THE ELECTRIFICATION MECHANISM IN A FLUIDIZED BED

V. L. Ganzha

Inzhenerno-Fizicheskii Zhurnal, Vol. 13, No. 2, pp. 243–249, 1967

UDC 541.182.3

On the basis of numerous data available in the literature, as well as according to the experiments which we have carried out, a hypothesis is proposed for the mechanism of static electrification in a fluidized bed.

The rapid development of the fluidized-bed technique in the most diverse branches of industry requires a thorough and penetrating study of the numerous phenomena associated with the achievement of fluidization.

One of the least studied phenomena—entirely disregarded by the classical theory of fluidization—but of considerable influence in the hydrodynamics and heat transfer of a fluidized bed is the phenomenon of static electrification, i.e., the appearance of electrical charges (their potential attains 25 kV) on system elements, leading to adhesion of the solid-particle bed to the walls of the installation and to various items immersed in the fluidized bed, leading to the agglomeration of the fluidized material into conglomerates, making normal progress for the fluidization process difficult, and also presenting the danger of explosion in certain cases.

This problem has not been the subject of systematic investigation up this time. A few publications are cited in the literature [1–4]. A brief discussion of this problem is found in [5]. However, up to this time the mechanism of this phenomenon has not been made specifically clear, and the data on the influence of electrification on the hydrodynamics and heat transfer in a fluidized bed, as presented by various authors, are highly contradictory.

This is doubtlessly explained in part by the inadequacy of our knowledge within the field of the mechanism of static electrification, and it is also due to the great complexity of the subject system (the "fluidized bed") as pointed out with justification by Ciborowski, Koncar-Djurdjevic, et al., as well as due to the abundance of factors affecting electrification—the humidity of the fluidizing air, the kind and shape of the material of the particles and column walls, the rate of fluidization, the temperature of the bed and of the fluidizing air, the presence of "foreign bodies" in the bed, such as the electrode wire intended to measure the potential in the bed, sensors to measure the heat-transfer coefficients, thermometers or thermocouples, etc.

Koncar-Djurdjevic, Baic, and Djordjevic [4], investigating electrification in the bed of a uniform mass, came to the conclusion that in the fluidization process, as a result of separation, mutual friction, and collision, particles of identical material acquire both negative and positive charges.

An analogous phenomenon of symmetric charging was observed in the Kunkel research at the Loeb Laboratory during pulverization of sulfur and quartz powders exhibiting diameters ranging from 1–30 μm [7].

We carried out the following experiments to determine the charge polarity for the fluidized material particles.

Two flat copper electrodes of semicircular shape, connected to a dc source, were installed in a column in the fluidized bed, at a height exceeding the maximum particle-lift height by 15–20 mm. The difference in the potentials introduced by the electrodes amounted to 2.5 kV. The rate of fluidization then instantaneously increased to such an extent that the particle-lift height exceeded the level of the electrode leads by 50–70 mm. The fact that the ejected particles adhered strongly to the two electrodes indicates the existence of charges of both signs among the fluidized particles. The polarity of the electrodes was monitored during the experiment.

Ciborowski and Wlodarski [1] share this opinion.

Thus, on the basis of the foregoing we draw the conclusion that in rather narrow fractions particles of even uniform material are charged both positively and negatively upon fluidization in the fluidized bed. However, this symmetrical charging of particles cannot lead to the development of high potentials in the system, since according to the law of the conservation of charge, the sum of positive charges is equal to the sum of negative charges ($\Sigma q_i = 0$), and the separation of oppositely charged particles, because of intensive longitudinal transverse mixing, is impossible.

