SUPERCONDUCTIVE HELICAL FLOW MAGNETIC ORE SEPARATOR

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Abstract

A high field helical flow-through separator to concentrate weakly magnetic ores is described. The process is to flow slurry helically around a current carrying conductor in a cylindrical annulus. The magnetic field gradient forces magnetic particles inwards towards the conductor. Nonmagnetic particles (gangue, sands, etc.) are deflected outwards by centrifugal force. Separation occurs at the exit end of the channel where a divider separates inboard from outboard slurry. The experimental part of this experimental and theoretical study is reported here. Carefully sized synthetic ore particles with and without sand in a slurry are used. Experiments cover a wide range of particle sizes (100 - 800 microns), magnetic moments (1.4 - 4.8 Am^2/kg), velocities (1.5 - 4 m/sec), magnetic flux densities (0 - 1.6 T), input solid concentrations (2.6 - 15% by weight), and input grades (16.5 - 100%). Satisfactory separation is found within the above parameter regions.

Introduction

Only two flow-through separator systems were available at the start of this work [1,2]. In the first a slurry of magnetic and nonmagnetic material flows through a horizontal channel positioned under a longitudinal straight wire conductor [1]. Magnetic particles deflect up towards the conductor and nonmagnetic particles deflect down due to gravity. The concept was successful up to through-put velocities of 3 ft/sec above which excess turbulence was present in the 1/2" by 2" experimental channel. At the end of the channel, the two materials were collected separately by means of a divider.

In the second scheme an early model utilized a helical ramp around a vertical quadrupole [2]. Particles settled on the ramp and moved as a sliding bed with magnetic particles migrating in towards the quadrupole and nonmagnetics migrating outwards. The present helical channel separator uses centrifugal force instead of the gravitational force of the first concept above. This centrifugal force is created by rotation of particles with the fluid around the axis of the channel. The centripetal magnetic force attracts magnetic particles inward while nonmagnetic particles are deflected outward by the centrifugal force. The magnetic and nonmagnetic materials are separated at the end of the channel into two separate outlets, one for the concentrate and the other for the tailings.

The Separator

A prototype separator is used to test the concept and to study the effect of the different parameters on the separation process. The separator consists of two main elements: a channel and a magnet.

The channel is two concentric cylinders with one inlet and two outlets (Fig. 1). The inner diameter of the channel is 14.60 cm, the outer diameter is 18.60 cm and the height is 25 cm. The cross section of the inlet and outlet ducts are 2 cm by 4.4 cm. The outlet duct is separated into two channels each 1 cm wide. The inboard channel carries the inward deflected enriched magnetic ore.

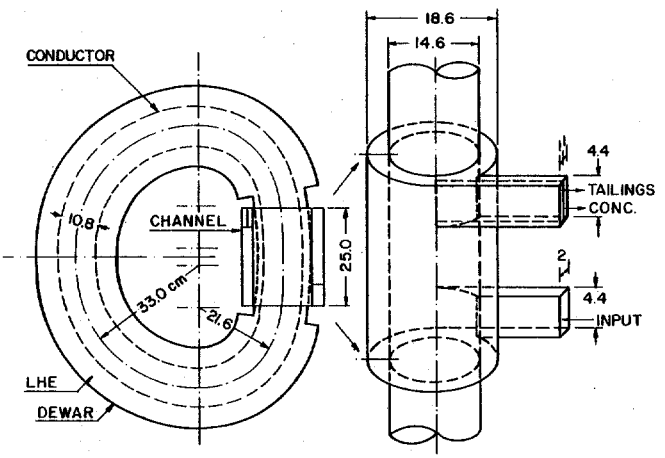

Fig. 1. The separator. Number of turns of the superconducting magnet = 2095, current < 400 A, field at channel mid-surface < 1.6 T, inductance = 3.94 H. The inlet duct of the channel is 2 x 4.4 cm and the outlet ducts are 1 x 4.4 cm each. The practical flow velocity is 1.5 < V < 3.4 m/sec.

The superconducting magnet resembles a doughnut with a slightly curved straight section in the channel region (Fig. 1). The windings of the conductor are 10.8 cm minor diameter inside a 12.5 cm diameter cryostat vessel. The inner dewar is 11.8 cm diameter and the vacuum space is filled with layers of superinsulation. There are two gas ventilated electrical leads and a liquid helium level indicator.

The Experiment

A magnetically homogeneous synthetic ore is fabricated in order to systematically study the performance of the separator. A small amount of very fine magnetite powder blended thoroughly with epoxy resin liquid added to the hardener is continuously shaken to maintain the magnetite in suspension. After setting, the mixture is crushed and ground to the required size. These magnetite-epoxy particles are then mixed with sand to simulate a real ore for test experiments.

