RESISTANCE CHARACTERISTICS OF FLUIDIZED BEDS OF CONDUCTIVE PARTICLES

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The effect of the principal characteristics of a fluidized bed of graphite particles and the current density on the resistivity of the bed has been experimentally investigated at temperatures up to 900° C.

Electrical heating combined with the properties of a fluidized bed can be very useful in a number of branches of chemical engineering and metallurgy [1, 3, 5]. In an electrothermal fluidized bed, electric current flows through a bed of conductive particles, and the bed acts as a resistance, converting the electrical energy into heat. Of course, to design suitable apparatus, it is necessary to know the electrical characteristics of the bed and, particularly, its electrical resistance. So far, only a limited amount of information has been published on this subject [2, 4, 6, 7].

Our object was 1) to investigate the effect of the particle diameter and gas velocity on the resistivity of a fluidized bed at various fixed bed thicknesses, together with the effect of the current density in the bed and the effect of temperature in the range up to 900° C, and 2) to ascertain the conduction mechanism.

The resistivity of the fluidized bed is defined as the resistance of a bed having the dimensions of a cube w with sides 1 cm long. It was calculated in the same way as for ordinary conductors from the expression

$$\rho_b = R\,\frac{S}{l}\,.$$

The possibility of applying this expression to fluidized beds was confirmed by our preliminary investigations, the results of which are consistent with the conclusions reached in [4]. When the electrodes took the form of rods 6 mm in diameter, separated at a distance l apart, the ratio S/l was determined from calibration experiments using a 0.01 N solution of KCl.

The test beds consisted of graphite particles obtained in the course of machining graphite articles on a lathe. The starting material was separated into narrow fractions on 0.063–0.1; 0.1–0.16; 0.16–0.2; 0.25–0.315; and 0.355–0.4 mm screens.

The effect of gas velocity and particle diameter at various fixed bed thicknesses was investigated at the same bed temperature. The fluidizing agent was air and the plexiglas apparatus had a rectangular cross section measuring 52 × 108 mm. The distributor was made of silk cloth, tightly stretched over a stiff wire frame. The electrodes were polished copper plates of the same width as the bed but higher than the maximum expanded bed thickness reached in the experiments. The resistance of the bed was calculated from the measured voltage drop in the bed and the current. The thickness of the fixed bed was 25, 50, and 100 mm. The results of this series of experiments are presented in Fig. 1.

It should be noted that, in addition to the gas velocity and the particle diameter, the thickness of the fixed bed has an important influence on bed resistivity. This is most apparent for particles 0.0795, 0.127, and 0.179 mm in diameter in the presence of developed fluidization, when the bed becomes inhomogeneous owing to the passage of gas bubbles. The nonlinear dependence of resistivity on gas velocity is typical. The resistance of the bed changes most sharply (by a factor of 5–10) on transition to the fluidized state.

The effect of current density was investigated at temperatures up to 800–900° C on the apparatus shown schematically in Fig. 2. Special attention was directed toward averaging the transient current fluctuations caused by nonuniform fluidization. For this purpose, two-stage smoothing was employed. The first stage was a TVB-2 type thermal converter, the second an LC filter. This made it possible to carry out measure-

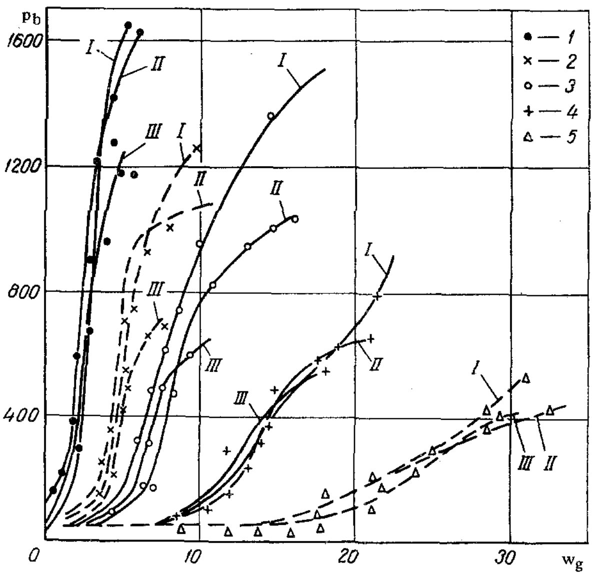

Fig. 1. Effect of gas velocity w_g (cm/sec) on the resistivity ρ_b (ohm · cm) of a fluidized bed of graphite particles with mean diameter: 1) 0.0795; 2) 0.127; 3 3) 0.179; 4) 0.28; 5) 0.377 mm at a fixed bed thickness H_0: I) 25; II) 50; and III) 100 mm. Measuring current 100 mA.