We therefore carried out further research to ascertain the fundamental factors leading to the devel-

Change in Potential Polarity Over Bed Height

Particle material, μm	Air flow rate m/sec	Height of electrode installation above grid, mm						Humidity of fluidizing air, %	Temperature of fluidizing air, °C
		20		45		70			
		Potential	Polarity	Potential	Polarity	Potential	Polarity		
Glass beads 750–800 μm	0.95	3000	—	0		2500	+	50	23
Quartz sand, 710 μm	1.15	2100	—	1500	—	4800	+	65	24
MSN copolymer, 680 μm	0.41	2550	—	1400	—	300	+	55	25

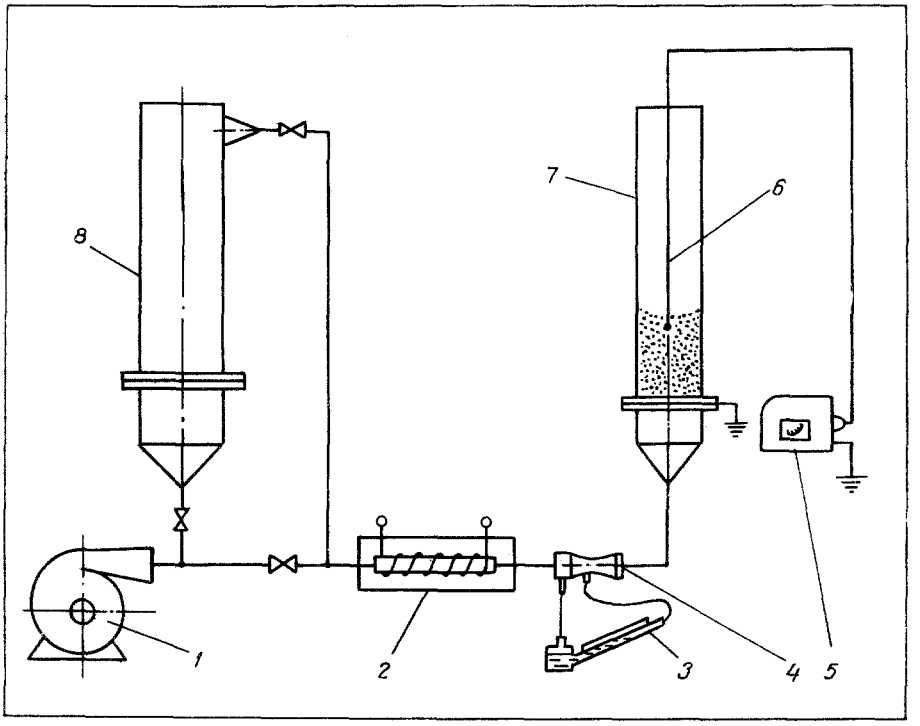

Fig. 1. Schematic drawing of experimental unit: 1) fan; 2) heater; 3) micromanometer; 4) flowmeter nozzle; 5) electrostatic voltmeter; 6) electrode; 7) fluidized bed column; 8) zeolite column.

opment of the indicated potentials. The experimental installation is shown schematically in Fig. 1.

The mesh to hold the grain material and to distribute the fluidizing air is made of sheet metal with orifices 1 mm in diameter; the cross section is on

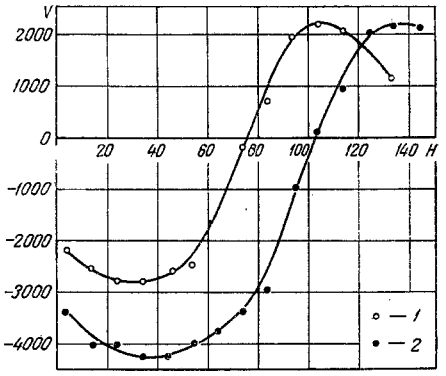

Fig. 2. Electrode potential V (V) versus its height H (mm) over grid, air velocity of 1) 0.3; 2) 0.432 in m/sec.

the order of 10% and a copper grid with cells 40 × 40 μm is mounted in a movable wooden cassette which makes it possible to alter the diameter of the column, packed with porolon and sealed airtight with rubber. The material (oak) of the cassette and of the column mounting flange at the same time make it possible to reduce charge leakage. The design of the base is such as to make possible the changing of the column diameter within wide limits up to 130 mm. The base also contains a connecting tube for the insertion of the