Closed loop continuous slurry flow is used to allow time for flow adjustments. The loop components are a mixer, a pump and the separator. The slurry enters the pump which drives it through a venturi meter into the separation channel. The slurry enters the channel tangentially from the bottom, circulates through the separator which enriches the "inner" flow, and then is separated by a thin partition at the exit into two pipes which both return flow to the mixing tank. In the tank the particulate solids are mixed homogeneously throughout the liquid before returning to the separator from the tank bottom.

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The parameters varied are the slurry flow rate, magnetic field, and particle size. Slurry flow rate is measured via a venturi meter. The difference in pressure across the venturi is calibrated to read flow rate. The circumferential magnetic field at any point in the vicinity of the channel is proportional to the current. The magnetic field at the surface of the cryostat is measured with a calibrated transverse Hall probe and a Gauss meter to calibrate the calculated field from the current measurement.

Recovery and enrichment ratios are measured. Recovery is the weight percentage of the synthetic magnetic ore collected in the concentrate compared to the total weight of the magnetic ore in the input. Recovery is evaluated by solid concentration analysis combined with a grade analysis of both concentrate and tailing slurries. The concentration is evaluated for representative samples from the two outlets (inboard and outboard) through solid content analysis. The enrichment ratio is the ratio of concentrate grade to the input grade. The grade of an ore is the weight percentage of the desired constituent which is the synthetic magnetic particles in this case. The grade of both concentrate and tailing is determined by neutron activation analysis and by manual sorting.

Discussion

The properties of the different ore mixtures used in the experiment are listed in Table 1. Separation studies are carried out for through-puts between 1.3 and 3.5 lit/sec. At low flow rates, solid phases settle in the pipes and channels. At high flow rates, the flow become excessively turbulent. The adjustable magnetic field at the mid-surface of the channel is from 0 to 1.6 tesla. In the following graphs the curves are theoretical [3] while the points are experimental.

TABLE 1. PROPERTIES OF SYNTHETIC MAGNETIC ORE AND SAND MIXTURES

#	Particle Size Micron	Magnetic Moment of Synthetic Ore Am^2/kg	Input Solid Conc. %	Percentage of Synthetic Ore in the Mixture
S1	400-800	4.81 ± 0.27	7.9 ± 1.2	38.2 ± 4.2
S2	400-800	1.42 ± 0.12	3.8 ± 0.2	100%
S3	400-800	1.42 ± 0.12	9.1 ± 2.1	35.1 ± 4.3
S4	200-400	3.9 ± 0.54	2.6 ± 0.2	100%
S5	200-400	3.9 ± 0.54	10.9 ± 1.4	23.3 ± 3.0
S6	200-400	3.9 ± 0.54	15.0 ± 2.3	16.4 ± 2.2
S7	100-200	2.46 ± 0.20	3.1 ± 0.1	100%
S8	100-200	2.46 ± 0.20	7.2 ± 1.6	33.3 ± 3.1
S9	100-200	2.46 ± 0.20	10.4 ± 0.8	21.1 ± 2.9

The dependence of separator performance on magnetic field for different ores is shown in Figs. 2 to 5. Recovery and enrichment ratios are plotted as a function of magnetic field at the channel mid-surface. Recovery increases with magnetic field as expected. The rate of increase is higher for larger particle size, for higher magnetic moment, and for slower flow. The enrichment ratio increases with the field and then reaches a maximum and becomes constant. For most of the ores, the enrichment ranges from 2 to 4 which is an improvement of 200 - 400% in grade. In Fig. 2 separation efficiencies for ore # S1 at a velocity of 2.47 m/sec are plotted as a function of magnetic field. An upgrade from 34.5% to 75% with recovery over 90% is achievable at magnetic fields as low as 0.65 T. Figure 3 presents the recovery and

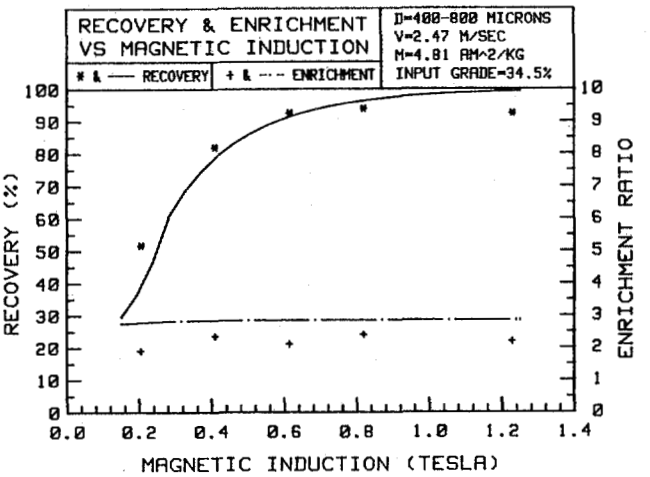

Fig. 2. Recovery and enrichment ratio versus magnetic field for ore # S1 at velocity of 2.47 m/sec.

