

CALCULATION OF AVERAGE BED POROSITY

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Results of various authors on the average porosity of different shapes of grains (spheres, cylinders, lumps, Rashing rings) are codified, and relationships are derived between the porosity of fixed granular bed and the ratios of vessel diameter to grain diameter and the shape of the grains.

A formula is proposed for engineering evaluation of bed porosity, the accuracy of the calculation from which is improved as a result of the statistical representativeness of an array of experimental data.

A fixed granular bed (FGB) of sorbent, catalyst, or inert packing, which is charged into an industrial vessel, is a complex system. The free-volume fraction of the FGB is known as the porosity of the granular bed. Here, the internal pores of individual grains are disregarded in the calculation. The average porosity ε of an FGB is a statistical characteristic of the bed, which is required for thermal and hydraulic analyses of contact and adsorption vessels.

The porosity of FGB will depend on the method of charging, the shape of the grains, the ratio of the vessel diameter D to the grain diameter d , and a number of other parameters [1].

The exact porosity value can only be determined experimentally by measuring the bulk density ρ_b of the bed and the density ρ_s of the grains of the solid phase:

$$\varepsilon = 1 - (\rho_b / \rho_s).$$

Formulas proposed for porosity calculation as a function of the geometric parameter D/d [1–8] yield substantial differences even for grains of the same shape. For grains in the form of cylinders, therefore, discrepancies may reach 50% in evaluating porosity (Fig. 1).

For ratios $D/d < 2.4$, Pushnov [9] derived the empirical expression $\varepsilon = A(D/d)^m e^{n(D/d)}$ (where $A = 12.6$, $m = 6.1$, and $n = -3.6$), which makes it possible to calculate the porosity of a bed of spherical grains with sufficient accuracy.

Generalization of results of my own experiments and data [1–8, 10] on the average porosity of grains of different shape indicated that for cylindrical vessels with $D/d > 2$ and FGB height $H > 20d$, they all can be approximated by the expression

$$\varepsilon = \frac{A}{(D/d)^n} + B, \quad (1)$$

where A , B , and n are constants dependent on the shape of the grains (see Table 1).

Figure 2 presents graphical relationships between FGB porosity and ratios $D/d > 2$ for grains of different shape, which were obtained from formula (1). The average deviation of the experimental ε values from those computed on the basis of formula (1) is: $\pm 5.26\%$ for spherical grains, $\pm 12.9\%$ for cylinders, $\pm 10.47\%$ for lumps, and $\pm 14.23\%$ for Rashing rings. Figure 3 shows the scatter of local average-porosity values (cross-hatched) with respect to experimental data derived by various authors [1–9].

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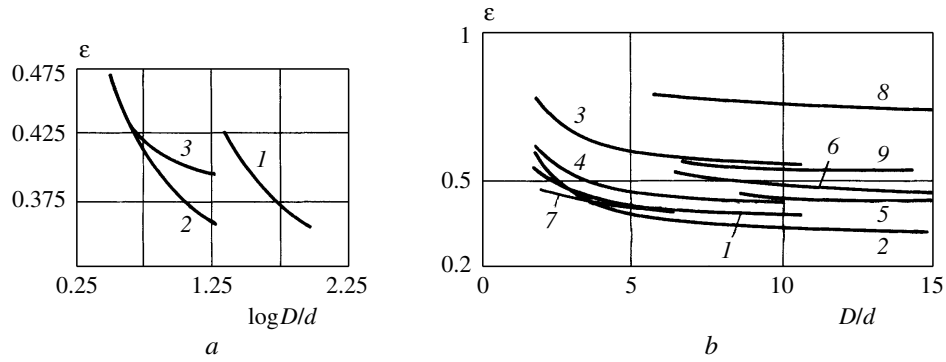


Fig. 1. Dependence of FGB porosity on ratio D/d according to various authors: a) spherical grains: 1) [7]; 2) [8, 6, 2]; 3) [3]; b) grains of different shape: 1) spheres [1]; 2) cylinders [1]; 3) Rashing rings [1]; 4) grains of irregular shape [1]; 5) cylinders, $d_{\text{avg}} = 11.4$ mm [4]; 6) cylinders, $d_{\text{avg}} = 14.85$ mm [4]; 7) spheres, $d = 12, 17$, and 25 mm [5]; 8) Rashing rings with dimensions of $50 \times 50, 35 \times 35, 25 \times 25$, and 15×15 mm [5]; 9) lumps, $d_{\text{avg}} = 7$ and 12 mm [5].

