THE MATRIX-TYPE MAGNETIC SEPARATOR

By Foster Fraas

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THE MATRIX-TYPE MAGNETIC SEPARATOR

by

Foster Fraas[1]

ABSTRACT

A separator for minerals of low magnetic susceptibility and fine particle size in a water suspension is described. A ring-shaped matrix of ferromagnetic fragments rotating so as to pass successively through magnetic-field and field-free regions provides for the separation. Application is illustrated in the separation of hematite and ilmenite from quartz.

INTRODUCTION

Bureau of Mines research on the magnetization of minerals started with an investigation of the magnetization time factor (3),[2] and later extended to a correlation of magnetic susceptibility with composition (2, 4). This resulted in the design of a matrix-type separator. Although the original objective was to measure the time factor effects, the time of magnetic exposure of minerals was found to be too long to obtain significant results. However, the device has merits as a new type of high-intensity separator for minerals in water suspension.

Magnetic separation is of unique value for certain ores, particularly hematite ore and ores containing titanium, tin, chromium, columbium, manganese and the rare earths. For these separations a high intensity separator is needed. Present commercial high intensity separators are restricted to dry feeds. A water suspension-type separator has some features which would result in increased applications. It would not require a preliminary drying stage when inserted in a water suspension mill circuit, and it would be particularly adaptable to small particle sizes, since ores ground to very fine sizes are more easily dispersed in water.

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[2]Underlined numbers in parenthesis refer to items in the list of references at the end of this report.

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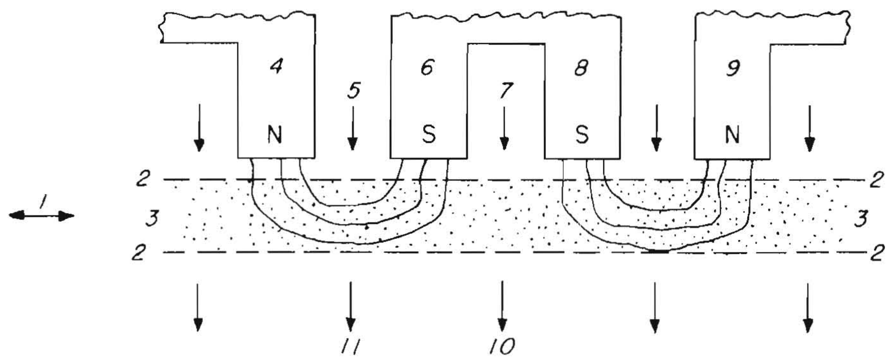

FIGURE 1. - Schematic Diagram of Matrix-Type Separator.

PROCEDURE AND RESULTS

Basic Feature of Separator

The basic feature of the separator is illustrated in figure 1 where 2 are porous confining walls for the purpose of retaining matrix 3. The matrix consists of discrete fragments of ferromagnetic material having a low magnetic retentivity. For illustrative purposes the fragments may be envisioned as spheres of annealed iron. Placed close to the matrix are magnet poles 4, 6, 8, and 9. Poles 6 and 8 have the same polarity. A similarity in polarity also exists between pole 9 and the next succeeding pole and pole 4 and the adjacent preceding pole. As a result, the magnetic field between 4 and 6 passes through the matrix. A second field exists between 8 and 9. Any number of poles may thus be added along the matrix.

With discrete bodies the variation in the continuity of the ferromagnetic mass in the direction parallel to the magnetic flux provides a pinching effect on the flux and resulting nonhomogeneous stray fields outside the ferromagnetic mass and within the interstices. If particles of a mineral of sufficiently high magnetic susceptibility are permitted to flow through the interstices, they will be retained by the magnetic forces of these stray fields. Nonmagnetic particles and those of lower magnetic susceptibility, flow through without retention. Operation as a separator is provided by moving the matrix continuously in one direction or reciprocating as indicated by the arrow 1. By feeding at point 5 a suspension of particles in a fluid such as water, the magnetic particles will be retained and the nonmagnetic particles will be discharged at point 11. If the matrix is moved to the right, that portion containing the magnetic particles will be in the zero field region between poles 6 and 8. A stream of wash water at point 7 removes these magnetic particles which exit at point 10.