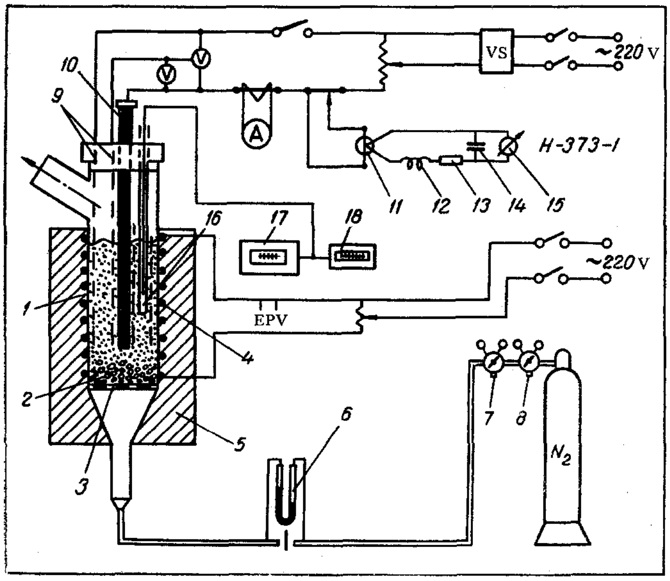

Fig. 2. Diagram of the experimental apparatus: 1) 41-mm quartz tube; 2) large particles of quartz glass; 3) quartz distributor; 4) heating coil; 5) thermal insulation; 6) rheometer; 7, 8) reducers; 9) cylindrical nichrome-mesh electrodes; 10) Kryptol electrode; 11) TVB-2 thermal converter; 12) inductance; 13) resistance; 14) 6000-μF capacitor; 15) null indicator; 16) thermocouple; 17) potentiometer; 18) millivoltmeter.

ments over a broad range of gas velocities, while the use of a quartz-glass column enabled us to conduct the investigation at temperatures up to 900° C.

The electrodes consisted of a 34-mm cylinder of nichrome mesh and a 6-mm coaxial Kryptol rod, between which we introduced another 12-mm nichrome-mesh cylinder. This made it possible to register separately the voltage drop at the inner electrode and in the bed itself. The desired bed temperature was maintained by supplying energy from a nichrome spiral wound around the column containing the fluidized bed. In the steady-state thermal regime, an electric current of the desired strength was passed through the bed for a few seconds. Switching on the current for an extended period would have caused undesirably sharp heating of the bed. However, in all the experiments, the maximum current density in the bed did not exceed 0.4 A/cm^2, owing to the risk of arcing between the inner electrodes. The temperature of the bed was measured with a platinum/platinum-rhodium thermocouple sheathed in quartz glass and connected to an MPShchPr-54 pyrometric millivoltmeter and an EPV-01 regulating potentiometer.

Typical examples of the results of this series of experiments are presented in Fig. 3. The effect of current density is very important at all temperatures (from 20–40 to 900° C). The effect is strongest for particles with an average diameter of 0.0795 mm. Moreover, the effect of current density is the greater, the greater the expansion of the bed and the lower its temperature. For the fixed bed, the dependence of resistivity on current density is much weaker. The nature of the fluidizing gas (nitrogen and argon were used) did not appear to have any effect, although intense sparking was observed at the inner electrode and, to a lesser extent, in the bed itself.

To exclude the observed influence of current density on resistivity and to isolate the temperature effect, we modified the apparatus illustrated in Fig. 2, using a bridge measuring circuit in which one of the arms was the resistance of the fluidized bed between two Kryptol electrodes 6 mm in diameter and 17 mm apart. The use of carbon electrodes gave a clean (no oxide film) surface in all the experiments. As before, the electrodes were arranged vertically and parallel to the column walls. The bridge was supplied with direct current from a dry battery whose voltage could be regulated with rheostats. As the indicator, inserted in the bridge diagonal, we used an N-373-1 dc recording instrument with a high input resistance and the zero in the center of the scale. This made it possible to insert the indicator into the measuring diagonal of the bridge across a five-cell RC smoothing filter. The filter time constant was 0.1 sec. To eliminate the effect of the gas velocity on the measurements, the flow rate of fluidizing gas was so regulated that the expansion of the bed remained unchanged when the temperature was varied. The results of the corresponding m measurements for a bed composed of particles in the 0.355- to 0.4-mm fraction are presented in Fig. 4a. It should be noted that, for all the beds investigated, with particles of different diameters, the resistivity was most sharply reduced (by a factor of 2–3) in the temperature range from 20–40 to 500–600° C. Measurements of the resistivity of the electrical graphite used in the bed did not reveal any significant temperature dependence in the range in question. The results of these measurements, presented in Fig. 4b, suggest