TABLE 1

Shape of grains	Coefficients*		
	A	B	n
Spheres	1.0	0.375	2
Cylinders	0.9198	0.3414	2
Lumps of irregular shape	1.5	0.35	1
Rashing rings	0.349	0.5293	1

* Obtained with free charging of grains and no additional compaction.

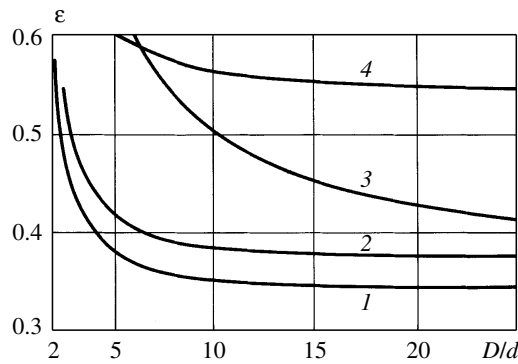


Fig. 2. Dependence of FGB porosity on ratio D/d for grains of different shape; 1) spheres; 2) cylinders; 3) lumps; 4) Rashing rings.

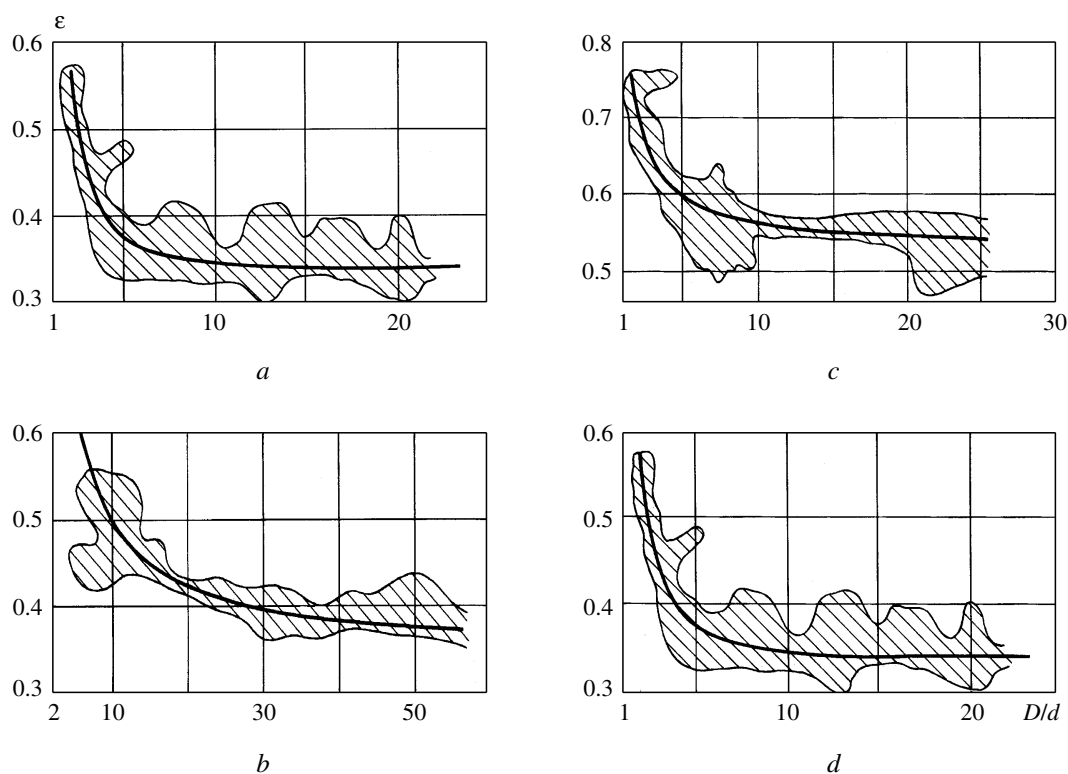


Fig. 3. Dependence of FGB porosity ε on ratio D/d and shape of grains: a) cylinders; b) lumps; c) Rashing rings; d) spheres.

Formula (1) is recommended for engineering evaluation of the most probable value of average porosity in cylindrical vessels with grains assuming shapes most widely encountered in industrial practice – spherical, cylindrical, lump, and annular. The accuracy of FGB porosity ε calculated from the proposed formula is improved as a result of the significant statistical representativeness of an array of processed experimental data on average porosity.

Thus, the proposed relationships make it possible to enhance the computational accuracy of the average porosity, and can be used in the chemical and oil-and-gas industries, thermal-power engineering, and other branches of industry, where contact and adsorption vessels with FGB are in use.

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