Ring-Type Matrix Separator

Figure 2 illustrates a separator in which the matrix is in the form of a ring or rather a disk with a central hole. In the cross sectional view, 10-mesh aluminum wire screens 14 retain matrix 15. The screens and matrix are in the annular space between aluminum ring 1 and aluminum disk 7 which is fastened to steel shaft 13. The ring assembly is placed in the magnet pole slots 3, 6, 12, and 9 which are sufficiently wide to allow a 1/16-inch gap on either side. The zero field regions are between poles 3 and 12, and poles 6 and 9. The magnetic flux between poles 3 and 6, and poles 12 and 9 must necessarily thread its way through the matrix 15.

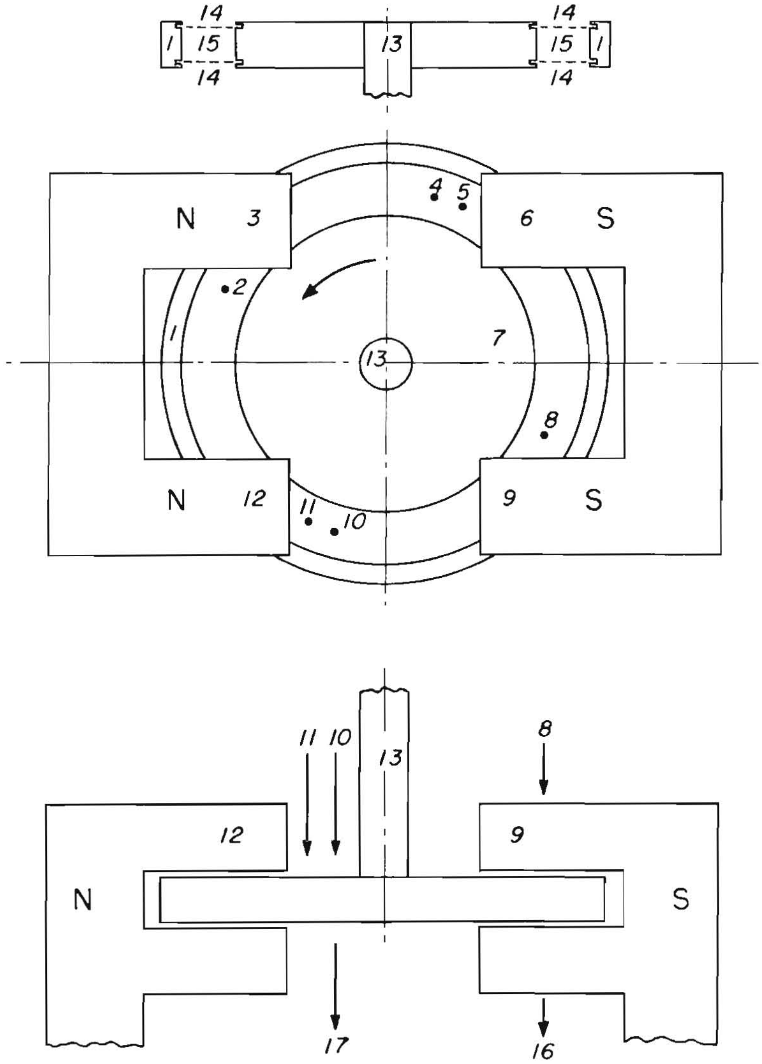

FIGURE 2. - Ring-Type Matrix Separator.

As the shaft turns in the direction indicated by the arrow, feed in water suspension is added at point 11. Operation of this arrangement indicates that additional wash water is needed to completely remove the nonmagnetic particles from the matrix. This wash water is added at point 10. The nonmagnetic particles exit at point 17. After the magnetic particle laden portion of the matrix rotates from between poles 12 and 9 to the zero field region between poles 9 and 6, wash water is added at point 8, and the magnetic particles are released and exit at point 16. Since in one revolution the operation passes through two cycles, feed can also be added at point 5, and wash water at points 4 and 2. The location of the mechanical drive and discharge launders above and below the matrix is illustrated in figure 3. Magnetic short circuit by the mechanical drive support was avoided by using stainless steel for the vertical threaded rods and aluminum for the horizontal bars.

