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ANALYSIS OF MAGNETIC AND HYDRAULIC FORCES IN AN ORIENTED REAL MATRIX OF A HIGH GRADIENT MAGNETIC SEPARATOR

V. HENCL[x], K. JAHODA[x], E. MADAI[xx]

Abstract The application of existing theoretical models for the computation of magnetic and hydraulic forces in a real oriented matrix consisting of regularly arranged rods and wires indicates that these models produce no exact results. The differences between computations and measurements of force effects documented by Maxwell[1] lead to the conclusion that it is necessary to start with different physical assumptions when modelling a high-gradient separation process. First of all, the magnetic field of the rods or wires system differs from the magnetic field of a single rod. Second, the particle need not be attracted to the rod surface, it is brought there by the suspension stream and the magnetic force must hold it, so that it is not entrained by the streaming suspension. As the layer of attracted particles grows, the magnetic attractive force on the surface of the growing layer decreases until the magnetic attractive force is in equilibrium with the entraining force of suspension flow.

MAGNETIC FIELD FORCES

The magnetic potential of a single rod placed in a magnetic field in distance z from its centre as the point A in Fig. 1 shows, is given by the equation

$$\phi = -i\, H_o(z + R^2/z), \quad /A/ \qquad (1)$$

where $i = \sqrt{-1}$.

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The position of the point A is given by the complex variable $z = x + iy$, the potential is usually expressed as the product of the field intensity H_o and the function of a complex variable $F(z)$ according to the equation

$$\phi = H_o \, F(z) \qquad /A/$$

where $F(z) = -i \, (z + R^2/z) \qquad /m/ \qquad (2)$

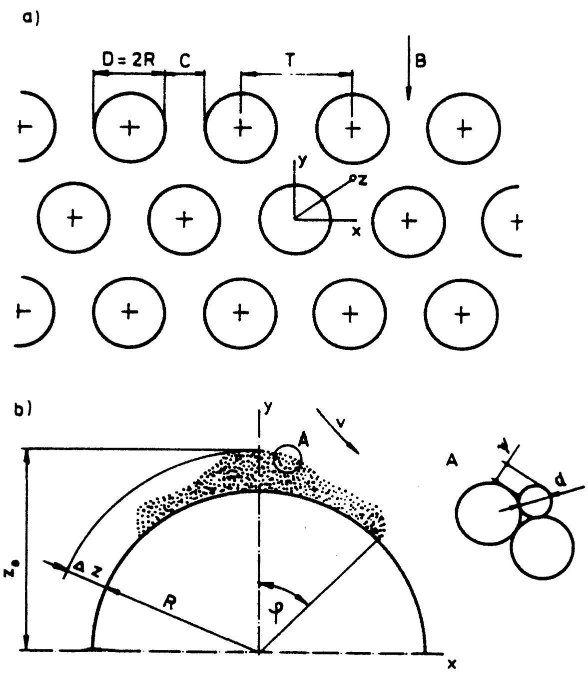

FIGURE 1 Scheme of rod oriented matrix and schematic illustration of sedimented layer on the matrix element

Madai[2] has expressed the function of potential in the point A of matrix consisting from many rows of rods or wires /see Fig. 1/ by Eq./2/ and its complex part by the equation

$$F(z) = -i \, (F_1/z/ - F_2/z/). \qquad (3)$$

In order to determine the magnetic force as a vector, we decompose the complex potential F(z) into its real and imaginary parts according to the equation

$$F(z) = u + iv \tag{4}$$

The components of the magnetic force f_x and f_y are determined by substitution into Eq./3/ from derivatives of the real part with respect to coordinates x, y. Then we can compute the magnetic force according to the equation

$$f_m = \sqrt{f_x^2 + f_y^2} \tag{5}$$

The example of such a very complicated calculation is given in Fig. 2b. For example, the line connecting force contour lines on the level 0.3 connects the points, where the magnetic force f_m equals three tenths of the maximum force f_{oo} acting on the surface of a rod in the direction of the y-axis. The force countour lines calculated from the classical equation for a single rod are shown in part a of the same Figure and it is obvious that values so obtained differ considerably.

EROSION FORCES OF A STREAMING SUSPENSION

The velocity of suspension flow in the matrix, schematically shown in Fig. 1, depends on the height of the suspension's surface h_1 over the upper row of rods and on the count of rows i with the height h. The thickness of intercepted magnetic fraction Δ_z depends on the velocity of streaming suspension with the constant magnetic force f_m. When the velocity of streaming is higher, outer particles of the intercepted layer are taken along more intensively by the suspension flow and the thickness of intercepted layer gets smaller. The magnetic attraction forces able to intercept and keep the magnetic particle on the rod surface are concentrated in an area determined by the angle ψ of Fig. 1. If the suspension

