Physicochemical Problems of Mineral Processing, 38 (2004) 301-309
Fizykochemiczne Problemy Mineralurgii, 38 (2004) 301-309

Özcan Y. GÜLSOY*, Eren Caner ORHAN*

IMPORTANCE OF MAGNET-STEEL CONFIGURATION IN DRY HIGH INTENSITY PERMANENT MAGNETIC ROLLS: THEORETICAL AND PRACTICAL APPROACH

Received May 12, 2004; reviewed; accepted June 28, 2004

Permanent magnetic rolls have found wide area of applications in separation of paramagnetic minerals from diamagnetics especially after the development of neodymium-iron-boron magnets. Their simple separation principles together with relatively high magnetic induction values and relatively low capital and operational costs made them preferable in industrial minerals processing. Besides the magnetic field and induction values of the magnets, another important factor is the magnet-steel configuration where the magnet:steel width ratio is the key factor that should carefully be selected depending on the feed particle size. In this study, the effects of magnet-steel configurations on the removal of iron-bearing impurities from a feldspar sample are investigated.

Key words: magnetic separation, permanent magnetic rolls, magnet-steel configuration

INTRODUCTION

Enrichment of minerals depending on the difference in their magnetic susceptibilities is being used since the beginning of 20th century. However, the use of permanent magnets in treating minerals is comparatively recent (Parker, 1977). Parallel to the advances in materials sciences and technologies, permanent magnets have been used in mineral processing since 1970's (Fig. 1). However, due to relatively high cost, low magnetic field and/or induction levels, permanent magnets such as Alnico 5 and cobalt-samarium (Co-Sm) had found limited area of applications. The development of neodymium-iron-boron (Nd-Fe-B) ceramic magnets in mid 80's made permanent magnets possible to be used in separation of weakly paramagnetic minerals (i.e. mica minerals, hornblende, etc.).

* Hacettepe University, Department of Mining Engineering, 06532, Beytepe, Ankara, Turkey;
email: ogulsoy@hacettepe.edu.tr

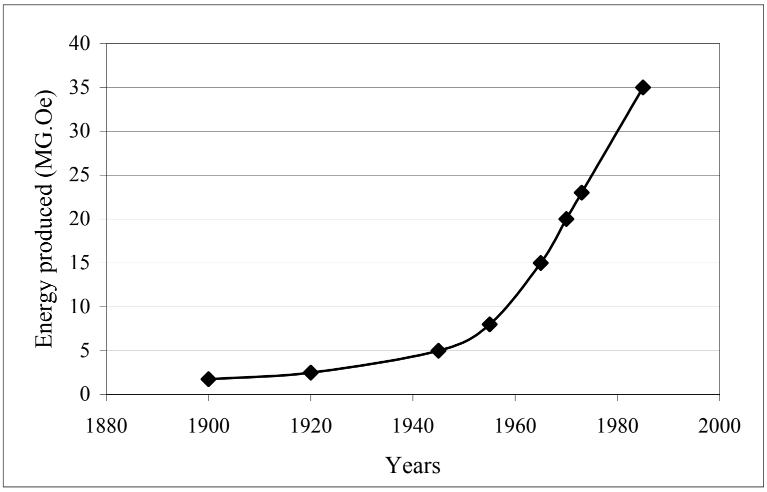

Fig. 1. Advances in magnet manufacturing (modified from Arvidson, 1990)

This development has been appreciated by the industrial minerals industry as Nd-Fe-B magnets offer relatively high magnetic induction and low capital and operating cost. Hence they have been used in beneficiation of industrial minerals (i.e. feldspar, magnesite, etc.) successfully since 1990's.

Dry high intensity permanent magnetic rolls are manufactured using series of Nd-Fe-B magnetic disk - steel disk combinations assembled along a steel roll. Besides the magnetic field and induction properties of the magnets, the magnet:steel width ratio has a considerable importance in this simple design. Although without experimental support, Kopp (1984) theoretically mention the importance of the separator configuration where he derived the physical equations governing the magnetic separation in permanent magnetic rolls.