Performance of Separator

For these demonstrative tests the matrix consisted of cadmium plated steel round-head machine screws with a 1/4 inch length and a 6/32 thread. The screws were simply poured through holes 2 in the outer ring 1 illustrated in greater detail in figure 4. The ring 1 was split at 4 into two halves permitting assembly with the screens held in slots 7 and 8. Eight zinc chromate plated steel screws 3 with a 10/24 thread fastened the ring to the disk 5. For larger diameter commercial separators, screws 3 could be replaced by rigid ferromagnetic spokes fastened to a nonmagnetic hub. The four magnetic poles would also be increased in number.

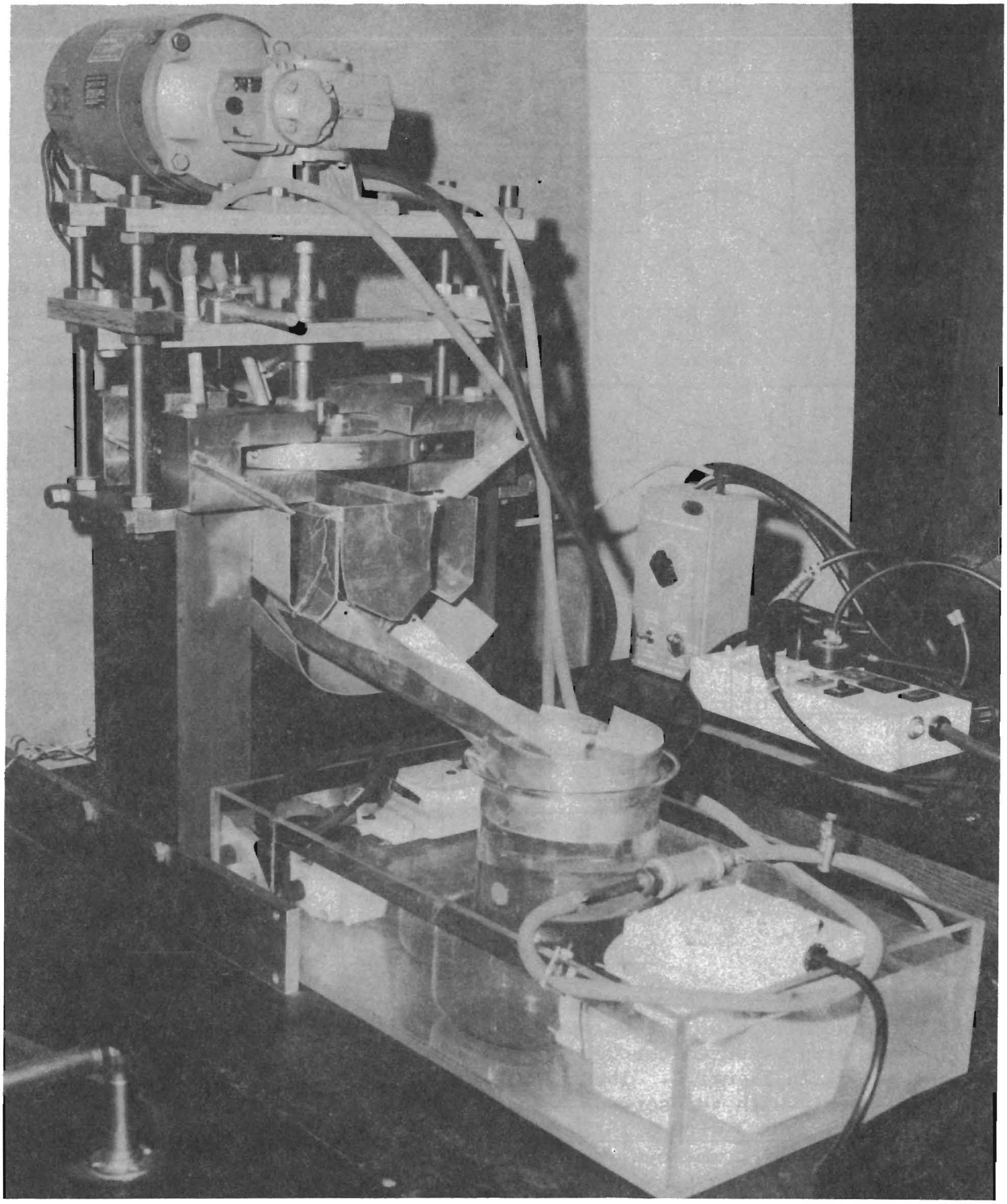

FIGURE 3. - Complete Separator With the Mechanical Drive Above the Matrix and the Magnetizing Coil Below the Discharge Launders.

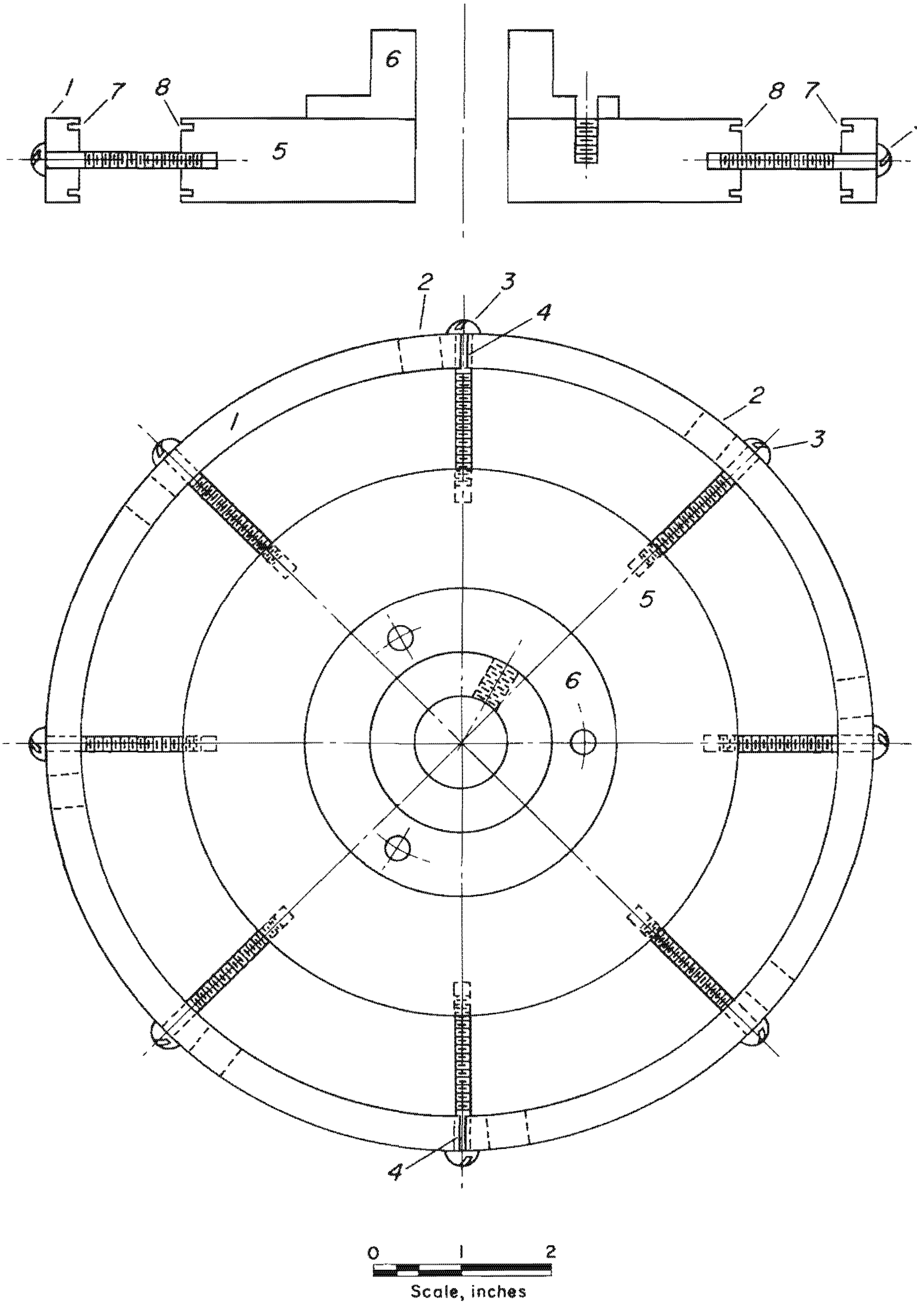

FIGURE 4. - Construction Detail of Matrix Ring.