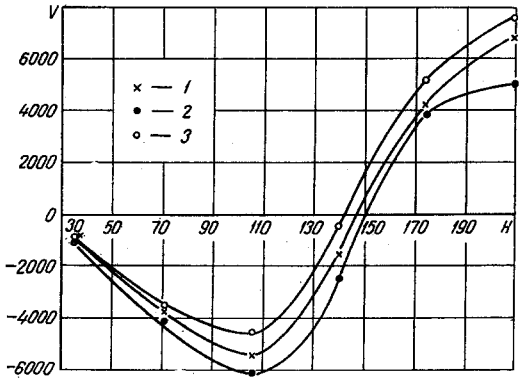

Fig. 3. Electrode potential V (V) versus its height H (mm) over grid, at air velocity 1) 0.105; 2) 0.315; 3) 0.525 in m/sec.

thermometer to measure the temperature of the fluidizing air, as well as connecting tubes for the insertion of a temperature regulator-sensor connected by means of an intermediate RKS-3 relay to the air heater and tubes for the connection of a micromanometer to measure the bed resistance.

The measurement portion of the installation (because of the narrow limits of the measurements) consists of 3 electrostatic voltmeters connected by means of switches to the electrode inserted into the column with the fluidized bed. The electrode is a copper wire 1 mm in diameter with a bead at the tip. It can be moved freely in the vertical and horizontal directions by means of a holder and a Capron centering insert. The electrode is insulated from the holder with teflon.

To stabilize the readings of the installation, the latter is surrounded with a metal screen (grid) that is grounded.

The preliminary experiments were carried out in 1200-mm-high glass columns 108 and 58 mm in diameter. Glass beads 750–800 and 190–200 μm in diameter served as the fluidized material, as did sand with a diameter of 250 μm.

It was noted during the course of the research that after the steady state had been attained no significant changes in electrode potential resulted from the movement of the electrode in the horizontal plane, i.e., in the direction perpendicular to the axis of the installation.

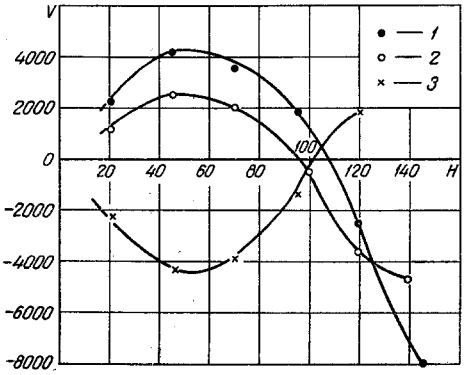

Fig. 4. Electrode potential V (V) versus its height H (mm) over grid, air velocity of 1) 0.850; 2) 1.1; 3) 0.71 in m/sec.

On the other hand, movement of the electrode in the vertical plane, i.e., in a direction parallel to the axis of the column, resulted in a significant change in electrode potential. With a constant fluidization rate this change in potential exhibits excellent qualitative reproducibility. We have in mind here the reproducibility within a single experiment at a constant fluidization rate and with constant humidity and temperature for the fluidizing air.

In studying the electrode potentials as a function of electrode height above the grid (Fig. 2) we carried out the experiment in a glass tube 108 mm in diameter, with glass beads 190–200 μm in diameter for an insignificant initial bed height of H_0 = 46 mm. The temperature of the fluidizing air was 20° C and that of the ambient air was also 20° C, while the relative humidity, respectively, came to 50 and 55%, with the barometric pressure at 738 mm Hg.

As we can see from the figure, the curve showing the potential as a function of electrode height above the grid exhibits two maxima. A function of analogous character was derived for the relative humidity of ambient and fluidizing air, i.e., 45 and 40%, res-

pectively, as well as in experiments with glass beads 750–800 μm in diameter for a relative humidity of 46% of the fluidizing air in the same column.

In view of the fact that it is impossible—with the above-described electrode—to ascertain the true nature of the relationship between the potential of the electrode and its height above the grid, since with this method of measuring the potentials certain averaged values are obtained and, moreover, great fluctuations in instrument readings are noted, for the final determination of the nature of this relationship, as well as for precise determination of the magnitudes of the potentials acquired by the electrode in the various cross sections of the column in a 58-mm diameter glass tube, 6 orifices (3 mm in diameter) were made in staggered array along the diametrically positioned generator of the column, separated by 35 mm in height, beginning from the grid. Electrodes were inserted into the orifices, perpendicular to the axis of the installation. Coaxial RK-6 cable was used for the electrodes, and it was introduced into the orifices so that its installation was flush with the insides of the column, with the copper wire entering the fluidized bed to a depth of 5 mm. The fact that the shifting of the electrode in a direction perpendicular to the axis of the column has virtually no effect on the magnitude of the potential (fluctuations in the voltmeter readings do not exceed 10%) was tested in advance and confirmed once again.

