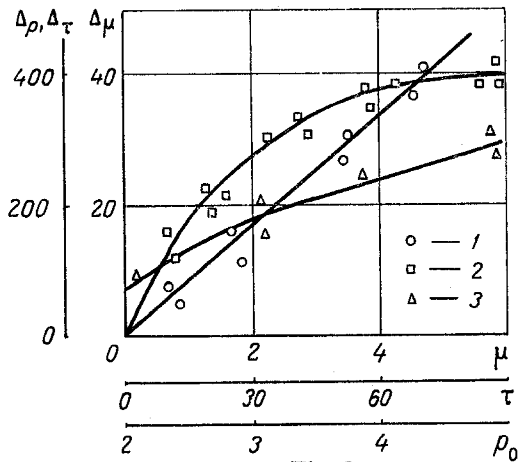

Fig. 3

Fig. 2. Cylindrical nozzle 1 assembled with entrance section 2. The dashed line represents the nozzle profile after operation.

Fig. 3. Nozzle wear as a function of the flow parameters: 1) wear (Δ_μ, %) of steel nozzle as a function of corundum particle concentration; 2) wear (Δ_T, %) of acrylic plastic nozzle as a function of flow time ($p_0 = 5$ atm abs.); 3) wear (Δ_p, %) of acrylic plastic nozzle as a function of inlet pressure. τ, min; p, atm abs.

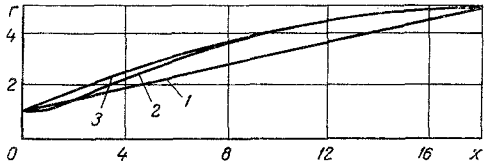

Fig. 4. Comparative nozzle profiles: 1) conical nozzle; 2) experimental nozzle; 3) Rao nozzle.

and the lagging of the particles behind the gas in relation to the rotation of the gas streamlines in the throat [5]. Calculations show that there are no particles in the plane of the throat at a distance from the axis greater than 70-80% of the throat radius.

The fact that the radius of curvature in the throat is greater in the experimental than in the Rao nozzle can also be attributed to the lagging of the particles behind the gas in the radial direction.

The stabilization of the shape of the nozzle with time takes place as follows. During flow the nozzle surface is abraded as a result of particle impact and friction. This continues unti the nozzle geometry becomes optimal from the gas-dynamic standpoint. At this point the particles cease to come into contact with the nozzle surface as a result of lagging behind the gas in the gas in the radial direction and we get smooth separation flow.

Thus, cylindrical nozzles are unsatisfactory from the standpoint of wear. The best nozzle is that formed by the abrasive flow itself. An ideal (e.g., Rao) nozzle satisfies the wear requirements to the same degree as the experimental nozzle (Fig. 4). Conical nozzles have a high (though less than the experimental nozzle) degree of wear resistance at a certain ratio of the outlet to throat (d_0/d_t) diameter. For the investigated nozzle lengths this ratio is equal to 3-5.

NOTATION

d_0 and d_f	are the diameters of the nozzle outlet section before and after the experiment respectively;
G_g and G_s	are the gas and solids flow rates;
p_0	is the nozzle inlet pressure;
r	is the radius of the nozzle cross section;
x	is the coordinate along the nozzle axis;
μ	is the particle concentration;
τ	is the duration of the test;
Δ_p, $\Delta\mu$, and $\Delta\tau$	are the nozzle wear values as functions of pressure, particle concentration, and flow time.

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