Typical performance is illustrated by table 1 which supplies data for the separation of a synthetic mixture of crushed quartz and ilmenite sand with a size range of minus 35 plus 100 mesh. The magnetic and nonmagnetic fractions from one passage through the separator were each recleaned with a second passage. Four fractions were thus obtained, a recleaned magnetic fraction, a recleaned nonmagnetic fraction, and two additional fractions resulting from the recleaning operations. The water suspended feed had a flow of 0.8 gallons per minute, while the wash water flows for nonmagnetic and magnetic dislodge were 0.6 and 1.7 gallons per minute respectively. The ring rotated at 10 rpm.

TABLE 1. - Separation of ilmenite and quartz

Fraction	Weight-percent	Composition percent ilmenite[1]	Calculated recovery, percent	
			Ilmenite	Quartz
Recleaned magnetic fraction............	64.6	99.8	84.2	0.4
Reject from reclean of magnetic fraction	7.2	76	7.1	7.4
Reject from reclean of nonmagnetic fraction............................	7.7	85	8.5	4.9
Recleaned nonmagnetic fraction..........	20.5	0.55	0.2	87.3
Total............................	100	76	100	100

[1]Analysis by hand magnet and weighing.

The ilmenite in these tests is the trivalent iron-type described in a previous publication (3). Trivalent iron ilmenite is of a lower magnetic susceptibility than the divalent iron ilmenite. The results were obtained with a magnetic flux source of 11,400 ampere turns[3] around an Armco[4] iron core 6 inches in diameter and 8 inches long. With the same flux, 40 percent of a pure monazite feed is retained as magnetic. In a nonrotative test with a calculated 50-percent increase in flux, all of the monazite was retained as magnetic.

The magnetic susceptibility of the monazite and ilmenite may be estimated from the data in reference (3) which includes as magnetic standards the pure compounds, ferrous ammonium sulfate [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$], nickel ammonium sulfate [$Ni(NH_4)_2(SO_4)_2 \cdot 6H_2O$], and chromium potassium sulfate [$CrK(SO_4)_2 \cdot 12H_2O$]. The magnetic susceptibility of these standards is summarized in table 2. From this data and the data of reference (3) the specific magnetic susceptibility of the sample of monazite is estimated to be approximately 12×10^{-6} emu. The magnetic susceptibility of the ilmenite is greater than 32×10^{-6} emu.

A similar test was conducted with a black specular hematite ore ground to minus 35 mesh and deslimed. However, the coarse size particles consisted of locked grains of hematite and quartz. Table 3 summarizes the data for the minus 150-mesh portions of the separated fractions. For this finer material the recleaned concentrate represented a 66-percent recovery in a fraction

[3]32.4 ohm coil of 4,000 turns of 16 B & S gauge wire.
[4]Trade names are used for information only, and endorsement by the Bureau of Mines is not implied.

assaying 98.9 percent hematite. Recovery could be increased by returning the rejects from the recleaning operations to the original feed.

TABLE 2. - Magnetic susceptibility of standards

Standard	Magnetic susceptibility emu	
	$\chi_m \times 10^6$ [1]	$\chi \times 10^6$ [2]
$Fe(NH_4)_2SO_4 \cdot 6H_2O$......	12,400	31.6
$Ni(NH_4)_2SO_4 \cdot 6H_2O$......	4,210	10.7
$CrK(SO_4)_2 \cdot 12H_2O$.......	6,100	12.2

[1]Magnetic susceptibility per mole from pages 50, 66, and 99 of reference (1).
[2]Specific or magnetic susceptibility per gram calculated from the molal values.