The magnetic force in a field B and field gradient ∇B is given with the well-known equation as

$$F_m = \mu_0 m \chi B \nabla B \tag{1}$$

where m is the mass of the particle in the field (kg), χ is the mass susceptibility (m^3/kg) and μ_0 is the permeability of free space (Henry/m) which is equal to $4\pi\times10^{-7}$. In permanent magnetic rolls, the equations for calculation of B and $B\nabla B$ is derived by Kopp (1984) as

$$B = B_0 \exp(-z/t) \tag{2}$$

$$B\nabla B = \frac{B_0^2}{t}\exp\left(\frac{-2z}{t}\right) \tag{3}$$

where B_0 is the magnetic field at the edge of the magnet, z is the distance of the particle from the magnet surface (m) and t is the width of the steel between magnets (m). Eq. 3 shows that magnetic force term $B \nabla B$ takes its largest value at $z = t/2$ which is the distance from the magnet surface magnitude being half the width of the steel disk. This suggests that the feed particle size should match with this value or the magnetic separator should be designed according to the particle size at which the separation will be carried out.

In this study, the effects of magnet:steel width ratio configurations of permanent magnetic rolls on the separation of coloring impurities from a feldspar ore at different particle sizes are investigated.

MATERIALS AND METHODS

The feldspar ore used in the experiment is a titanium bearing, micaceous albite ore and is supplied from Cine Akmaden Mining Co. The chemical composition of the ore is given in Table 1. Thin section analysis together with the chemical analysis showed that the sample is composed mainly of sodium feldspar with mica minerals (mainly biotite) and minor amount of hematite as paramagnetic impurities. Chemical analysis of carefully handpicked grains of mica minerals showed that they contain approximately 2% TiO_2 probably as a $Ti^{+4} \Leftrightarrow Al^{+3}$ substitution product. This case agrees well with the mineralogical observations of Deer et.al. (1974) and experimental evidences of Bayraktar et.al. (2001). Hence, a decrease in TiO_2 content should be expected in the concentrate.

Table 1. The chemical composition of the feldspar sample used in the experiments

Component	Content, %
SiO_2	64.97
Al_2O_3	20.50
Fe_2O_3	0.335
TiO_2	0.350
CaO	1.97
MgO	0.88
Na_2O	9.92
K_2O	0.68
P_2O_5	0.15
LOI	0.25
Total	100.005

The experiments are carried out using laboratory scale dry high intensity permanent magnetic rolls (Permroll) with 3 different magnet-steel configurations. Each configuration is achieved by the combination of different number of Nd-Fe-B disc magnets (4 mm width, 10 mm diameter) and steel discs (1 mm width, 10 mm diameter). The magnet-steel configurations investigated and built-in the magnetic separator are: (a) 4mm magnetic disks with 1 mm steel disks, (b) 8 mm magnetic disks with 2 mm steel disks, (c) 12 mm magnetic disks with 3 mm steel disks (Fig. 2).**Błąd!**

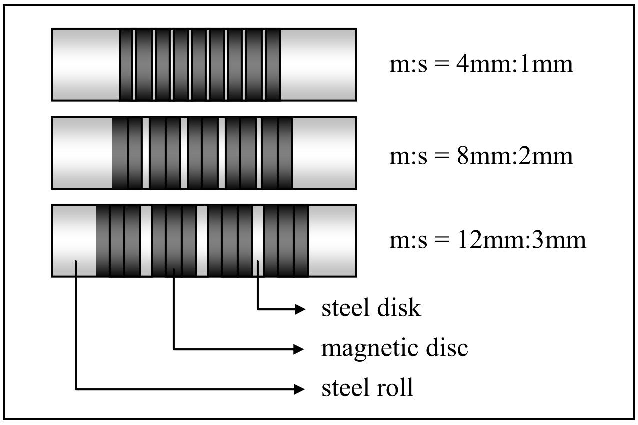

Fig. 2. Magnet-steel configurations

The effects of magnet-steel configurations are studied on three different size fractions being -2 mm, -1 mm and -0.5 mm. The sample preparation flowsheet is given in Fig. 3 and particle size distributions of the prepared samples are given in Fig. 4. Prior to the experiments, -0.075 mm fraction that deteriorates the separation (due to particle-particle and particle-belt electrostatic interactions) is removed from the feed.

