MEASURING THE ELECTROSTATIC POTENTIAL IN FLUIDIZATION BEDS BY MEANS OF AN IMMERSED PROBE

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An analysis is conducted of feasibility of measuring the electrostatic field potential in fluidization beds by means of a probe immersed in such a bed. Methods of measuring probe potential and current are described, and the essential results of such measurements are discussed.

During fluidization with gas of many polymer dispersions having excellent dielectric properties there accumulate electrostatic charges on the treated material as well as on various apparatus components. This has very often a detrimental influence on the technological process (solid particles adhere to the apparatus walls, dispersed particles agglomerate, etc.) and sometimes the process is in danger of actual breakdown. On the other hand, the said effect can be used for intensifying certain processes as, for example, separation of materials, ore dressing, surface coating, etc.

A study of electrization phenomena in a fluidization bed requires the development of procedures for electrostatic measurements during the flow of a dispersion in a gaseous medium. In many cases this has been done with a measuring electrode-probe immersed in the bed and connected to an electrostatic voltmeter [1-5].

The action of a probe in electrostatic fields consists in its acquiring the potential which some nearby point in space had before the field became distorted by the presence of this probe. Application of this measurement procedure to fluidization beds involves a few specific factors which substantially affect the potential of the immersed probe. First of all, there occur collisions of charged particles against the probe. No analysis of the process by which a probe acquires its potential in a fluidization bed has been published where this phenomenon is taken into account, although the effect of many other factors (material of the apparatus including the gas distributor, humidity of the fluidizing air, material of the treated object, etc.) on the electrode-probe readings have been considered rather thoroughly [1-5].

In order to explain the characteristics of potentials acquired by a probe during fluidization, taking account of this phenomenon, and in order to establish the feasibility of using a probe for estimating the charge level in a fluidization bed, the authors have performed experiments similar to those described in the references given here.

The laboratory apparatus is shown schematically in Fig. 1. The vessel made of Plexiglas had the following dimensions: $d_1 = 0.19$ m, $d_2 = 0.4$ m, and $h = 1.0$ m. The treated material was bisulfuric polystyrene with 1.5-2.5 mm size particles. The measurements were made by two methods: static and dynamic. The first method included the use of a measuring electrode-probe and an electrostatic voltmeter. In the second method the electrode-probe was used with a dc amplifier, an ac amplifier, and a loop oscillograph. The principle of this method is based on the motion of induced charges in an alternating field after a conductor has been inserted into that field. The process taking place here can be described by the equation:

$$\frac{ES}{4\pi C} - \frac{q}{C} = R\frac{dq}{dt}. \qquad (1)$$

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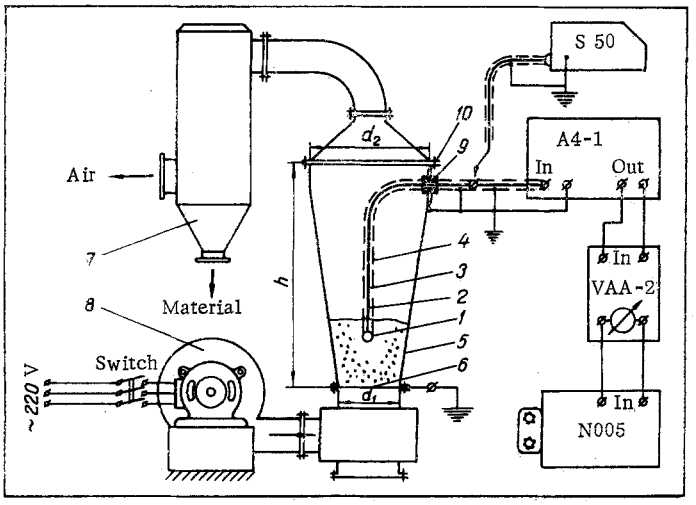

Fig. 1. Schematic diagram of the fluidization bed apparatus with instrumentation: 1) probe; 2) center core; 3) insulator; 4) shield; 5) vessel; 6) metallic grid; 7) cyclone; 8) air compressor; 9) insulating sleeve; 10) guard ring.

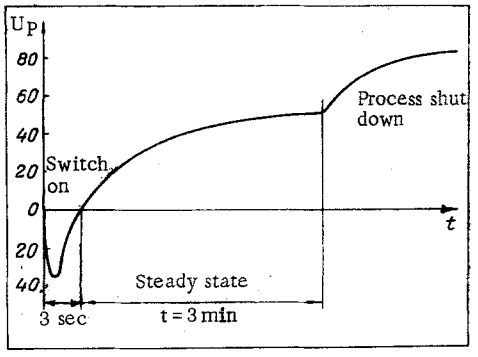

Fig. 2. Change in the probe potential after the apparatus has been started up. Probe potential $U_P(V)$, time t.