TABLE 3. - Separation of minus 150 mesh Ishpeming, Mich., hematite ore

Fraction	Weight-percent	Analysis by particle number, percent hematite	Hematite recovery, percent
Recleaned magnetic fraction[1]...............	54.6	[2]98	66.2
Reject from reclean of magnetic fraction...	14.5	80	14.3
Reject from reclean of nonmagnetic fraction	15.9	87	17.1
Recleaned nonmagnetic fraction............	15.0	13	2.4
Total................................	100	81	100

[1]Size analysis = 13.3 percent minus 325 mesh.
[2]Weight-percent composition calculated from specific gravity = 98.9 percent hematite. Chemical analysis = 69.3 percent Fe.

Although it is probable that finer size material could be separated, the tests here were limited by the size of the sedimentation vessels. With this sample of hematite and the previous ilmenite, the magnetic portion of the feed was retained only in matrix. There was no accumulation on the slotted pole caps. However, with a sample of red hematite from Ironton, Minn., some magnetite impurity in the sample accumulated on the pole caps. For feeds containing magnetite a preliminary low intensity separation would be necessary.

Magnetic Circuit Losses

The elements in the magnetic circuit illustrated in figure 5 are related by the equations,

$$\phi\ (Z_0 + Z_1 + Z_2 + Z_3 + Z_4 + Z_5) = \frac{4\pi}{10} NC \qquad (1)$$

$$Z = \frac{1}{\mu a} s \qquad (2)$$

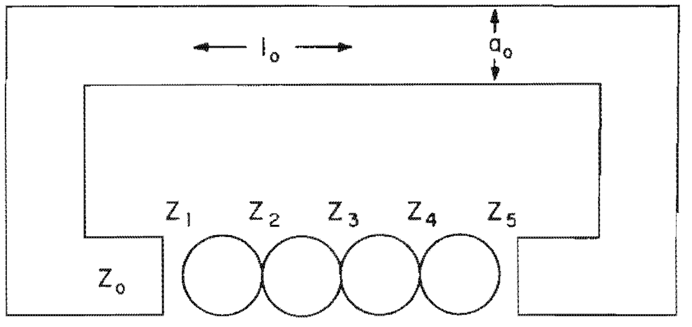

FIGURE 5. - Magnetic Circuit of Separator.

where ϕ = magnetic flux through the circuit, maxwells (1 maxwell per cm^2 = 1 gauss),

mmf = $\frac{4\pi}{10}$ NC = magnetomotive force, gilberts,

N = number of turns in magnetizing coil,

C = electric current per coil turn, amperes,

Z = magnetic reluctance, oersteds (1 oersted = reluctance of empty space, 1 cm long and 1 cm^2 cross section),

a = cross sectional area of circuit, cm^2,

l = length of circuit, cm,

μ = magnetic permeability,

and s = stray field leakage.

The magnetic circuit is analogous to the electric circuit with the exception that the magnetic circuit includes leakage due to stray fields. For the magnet compared to an electric cell, $\frac{4\pi}{10}$ NC would be equivalent to the cell potential, $\frac{l_0}{\mu_0 a_0} s_0$ the internal resistance of the cell, $\frac{l_1}{\mu_1 a_1} s_1$ the connected external resistance, and ϕ the resulting current. The significance of a_0 being large and l_0 being small is that of a large cell with low internal resistance. Magnetic permeability, μ, is comparable to the reciprocal of an electrical resistivity which is dependent on current flow.

Figure 5 is a simplification of the magnetic circuit for the separator illustrated in figure 2. Z_0 is the reluctance of the ferromagnetic core of the magnetizing coil and the magnet poles through which the matrix moves. Z_1 and Z_5 represent the reluctance of the air gaps between the magnet poles and matrix. The reluctance of the matrix is a composite value, but for illustrative purposes this has been represented in figure 4 as a single row of spheres, with the reluctance at contact points equal to Z_2, Z_3, and Z_4.

The mmf generated by the magnetizing coil is dissipated by the reluctance of the circuit, some of which is useful. The mmf drop through the matrix may be considered useful since the stray fields generated by this drop result in the tractive forces of separation. The mmf drop through the air gaps is a loss.