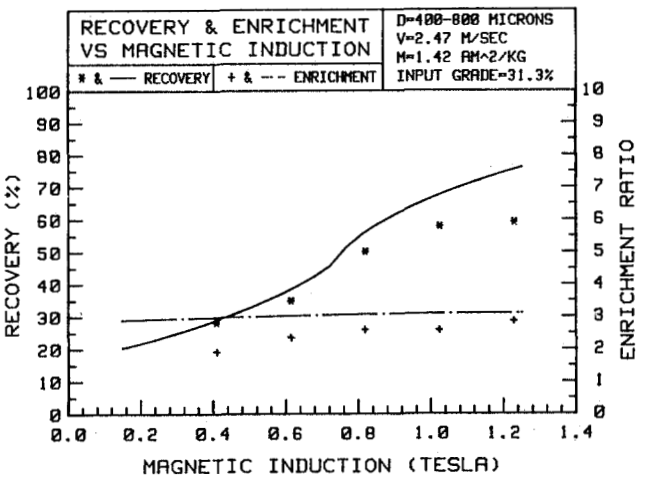

Fig. 3. Recovery and enrichment ratio versus magnetic field for ore # S3 at velocity of 2.47 m/sec.

enrichment for the weaker ore # S3. Ore S3 has a magnetic moment comparable to hematite at 3 T. An improvement in the grade from 31.3% to 90% with a recovery of 60% is shown. Fig. 4 shows the recovery and enrichment ratio versus magnetic field for the smaller particle size ore # S5 at a velocity of 3.04 m/sec. The ore is upgraded from 21.8% input grade to 66% concentrate grade with a recovery of 80% at a magnetic field of 1.22 tesla. The dependence of recovery and enrichment ratio of ore # S8 on magnetic field is shown in Fig. 5. At a field of 1.22 T the ore grade is doubled from 34% to 68% at a recovery of 68%.

Dependence of recovery and enrichment ratio on flow velocity for ore # S1 at a magnetic field of 0.82 T is shown in Fig. 6. Recovery decreases with velocity while the enrichment ratio increases. The fluctuations in enrichment ratio are within the limits of experimental error. Enrichment for the weaker ore at a magnetic field of 1.02 tesla is shown in Fig. 7. Figure 8 shows the relationship between recovery and enrichment ratio and flow velocity for ore # S5, a 200 - 400 μ ore.

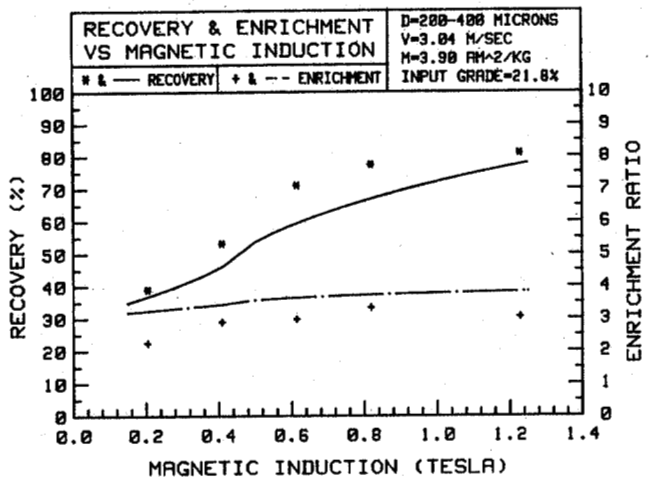

Fig. 4. Recovery and enrichment ratio versus magnetic field for ore # S5 at velocity of 3.04 m/sec.

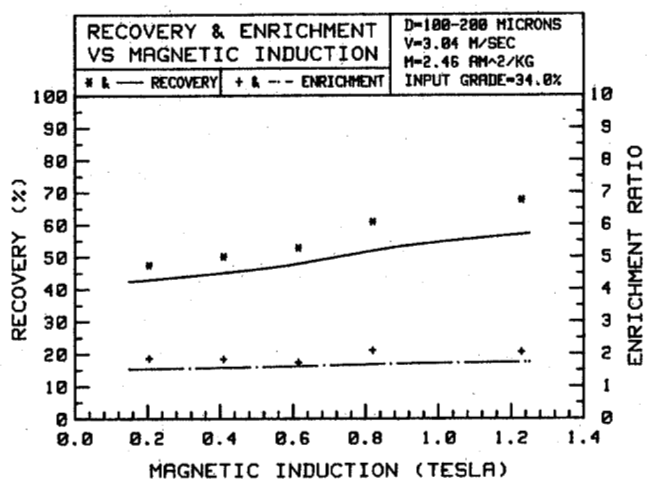

Fig. 5. Recovery and enrichment ratio versus magnetic field for ore # S8 at velocity of 3.04 m/sec.

