ELECTRIFICATION OF A HETEROGENEOUS FLOW INTERACTING WITH A METAL

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Experimental results are given on the static electrification arising when solid particles collide with metals.

Static electrification occurs when a mixture of solid and gas or liquid flows along a channel, on account of interaction between the solid parts. The resulting electrostatic forces can exceed the gas-dynamic ones and interfere with the flow (particle adhesion to the wall, particle clumping in a fluidized bed, and so on). Attempts have been made [1, 2] to describe the effects of the various factors on static electrification in such flows, together with the effects on the flow itself.

Here we consider mainly the effects of particle speed on the charge produced. The tests were done with a gas-dynamic system for use with such flows [3]. The gas flow bore quartz sand or carbon dust, in both cases of a narrow size range. The particle velocity at a given point was determined with the device described in [4]. The plates were made of St. 3 steel, 1Kh18N9T stainless steel, copper, aluminum, nickel, zinc, or T15K6 cermet. We varied the particle concentration and the angle between the particle velocity and the plane of the plate. The parameters such as the gas temperature and humidity were virtually constant at $t = 20°C$ and $\varphi = 90\%$ in all runs.

The charge reaching the plate was measured with a YI-2 dc amplifier; the input impedance of the instrument was varied widely, and we found that values between $5.1 \cdot 10^6$ and 10^9 ohm had no effect on the charge. However, higher resistances began to show an effect from the insulation resistance of the plate, which was 10^{11} ohm.

We found that the current tended to fluctuate, and that this occurred principally in the initial period or during transfer from one mode of flow to another (Fig. 1), thereafter vanishing. The length of the transitional period was dependent on the flow characteristics and the physical properties of the materials, for

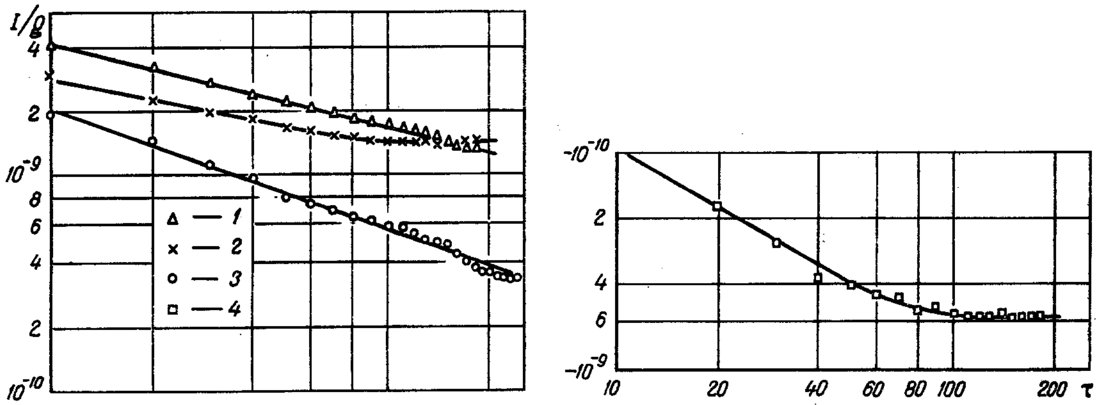

Fig. 1. Specific electrification current I/g (A-sec/g) as a function of time τ (sec): 1) nickel with quartz sand, $d = 0.2-0.25$ mm, $g = 0.28$ g/sec, $V = 12$ m/sec; 2) $d = 0.2-0.25$ mm, $g = 0.95$ g/sec, $V = 29$ m/sec; 3) $d = 0.16-0.2$ mm, $g = 1.05$ g/sec, $V = 14$ m/sec; 4) aluminum with carbon dust, $d = 0.1-0.16$ mm, $g = 0.51$ g/sec, $V = 15$ m/sec.

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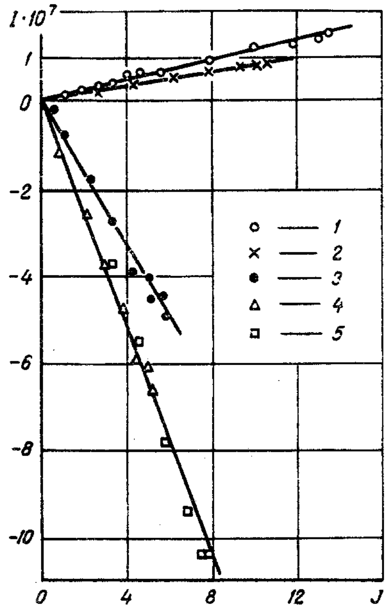

Fig. 2. Static electrification current I(A) as a function of J (J): 1) T15K6 cermet with quartz sand, d = 0.1-0.16 mm, g = 1.05 g/sec; 2) d = 0.32-0.5 mm, g = 0.52 g/sec; 3) 1Kh18N9T with carbon dust, d = 0.32-0.5 mm, g = 0.46 g/sec; 4) d = 0.2-0.25 mm, g = 0.38 g/sec; 5) d = 0.1-0.16 mm, g = 0.51 g/sec.

instance, the transition period fell as the speed and particle concentration were raised (curve 2). There was no transition period at all when the speed exceeded a certain value (40 m/sec for quartz sand or nickel), and also at all velocities when the plate hardness was greater than that of the particles (quartz sand on T15K6).