To determine what proportion of the mmf drop is lost, the magnetic reluctance of the matrix was measured by a substitution method based on the provision that with this method s in equation (2) would cancel out, at least to the extent required for an approximate calculation. In figure 6, 1 and 6 are the 4-inch-diameter movable pole caps of a magnet. With the matrix 5 poured into the plastic retaining ring 4, the magnetic circuit was completed with the 2-3/4-inch-diameter Armco iron cylinder 3 resting on top of the matrix. Nonmagnetic spacers 2 between cylinder 3 and magnet pole 1 provide a 1/4-inch air gap into which may be inserted a probe for flux intensity measurement.

By substituting an air gap with $\mu = 1$ for the matrix in space 5, the permeability of the matrix may be calculated. With the specific values of a 0.469-inch gap for the matrix filling and a 0.125-inch gap for the substituted air space, the permeability of the matrix calculated by equation (2) is $\mu = 3.8$. The ampere turns and the flux intensity of 3,300 gauss in gap 2 were maintained constant. Flux intensity was measured near the center of the cylinder with a Bell model 300 gaussmeter.

The calculated reluctance in table 4 shows that the introduction of the air gap to provide for the movement of the matrix through the magnetic fields results in very little increase in the mmf drop. Only 5 percent of the mmf drop is in the air gap. Since additional air gap loss may be tolerated, a close clearance gap would not be required in the design of large size commercial separators.

The flux intensity of 3,300 gauss used for the permeability measurements is close to actual values in separator operation. The measured value in the air gap for the separation reported in table 1 was in the range of 1,000 to 1,500 gauss. Since the magnetic flux source is not interrupted, the magnetic flux for the separator may be supplied by a permanent magnet or by superconductor coils at cryogenic temperatures.

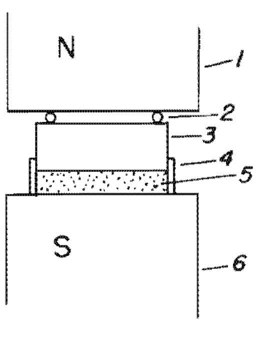

FIGURE 6. - Magnetic Circuit for Measuring Reluctance by a Substitution Method.

TABLE 4. - Calculated reluctance of separator circuit segments

Circuit segment	Segment dimension		Permeability, μ	Calculated reluctance, oersteds	mmf drop, percent
	Length, cm	Area, cm^2			
Air gap	0.318	23.6	1	[1]0.027	5
Matrix[2]	[3]10.2	5.1	3.8	.53	95

[1]Two air gaps, Z_1 and Z_5 in series.
[2]Randomly oriented round head machine screws, 1/4 inch long, 6/32 thread.
[3]Distance between poles 3 and 6, figure 2.

CONCLUSIONS

Minerals of low magnetic susceptibility may be efficiently separated in a separator in which a flat ring shaped matrix of ferromagnetic fragments moves continuously through alternate field and field free regions. The flat ring, or disk with a central hole, is an ideal design. The large area flat side of the disk provides a small mmf drop for flux passing into the matrix, while the smaller area cross section of the disk provides a large mmf drop for flux passing within the matrix. It is this large mmf drop within the matrix that generates the high intensity magnetic fields for separation. With feed flow perpendicular to the large area flat side of the disk, high feed rate capacities are possible.

REFERENCES[5]

1. Foex, G. Constantes Selectionees, v. 7 Diamagnetisme et Paramagnetisme. (Selected Constants, v. 7 Diamagnetism and Paramagnetism) Masson, Paris, 1957, 317 pp.

2. Fraas, F. Linear Correlation of Magnetic Susceptibility With the Chemical Composition of Minerals. BuMines Rept. of Inv. 6379, 1964, 13 pp.

3. _____. Magnetization Delay in the Separation of Minerals. BuMines Rept. of Inv. 6411, 1964, 13 pp.

4. _____. Calculation of Adsorption Energy. BuMines Rept. of Inv. 6639, 1965, p. 2.

[5] Titles enclosed in parentheses are translations from the language in which the item was published.