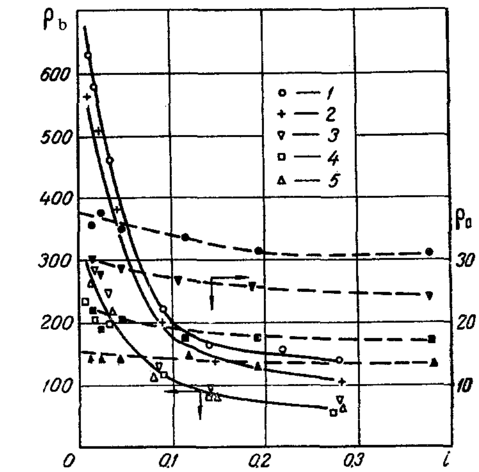

Fig. 3. Resistivity of fluidized ρ_b (ohm · cm) and fixed ρ_0 (ohm · cm) beds of graphite particles, mean diameter 0.0795 mm, as a function of the current density i (A/cm^2) at bed temperatures of: 1) 25; 2) 200; 3) 400; 4) 500; 5) 900° C. Relative expansion of the fluidized bed, $H/H_0 = 1.3$.

that the effect of temperature on the resistance of the fluidized bed depends chiefly on a change in the contact resistance between the particles.

Thus, the experimental data obtained show that the passage of an electric current through a fluidized bed of conducting particles is a very complex process, since the bed hydrodynamics must be taken into account. The preferred flow paths of the electric current are being continuously disturbed by the passage of gas bubbles and new ones are being formed. If the number of paths destroyed in unit time is equal to the number of paths newly formed, the flow of current will be steady. Steady-state flow can be promoted by increasing the surface of the electrodes and the distance between them and by reducing the particle diameter, the thickness of the bed, and the gas velocity.

When the bed goes over into the fluidized state, the resistivity increases sharply from the moment when the particles begin to be suspended in the ascending flow of gas and cease to press against each other, i.e., when the compressive force is compensated. When the entire bed has entered the fluidized state, the subsequent increase in resistivity is due to the gas bubbles, which have a very high resistance in comparison with the solid phase. The decrease in the resistivity of the bed with increase in thickness at the same gas velocity may be due to a decrease in the average porosity of the bed, owing to "bunching" of the particles.

The electrical resistance of the bed can be represented in the form

$$\rho_b = \rho_c + \rho_{c.g} + \rho_m.$$

Our experiments showed that the resistance of the bed is several orders higher than the resistance of the particles themselves (see Fig. 4). Therefore, the dominant factor must be the contact resistance between the particles.

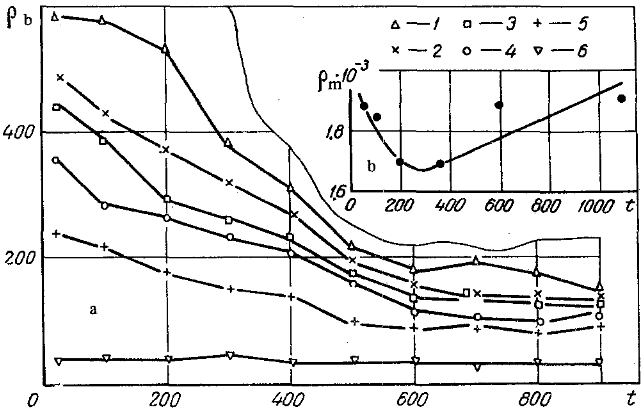

Fig. 4. Resistivity as a function of temperature: a) fluidized bed of graphite particles with an average diameter of 0.377 mm at various bed expansions H/H_0 (1) 1.5; 2) 1.4; 3) 1.3; 4) 1.2; 5) 1.1; 6) 1.0); b) rod of electrical graphite.

An increase in current density and bed temperature reduces the resistance at the contact point and causes the current to propagate in the form of spark discharges between particles across the gas contact gaps.

NOTATION

i is the current density, A/cm^2; l is the distance between the electrodes, cm; R is the measured resistance of the bed, ohms; S is the cross-sectional area of the bed for the passage of current, cm^2; ρ is the electrical resistivity of the bed, ohm · cm. Subscripts: b denotes the bed; m denotes the material of bed particles; c indicates contact between the particles; 0 represents the fixed bed; c.g. represents the contact gaps between the particles.

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