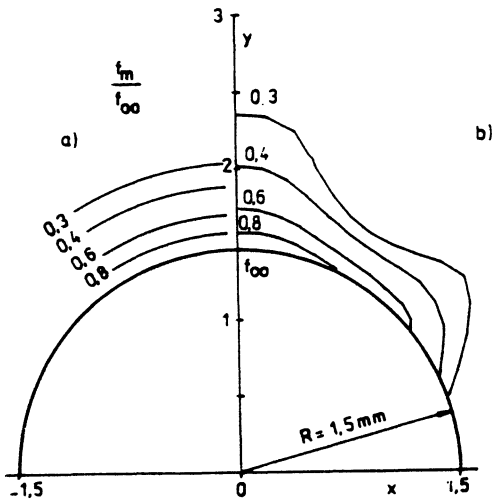

FIGURE 2 Force contour lines of magnetic field of single rod /a/ and a rod in a real matrix /b/

flows perpendicularly to the rods in the direction of magnetic force contour lines, then there is an area 2 R sinψ for each distance $\underline{T}$, where the particle can be intercepted. The probability of particle interception on one row of rods is given by Eq./6/. For $\underline{i}$ rows of rods this probability increases according to the equation /7/

$$p = 2R \sin\psi T \tag{6}$$

$$p_l = 1-(1-p)^i \tag{7}$$

For example, when the matrix has 32 rows of rods, the probability of possible particle interception p_l = 99,9996%.
In order to compute the erosion force taking the intercepted particles away from the rod surface, it is necessary to determine the elevation force caused by the difference of flow velocity around the particles and among them. The suspension with specific density

ρ_r streaming with flow velocity $\underline{v}$ causes the underpressure against the space among intercepted magnetic particles $\Delta p = 0.5\ \rho_r\ v^2$. This underpressure elevates a particle of diameter d by the force $\Delta p\ \pi d^2/4$. If this force is related to a spherical particle of unit mass, the erosion force can be computed according to the equation:

$$f_e = \frac{3\rho_r\ v^2}{4\rho_z d}\ (1 + 18.5\ \psi Re^{-0.6}) \qquad /N/kg/ \qquad (8)$$

where Re is the Reynolds number of the particle and where ψ (the 'erosion coefficient') is the fraction of the surface exposed to the entraining effect of the flow.

The magnetic and erosion forces of a streaming suspension are in equilibrium on the interception boundary of the magnetic particle layer. This equilibrium can be expressed by the simple equation

$$f_m = f_e \qquad /N/kg/ \qquad (9)$$

APPLICATION OF MAGNETIC AND EROSION FORCES EQUILIBRIUM MODEL

An example of magnetic and erosion forces equilibrium model application is the computation of the limiting grain size resulting from Eqs. (8) and (9). The limiting grain size can be determined by the equation

$$d_{min} = \frac{3\ \rho_r\ v^2}{4\ \rho_z\ f_m} \qquad /m/ \qquad (10)$$

This example of computations application is shown in Fig. 3. From the diagram we can determine e.g., that the limit grain size is approximately 10 μm at suspension flow velocity 0.1 m/s and specific magnetic force f_m = 240 N/kg on the boundary of the intercepted layer, considering rod radius R = 1.5 mm, distance between

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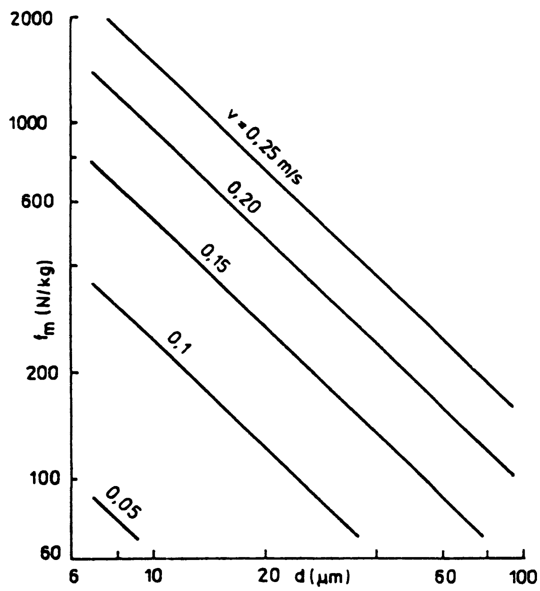

FIGURE 3 Dependence of limit grain size in a matrix on the flow velocity /v/ and magnetic force /f_m/

Figure 3a shows curves of Fe recovery into separate granulometric classes in feed and in magnetic fraction obtained during experimental verification of slightly magnetic iron ore separation on the Czechoslovak VMS type high gradient magnetic separator[3] with this matrix of rods. The results were obtained under the same conditions as those in the limiting grain size computation.