The curves were plotted from the results. Figure 3 shows a graph of the change in potential along the height of the fluidized bed, the curves having been plotted from the readings of the voltmeters connected to the electrodes mounted in the manner described above for the bed of glass beads 190–200 μm in diameter. In view of the fact that the fluctuations in the instrument readings, in either direction of the center, were on the order of 50–150 V, the average potential values were taken for the plotting of the curves. The height of the nonmoving bed was H_0 = 105 mm. The relative humidity of the fluidizing air was 35%, while its temperature was t_a = 17° C; the humidity of the ambient air is 40%.

We should take note of the unstable magnitude of the potential for the electrode mounted at a height of 142 mm above the grid. Thus, for example, at an air flow rate of 0.315 m/sec it amounts to 1400–2600 V, reaching 3000 V on occasion, while on other occasions dropping to zero. At an air flow rate of 0.525 m/sec it behaves analogously, the only difference being that in this case it does not reach 2000 V.

An additional series of experiments was carried out by us to determine the nature of the change in the sign of the potential acquired by the electrode along the height of the column.

The Koncar-Djurdjevic et al., experiments indirectly indicate the absence of a uniquely defined electrode potential over the height of the fluidized bed. According to the valid assumption of the authors [3], the fact that material is deposited at two points on an electrode deeply immersed in the fluidized bed (with the purer material collected at the bottom, see Figs. 2 and 3, [2]; the formation of two "clusters" on the insulated electrode, see Fig. 3, [3]) is a result of the existence of extremely complex electrical fields within the given systems.

We carried out the experiments in a plastic tube 58 mm in diameter and with a height of H = 1200 mm. As in the case of the glass tube, 15 orifices 2.5 mm in diameter were cut, the only difference being that the first orifice was located at a height of 20 mm, while the remaining orifices were spaced 25 mm apart, making it possible to derive a more complete picture. The sign of the potentials acquired by the electrode was checked on an electroscope and on a zero galvanometer. The electrode was inserted perpendicular to the column axis. To avoid charge leakage through the grid, the latter was made of teflon. The cross section was 10% and the orifices were 0.6 mm in diameter. The teflon grid served as the third layer of the earlier employed grid.

Experiments with glass beads 750–800 μm in diameter were also carried out, as were experiments with sand grains 710 μm in diameter and with the copolymer MSN 680 μm in diameter. The height of the nonmoving bed was H_0 = 80 mm. The maximum height of electrode installation was H_{el} = 70 mm, since the sign of the potential is positive at all points above that height.

The resulting data have been reduced in the following table.

The sequence of changes in electrode potential sign with movement of the electrode over the height remains the same as in the previous experiments. Instead of a plastic tube we therefore used a polyvinyl chloride tube 50 mm in diameter, fabricated in analogous fashion, the position of whose material in the triboelectric series relative to glass made it possible to assume an altered pattern. The experiments were carried out with glass beads 780–800 μm in diameter at H_0 = 90 mm, with a metallic grid, an ambient-air relative humidity of 45%, and an air temperature of 20° C (curves 1 and 2, Fig. 4).

Figure 4 shows curve 3 plotted for the same beads, but with their fluidization in a plastic column 58 mm in diameter and H_0 = 70 mm. The grid and the parameters of the air are the same as in the case of the polyvinyl chloride tube.

In addition to those mentioned above, quartz, pressboard, single-ply plywood, and metallic foil were investigated as materials for the column walls. The lowest potentials acquired by the electrode occurred with the metallic foil (V = 550 V).

Proceeding from the foregoing, we will attempt to analyze the subject "fluidized-bed" system relative to the possible role of each of its elements in the generation of static charges. For this we will conditionally divide the entire system into the following pairs: particle-particle; particle-grid; air-particle; and, finally, particle-column wall.

