EXPERIMENTAL DETERMINATION OF THE CONDITIONS FOR THE GRANULATION (BREAKDOWN) OF ALUMINUM OXIDE DROPS IN A HIGH-TEMPERATURE GAS FLOW

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The results of a determination of the critical Weber number for drops of aluminum oxide moving in a flow of combustion products are presented. It is shown that the values of W∗ lie in the range 17-22.

It is well known that the breakdown of molten drops in a gas flow with low Reynolds numbers plays an important part in a number of applied problems of mechanics, associated, in particular, with the motion of metal oxide particles in Laval nozzles [1]. The behavior of dibutyl phthalate and transformer oil drops in a low-pressure helium flow was studied in [2]. It was found that, when the Reynolds numbers lay in the range

$$R = \frac{\rho (U - U^0) d}{\eta} = 120 - 700$$

at the instant of drop breakdown, and the rate of flow around the obstacles increased gradually, the critical Weber number

$$W_* = \frac{\rho (U - U^0)^2 d}{\sigma},$$

at which the drop disintegrated lay in the range 15-22. Here σ is the surface tension of the liquid. The aim of the present investigation was to continue the earlier line of enquiry [2] and to determine the critical number W_* for drops of metal oxides moving in a high-temperature gas flow.

The experimental method was as follows. Aluminum oxide particles with a wide range of diameters (from tenths of a micron to several tens of microns) were added to a solid fuel material having a combustion

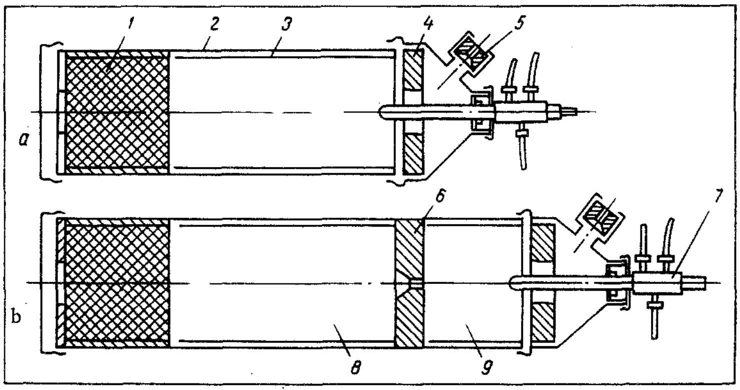

Fig. 1. Experimental apparatus.

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TABLE 1. Results of a Dispersion Analysis of the Particles

No. of experiment	5	6	7	8	9	10	11
P_+, bar	48	49	61	48	53	50	51
P_-, bar	21	17	25	12	28	16	21
d=10–11 μ	10	6	33		7	3	10
11–12	4	1	37	2	3	2	8
12–13			24				
13–14	1		10	1		1	1
14–15			6			1	
15–16		1	4				
16–17			3				
17–18			2				
>18	None						

temperature above the melting point of aluminum oxide. This material (indicated at point 1 in Fig. 1) was subjected to combustion in the experimental apparatus (depicted in the same figure), which consisted of a casing 2, thermal insulation 3, a diaphragm 4, and an outlet nozzle 5. The length of the combustion chamber 8 was 320 nm and its internal diameter 110 mm. When the combustion products passed through the intermediate nozzle 6, the largest particles disintegrated. The size of the particles in the combustion chamber and beyond the cutoff of the intermediate nozzle was monitored by means of the sample-selector 7. The value of W_* was determined from the maximum diameter of the nondisintegrating particles by a standard computing method.

The foregoing method of determining the maximum size of the stable particles (and hence the value of W_*) is more accurate than experimental methods in which the original aluminum oxide particles are formed by the combustion of aluminum [3]. In the latter case, in fact, the size of the oxide particles formed by combustion and subsequent coagulation may be less than that of the particles which disintegrate on passing through the nozzle. The results obtained by such methods may therefore lack validity.

The experimental conditions for determining W_* in the present investigation were as follows. The composition of the combustible solid material was taken such that, in the absence of heat losses, the calculated temperature of the combustion products was 2630°K. Chromatographic aluminum oxide was introduced to the extent of 5 wt.% into the solid material; it constituted particles in the form of scales, which after melting adopted a spherical shape. The comparatively low concentration of aluminum oxide particles in the combustion products prevented their coagulation.