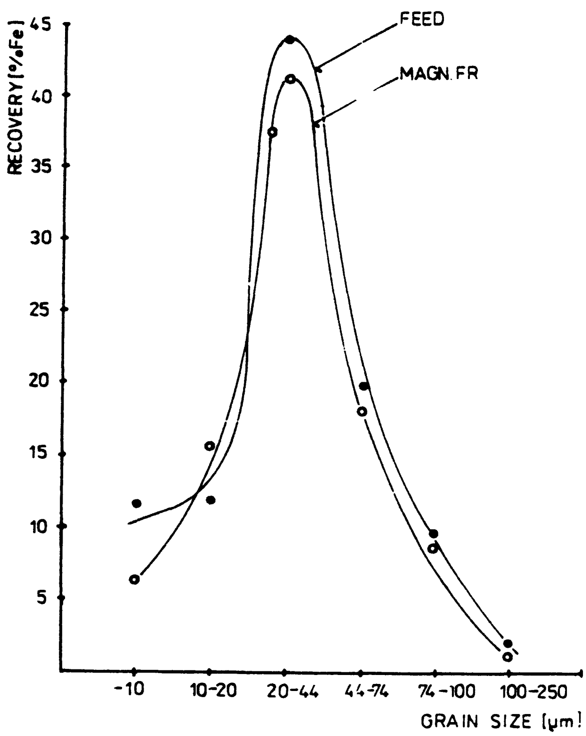

FIGURE 3a Fe recovery into grain fractions in feed and in the magnetic fraction

It is obvious that Fe recovery declines more considerably only at grain sizes under 10 µm and that the correspondence of computed and experimental results is very good for application of the equilibrium magnetic and erosion forces model. Another example of the new model application can be the computation of separation efficiency η in dependence on the specific load G_o and on the diameter of rods forming the matrix.

In Fig. 4 curves 2 and 3 show the computed dependence of separation efficiency on the diameter of rods with constant distance 1.5 mm, with two different values of specific load G_o

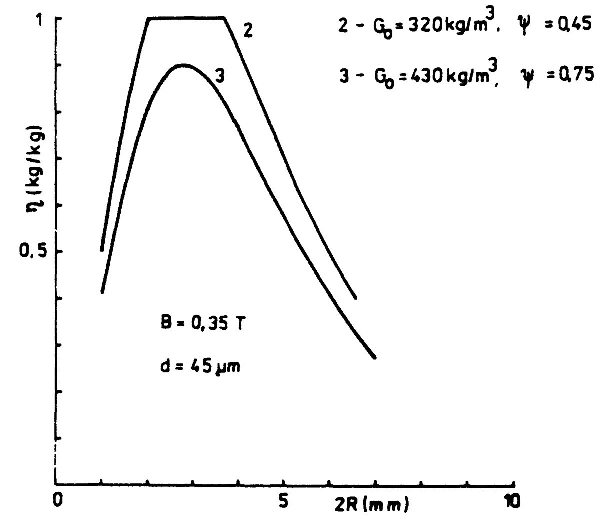

FIGURE 4 Influence of rod diameter 2R and specific load G_o on separation efficiency

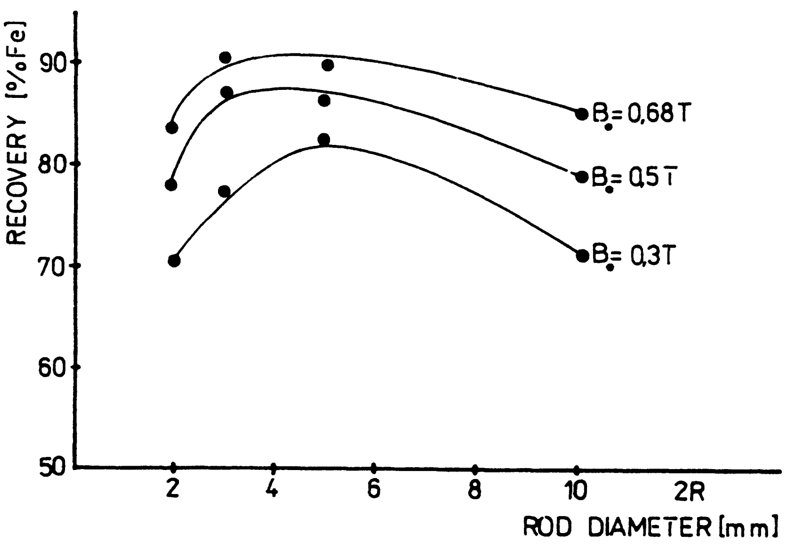

FIGURE 4a Influence of rod diameter on Fe recovery into magnetic fraction

and different erosion coefficient ψ. An efficiency optimum is achieved with rods diameter 2 - 4 mm.

Fig. 4a shows graphically the experimental results obtained during separation of the same slightly magnetic iron ore in matrices with rods of different diameter, also with distances 1.5 mm at different induction levels of magnetic field, B, and with constant specific load 330 kg/m^3. Obviously, curves shapes are similar to each other and the efficiency optimum dependence on rod diameter is consistent with the computed values.

CONCLUSIONS

The application of a high gradient magnetic separation process model based on the equilibrium of magnetic and erosion forces presents the satisfactory correspondence of computed and experimental results as documented by above mentioned practical application. Works of further verification and of defining the model more precisely are in progress.

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