As already indicated, we and other authors have established that during the process of separation and collision, particles of even uniform monodisperse

material are both positively and negatively charged (of course, it should be noted that the conclusions drawn by us above and in [4] are not sufficiently convincing because of the possibility of particle polarization in the external field with the experimental method employed). However, this charging should be significant [7–10] and because of the earlier indicated reasons can hardly play a major role in the development of the resulting potentials.

As regards the particle-grid pair, its role may be significant since the material of the particles and of the grid, as a rule, is different, and even in the case of a uniform material (nonsymmetric friction [7, 8]) the development of significant potentials is possible. To be sure, according to the data of the authors of [6], with increasing velocity, i.e., on reaching the velocities at which electrification is particularly intensive, the particles become suspended above the grid and this is associated with the transfer of momentum between the particles and the jets of air exhibiting high kinetic energy. In our opinion the grid therefore exerts influence on the electrification in the fluidized bed by affecting the hydrodynamics of the process. However, at smaller fluidization rates the more or less substantial participation of the fluidization directly in the electrification is possible. There is no doubt that these problems require independent investigation.

As we know from the literature [9, 7], a pure gas uncontaminated by liquid or dust is not electrified, so that participation of the fluidizing air in the process of static electrification would be possible only on destruction by the latter of the moisture film particles adsorbed on the surface. However, according to the data of a number of authors, cited in [7], such thin moisture films are formed on surfaces of glass, quartz, metal, and a number of other materials, even in air with a humidity of 90%, that the forces of adhesion with the surface are somewhat too large. To be sure, when these surfaces are contaminated the film thickness is increased noticeably.

In our opinion, consequently, such significant electrostatic potentials arise in fluidized beds as a result of the friction and collision of particles of the fluidized material with the column walls. This is indicated by many of our experiments with various column materials and also by literature data on electrification in pneumatic transport.

The magnitude of the derived potentials, however, depends on the material of the particles and the column, on the hydrodynamics of the process, the rate of air filtration, the parameters of the fluidizing and ambient air, i.e., on the conditions affecting the magnitude of the charges separated during the process of electrostatic contact charging (in the broadest sense, including triboelectrification [7]), governing a given mechanism of reverse leakage.

During the electrification process the column wall acquires a charge of one sign, while the particles acquire an excess charge of opposite sign (because of the presence of particles of both signs resulting from their collision with each other).

Since the wall material is a dielectric, the charges on the inside surface of the column will produce a field $E_w \neq 0$ in the bed.

Consequently, within the column there will exist the electric field

$$\bar{E} = \bar{E}_b + \bar{E}_w,$$

where $\bar{E}_b$ is the intensity of the field produced by the space charge of the fluidized bed; $\bar{E}_w$ is the intensity of the field produced by the column-wall charge.

REFERENCES

1. I. Ciborowski and A. Wlodarski, Chemical Engineering Science, 17, 1962.

2. S. Končar-Djurdjevic, L. Capo, and D. Vucovic, Genie Chimique, 86, no. 4, 1961.

3. S. Končar-Djurdjevic and D. Vucovic, Nature 1193, no. 4810, Jan. 6, 1962.

4. S. K. Koncar-Djurdjevic, D. M. Baic, and B. D. Djordjevic, Vestnik khim. obshchestva, Belgrade, 28, nos. 8–9, 501–512, 1963.

5. P. G. Romankov and N. B. Rashkovskaya, Drying in a Fluidized Bed [in Russian], Izd. Khimiya, 1964.

6. N. B. Kondukov, A. M. Kornilaev, A. S. Kruglikov, and I. M. Skachko, IFZh, no. 7, 1964.

7. L. Loeb, Static Electrification [Russian translation], Gosenergoizdat, 1963.

8. Y. Staroba and Y. Shimorda, Static Electricity in Industry [Russian translation], Gosenergoizdat, 1960.

9. N. G. Drozdov, Static Electricity in Industry [in Russian], Gosenergoizdat, 1949.

10. S. E. Frish and A. V. Timoreva, A Course in General Physics, Vol. 2 [in Russian], Fizmatgiz, 1961.

26 January 1967

Institute of Heat and Mass Transfer AS BSSR, Minsk