Microscopic examination showed that the particles penetrated into the soft materials and subsequently protected them from other particles; this was confirmed in tests with aluminum and quartz sand. The plate became heavier when the jet played on it for less than 1 sec, and this accumulation of trapped particles explains the transition period to some extent. There is also another possible cause of unstable electrification in this period. The metal surface at the site of impact alters in properties on account of work hardening [5], and this affects the charge produced by collision.

If the plate is softer than the particles, there is always such a transition period; this period becomes shorter as the speed and particle concentration are raised, and ultimately is so short that it could not be recorded with our equipment.

Figure 2 shows results on the static electrification for various materials after the transition period. The particle speeds vary from 10 to 170 m/sec. The results for each particle-plate pair fit satisfactorily to

$$I = ngV^2 \sin^2 \alpha, \tag{1}$$

where n is dependent on the physical properties of the bodies and the particle size.

These results relate to single impact of a given particle; when such a flow moves along a channel, one of course gets multiple collisions, and then the static electrification begins to be influenced by factors not incorporated in (1), such as the resistance of the wall and particles, and also the electrical strength of the gas medium, as well as the charge already accumulated by the particles.

The results allow one to calculate some parameters for the charged particles; the particles were taken as spheres, the diameter being determined as the arithmetic mean of the minimum and maximum diameters in the fraction. The current and the mass flow rate for the solid were used to determine the charge of one particle. For instance, the maximum charge for quartz sand interacting with the cermet occurred for the largest fraction, 0.32-0.5 mm, and was $15.1 \cdot 10^{-6}$ μC at a speed of 143 m/sec, which corresponds to a potential of 650 V. The area of contact on collision was deduced in accordance with [6]; the charge density in the contact spot increases with the normal component of the particle velocity (it attained 690 $\mu C/m^2$ under the above conditions). This would appear to be significant in explaining the electrification mechanism. One supposes that the charge density on the contacted bodies cannot exceed the charge density in the contact spot, so the particles and the walls in such a flow will be charged to a potential corresponding to the contact velocity. This potential will be dependent on the mode of flow. For

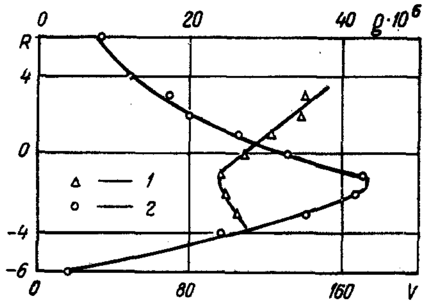

Fig. 3. Distribution in a disperse jet at 45 mm from the end of a horizontal cylindrical nozzle for: 1) local velocity V (m/sec); 2) g (g/sec). Quartz sand, pressure before nozzle 2 bar, d = 0.2-0.25 mm, G = 0.95 g/sec, nozzle diameter 8 mm. Positive R (mm) correspond to points above the axis, and negative below.

instance, a reduction in flow speed and hence in particle velocity should lead to some loss of charge, since the area of the contact spot is reduced. This may even reverse the sign of the charge on the channel wall. The increased normal component of the particle velocity at a bend in the channel should increase the particle charge. This explanation of the charging mechanism agrees well with experiment [2].

In conclusion we consider briefly an instance of practical use of the effect.

Electrostatic flow-rate tranducers are used in industry for solids in such flows; equation (1) for this case becomes

$$I = CGV^2, \tag{2}$$

where

$$C = n\frac{g}{G}\sin^2\alpha \tag{3}$$

where it may be taken as a constant for given measurement conditions.

It follows from (2) that the readings of an electrostatic transducer are dependent on the mass flow rate and on the particle speed, so the electrification can be used to measure either the velocity or flow rate only if the other of the quantities is either constant in all measurements or is determined by some independent method. For instance, Fig. 3 shows the particle velocity distribution for quartz sand emerging from a horizontal nozzle as determined with an electrostatic transducer. Here we had first derived the local flow rates for the solid in the same cross section with a special trap.

NOTATION

I is the current;
V is the particle speed;
g is the mass of particles striking transducer in unit time;
G is the mass flow rate of solid;
α is the angle of attack;
n is the coefficient of proportionality;
C is the transducer constant;
d is the particle diameter;
τ is the run time;
R is the jet radius;
φ is the relative humidity;
t is the temperature;
$J = gV^2\sin^2\alpha$.

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