Static Method. In our tests we used a model S50 electrostatic voltmeter with a 150 V scale. The probe was a steel ball 1 (Fig. 1) 12 mm in diameter fastened to a copper rod (2) 5 mm in diameter. For eliminating stray pickups at the rod from extraneous fields and to avoid the possibility of the rod becoming charged, the latter was shielded. The shielding also prevented any charges precipitating on the vessel walls during fluidization from falling on the probe. Teflon served as the insulation 3 between rod 2 and shield 4. The probe was inserted into the bed through the vessel side wall, insulated from the latter by means of a sleeve 9. The shield 4, the guard ring 10, and the metallic grid 6 were all grounded. In order to determine the probe polarity, the entire probe–voltmeter system was precharged from a dry cell up to a potential (80 V) of known polarity. The trend of the voltmeter potential vs time curve and its position relative to the initial potential of the system indicated the polarity of the potential acquired by the probe. A comparison between curves obtained with the voltmeter and the probe charged to potentials of different polarities, also the curve obtained without charging, has yielded the time characteristic of the probe potential (Fig. 2). In preliminary tests we had established that under our conditions the charge on polystyrene was predominantly negative.

An analysis of the curve in Fig. 2 shows that, at the instant when the apparatus is switched on and the material charged negatively as a result of contact with the metallic grid separates, the negative potential of the probe jumps sharply. This phenomenon may be explained by an induction of negative charges on the probe.

The effect of contact electrization on the probe potential is initially insignificant. The reason for this is that, because of the small contact area (as compared to the contact area between particles and the grid, where the particles become charged first), the probe charge is much smaller than the charge induced on it by charged particles in the bed. Subsequently, the negative probe potential decreases until it becomes positive in the steady state. After the apparatus has been shut down, the positive probe potential jumps up. The critical factor here is the presence during those tests of a positive potential on the probe under steady-state conditions. This can be explained neither in terms of a transport of charges by particles directly at the probe, nor in terms of the influence of charges precipitating at the vessel walls. This latter conclusion was reached on the basis of experiments in a vessel with metallic walls, grounded, where the same trend of the probe potential curve under steady-state conditions was noted as in the case of the Plexiglas

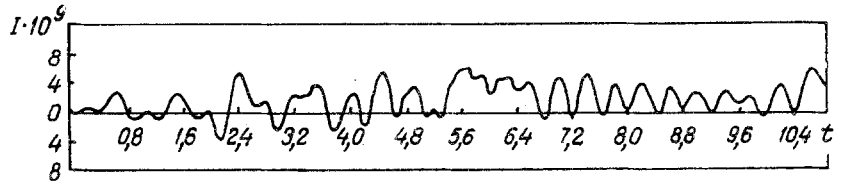

Fig. 3. Variations of the probe current during the fluidization process. Current I (A), time t (sec).

vessel. The positive steady-state probe potential is also an indication that the field of negatively-charged particles in the bed has less of an effect than the positive charges picked up by the probe. In order to discover the source of positive potential on the probe, we measured and recorded the probe current.

Dynamic Method. Unlike the static method, the dynamic method makes it possible to record instantaneous values of the measured current. Since these values are rather low, it was necessary to assemble the circuit shown in Fig. 1 for measuring currents of the order of 10^{-9} A. The polarity of the input signal to the amplifier was determined beforehand. The variations of the probe current are shown in Fig. 3.

It is evident here that positive current predominates. A mathematical evaluation of this curve has yielded an average current of $1.8 \cdot 10^{-9}$ A over a 10 sec period. The mathematical expression for the average current, taking into account a stream of particles around the probe, is

$$i_p = nwbS_M q_p. \quad (2)$$

Along with positive pulses there appear also negative pulses on the current graph. A closer examination reveals that the frequency of current pulses coincides with the frequency of density variations in the fluidized bed material around the probe, i.e., with the pulsation frequency of the electric field of charged particles.

When charged particles stream around an electrode-probe, the readings of the latter are affected by the following factors: the electric field, the transfer of charges from particles to probe, and last the electrization of the probe as a result of contact with the stream of particles. An analysis of test results has led to the conclusion that, under the conditions of our experiment, electrization of the probe as a result of contact with the treated material is the predominant factor here.

The experimentally proved hypothesis that the probe derives its potential from a predominant contact electrization can be supported by the following theoretical considerations.

Owing to the short duration of the contact between a charged particle and the probe, the transfer of charge from particle to probe can be effected only across the contact area. Across the contact area, however, charges are exchanged as a result of contact phenomena and the charge imparted to a particle is $Sc(\sigma_S - \sigma_0)$. The same charge is imparted to the probe. After the removal of the particle the charge acquired by the particle and the probe is $S_c(\sigma_p - \sigma_0)$. The surface charge density on a particle prior to contact with the probe σ_0 is always smaller than σ_p after separation from the probe and, therefore, contact electrization rather than transfer of charges takes place at the probe surface. The polarity of the charges on bed particles and the potential of the probe, both checked during the experiment in a metallic vessel with grounded walls and metallic grid, also indicate a predominance of contact electrization of the probe over the effect of the electric field in the bed. Another evidence of this is the characteristic jump of the probe potential after the apparatus has been shut down, when charges held by the probe become released by the precipitation of particles. The effect of the electrostatic field can be determined quantitatively by a graphical analysis of the diagram in Fig. 3, which represents the resultant effect of both the contact electrization and the pulsating electric field.