In order to determine the maximum diameter of the particles after melting, the apparatus was set up in the form of Fig. 1a. For selecting (sorting) the particles after passage through the disintegration nozzle, the arrangement of Fig. 1b was employed. The experimental apparatus was lengthened and the combustion chamber was separated from the selection space 9, in which the sampler was installed by means of an intermediate nozzle. The pressure in the combustion chamber P_+ was determined by the diameter of the critical cross section of the intermediate nozzle. For P_+ = 40-60 bar the diameter was 9-10 mm. The pressure in the rear cavity P_- behind the cutoff of the intermediate nozzle was held at about half the value in the combustion chamber by means of the nozzle bushing. This pressure drop was essential in order to ensure a gas velocity equal to the speed of sound in the critical section of the intermediate nozzle. Calculations showed that the most intensive conditions for particle disintegration occurred in the neck of the nozzle; the intermediate nozzle was therefore made without any supersonic section.

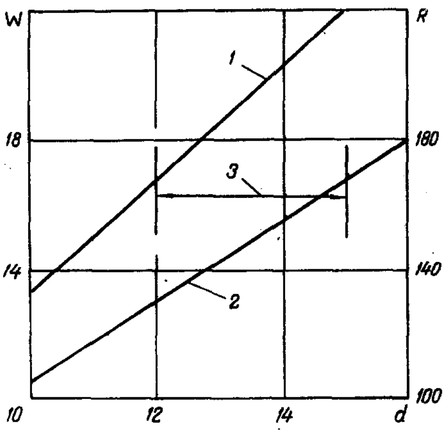

Fig. 2. Calculated relationships for the W and R numbers as functions of the particle diameter.

Placing the sampler in a space at a pressure much greater than atmospheric practically eliminates any possibility of particle disintegration being caused by the abrupt changes in compression (shock waves) beyond the cutoff of the intermediate nozzle.

In order to study the conditions of drop disintegration we carried out eleven experiments. In four of these we determined the maximum diameter of the spherical aluminum oxide particles obtained by the melting of the original aluminum oxide introduced into the combustion material. This amounted to 25-30 μ. In seven experiments we varied the critical section of the intermediate nozzle by + 10% in an attempt to determine the manner in which the maximum dimensions of the nondisintegrating particles depended on the pressure in the combustion chamber.

The results of our dispersion analysis of the particles in the last seven experiments are shown in Table 1. After each experiment the diameters of approximately 4000 particles were analyzed. The table only shows the numbers of particles with dimensions greater than 10 μ. Despite the fact that the influence of the pressure in the combustion chamber on the particle size was not established with any certainty, it is reasonable to assert that for $P_+ = 50$ bar the majority of particles with diameters of 12-15 μ disintegrated on emerging from a nozzle 10 mm in diameter. In order to determine the W number corresponding to this particle size, we require to know the density ρ^0 and the surface tension σ of aluminum oxide at the temperature of the particle in the critical cross section of the nozzle. By estimating the thermal losses from the combustion products in the experimental apparatus, which amount to around 400 kJ/kg, we find that the particle temperature is approximately 2300°K, the corresponding values of the parameters in question being $\sigma \approx 0.7$ N/m and $\rho^0 \approx 3 \cdot 10^3$ kg/m^3 [1].

Figure 2 shows the maximum W number (curve 1) and the R number (curve 2) corresponding to this W value in relation to the particle size. The curves are calculated, with due allowance for the increase in the resistance of the particles due to their deformation [1], for a nozzle with a critical cross section of diameter of 10 mm and a pressure of $P_+ = 50$ bar in the combustion chamber. The range of diameters above which (according to the experiments) the majority of the particles disintegrate is indicated by the number 3. It follows from these relationships that, when the drops move in a range of R values extending up to ~ 200, the critical W_* number lies in the range 17-22. This value agrees with the earlier results [2].

NOTATION

d	is the diameter of liquid drop;
P_+	is the pressure in the combustion chamber;
P_-	is the pressure behind the nozzle cutoff;
R	is the Reynolds number;
U	is the gas velocity;
U^0	is the drop velocity;
W	is the Weber number;
W_*	is the critical Weber number;
η	is the dynamic viscosity of the gas;
ρ	is the density of the gas;
ρ^0	is the density of the liquid;
σ	is the surface tension of the liquid.

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