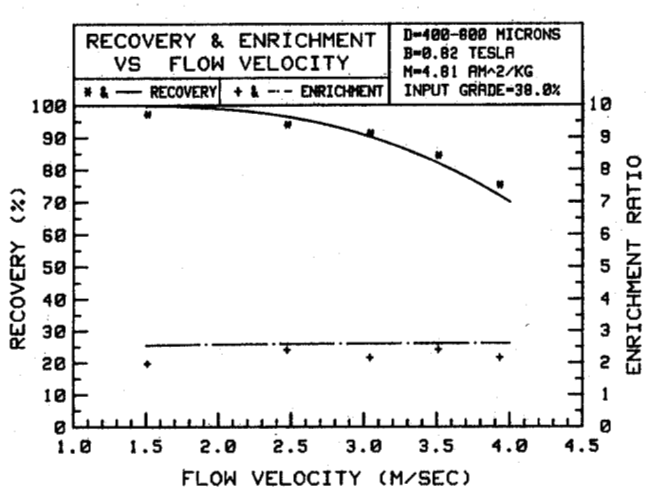

Fig. 6. Recovery and enrichment ratio versus velocity for ore # S1 at magnetic field of 0.82 T.

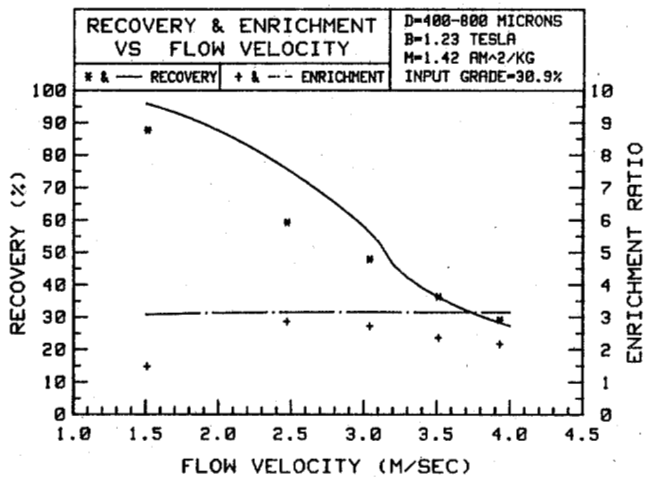

Fig. 7. Recovery and enrichment ratio versus velocity for ore # S3 at magnetic field of 1.23 T.

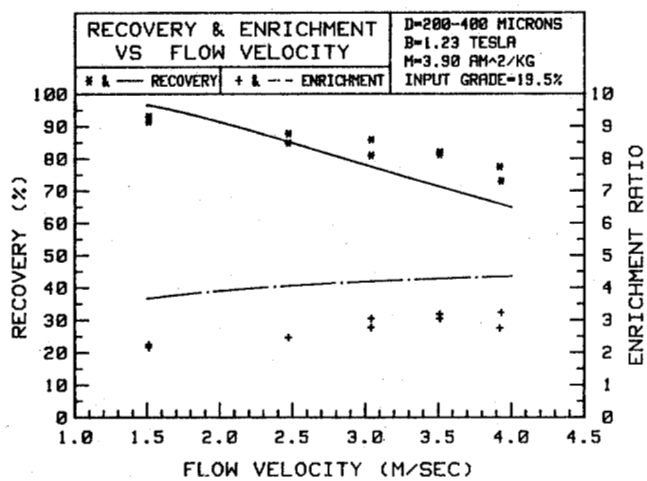

Fig. 8. Recovery and enrichment ratio versus velocity for ore # S5 at magnetic field of 1.23 T.

Conclusion

A superconducting 1.6 tesla magnetic ore centrifugal separator is introduced and successfully tested with synthetic ore. Theoretical and experimental studies show that this separator concentrates magnetic material with relatively high recovery and flow rates. A higher field 5 tesla separator of this centrifugal type would separate weakly magnetic hematite ores.

References

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3. M. Abdelsalam, R. W. Boom, and R. R. Hughes, "A Study of Superconducting Separators for Weakly Magnetic Ores", A Minerals and Materials Research Grant Report, Bureau of Mines, June 1983 (16 references sited).