Let us examine the variations of the probe potential in a stream of bed particles, without considering the scatter of probe charges. The merit of this approach is based on the satisfactory agreement between the test curve of potential buildup on the measuring electrode and the charging curve for bodies in a stream of particles.

It is well known that, if the resistivity of one of the bodies in contact is $\rho \geq 10^9\ \Omega \cdot$ cm, the surface charge density on the bodies after separation will be limited by the space charge in the gas. This means that, under the given conditions, σ_p is constant at the instant of separation.

The number of particles N simultaneously in contact with the probe can be determined from the condition of flow around a probe in a stream of particles [6]:

$$N = \frac{1}{L^2} S_M b, \tag{3}$$

where

$$L = \frac{0.807d}{(1-\varepsilon)^{1/3}}. \tag{4}$$

The charge density on the probe surface after contact with the first row of particles, if the initial charge density on the probe was zero, is

$$\sigma_1 = \frac{S_c}{S}(\sigma_p - \sigma_0) N = m\Delta\sigma_p N. \tag{5}$$

The charge density on the probe due to contact with the second row of particles only is

$$\sigma_2 = \frac{S_c}{S}(\Delta\sigma_p - m\Delta\sigma_p N) N = m\Delta\sigma_p (1 - mN) N. \tag{6}$$

Continuing in the same manner, we obtain for the total charge density on the probe

$$\sum_{i=1}^{n} \sigma_i = m\Delta\sigma_p N [1 + (1 - mN) + (1 - mN)^2 + \ldots + (1 - mN)^{n-1}] \tag{7}$$

or, finally,

$$\sum_{i=1}^{n} \sigma_i = \Delta\sigma_p [1 - (1 - mN)^n], \tag{8}$$

while

$$\lim_{n\to\infty} \sum_{i=1}^{n} \sigma_i = \Delta\sigma_p. \tag{9}$$

The resulting stepped curve of potential buildup on the probe may be replaced by a smooth curve of probe potential as a function of time.

The time of replacing one row of particles is

$$\tau = \frac{L}{w} = \frac{0.807d}{w(1-\varepsilon)^{1/3}}, \tag{10}$$

and the number of contacting rows is

$$n = t/\tau. \tag{11}$$

Inserting the value of n, and considering the charge rather than the charge density, we obtain

$$q = \Delta\sigma_p S [1 - (1 - mN)^{\frac{w(1-\varepsilon)^{1/3}}{0.807d} t}]. \tag{12}$$

An analysis of Eq. (12) is beyond the scope of this article. On the basis of this equation, we will now only try to explain the high potentials recorded by the probe in [1-5].

According to this equation, the probe potential can be expressed as

$$\varphi_p = \frac{q_{t\to\infty}}{C} = \frac{S\Delta\sigma_p}{C}. \tag{13}$$

Since $\Delta\sigma_p = a(\sigma_s - \sigma_0) = (a\varepsilon_0/\delta)\Delta u_c'$ and $C = 4\pi\varepsilon_0 r_B$, hence we have in the end

$$\varphi_p = a\Delta u_c' \frac{r_B}{\delta}. \tag{14}$$

With $\Delta u_c'$ assumed of the order of 1 V and $\delta \sim 10^{-8}$ m, the value of ratio r_B/δ indicates the possibility of high potentials appearing on the probe in a stream of particles. This theoretically derived equation cannot

serve as a true interpretation of the test curve of potential buildup, since neither the effect of the electric field nor the effect of probe charge scattering was taken into account in its derivation. It does, however, convincingly enough explain the qualitative aspects of potential buildup on the measuring probe.

The measured data on static electrization of the probe in a fluidization bed agree with the data in [8], where the electrization of a probe was measured during pneumatic transport of loose material through a pipeline.

NOTATION

a is the coefficient of charge leakage during the separation of bodies in contact;
b is the entrainment coefficient;
C is the capacitance of the measuring system;
d is the particle diameter;
E is the electric field intensity;
i_P is the probe current;
L is the distance between particles;
$m = S_c/S$;
N is the number of particles simultaneously in contact with the probe;
n is the number of contacting rows;
q is the electric charge;
$q_{t\to\infty}$ is the saturation charge on the probe;
q_P is the residual charge on the probe after separation of a particle;
R is the internal resistance of the measuring device;
r_B is the radius of the probe ball;
S is the surface area of the probe;
S_M is the median section area of the probe;
S_c is the contact surface area;
t is the time;
$\Delta u_c'$ is the contact potential difference, taking into account the initial charge on the surface of the contacting bodies;
w is the velocity of the particles toward the probe from a sufficiently large distance away;
δ is the distance between bodies on contact;
ε is the porosity of the bed;
ε_0 is the dielectric constant of air;
ρ is the electrical resistivity;
σ is the surface charge density on the probe;
σ_0 is the surface charge density on the particles prior to contact;
σ_p is the surface charge density on the particles after their separation from the body;
$\Delta\sigma_p = \sigma_p - \sigma_0$;
σ_s is the saturation surface charge density;
τ is the time of replacing one row of particles;
φ_P is the probe potential.

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