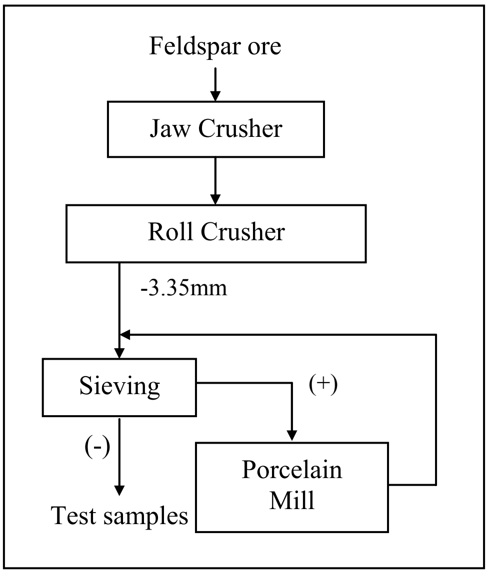

Fig. 3. Sample preparation flowsheet

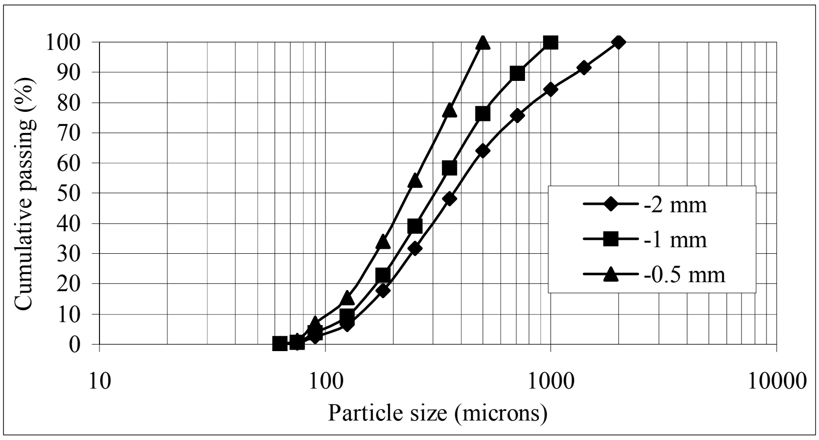

Fig. 4. Particle size distributions of test samples

In order to examine the change of magnetic field in each magnet-steel configuration, the magnetic induction values along the magnetic roll is measured. Then the magnetic induction change apart from the surface of the magnet is examined.

RESULTS AND DISCUSSION

The surface magnetic induction measurements show that maximum magnetic induction values (B_{max}) obtained is approximately 1.05 Tesla where magnet:steel = 4:1, 1.24 Tesla where magnet:steel = 8:2 and 1.27 Tesla where magnet:steel = 12:3 (Fig. 5).

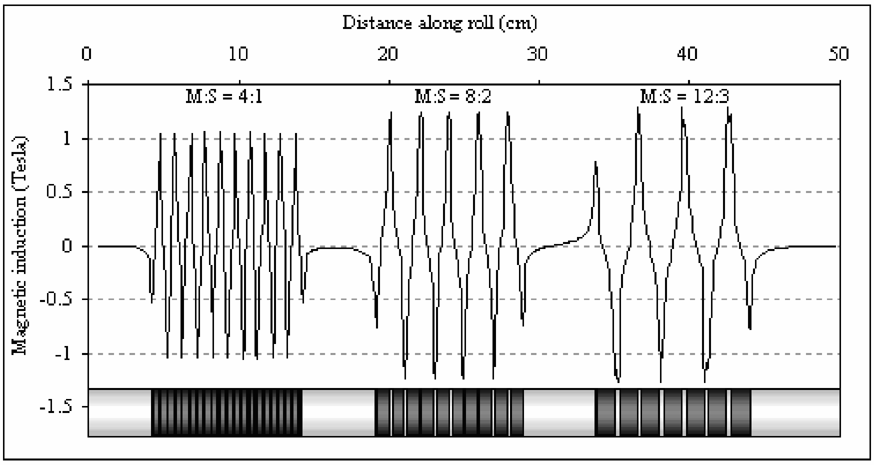

Fig. 5. Change in magnetic induction along the magnetic roll and different magnet-steel configurations

It is clearly seen in Fig. 5 that although the same magnets and steels are used in the configurations, B_{max} values increase in magnet:steel ratio order of 12:3 > 8:2 > 4:1. The same case is also valid for the magnetic induction values measured apart from the roll surface (Fig. 6) and m:s = 12:3 configuration provides the largest magnetic induction value at all distances. Fig. 6 (a) and (b) shows that the measured and calculated values from Eq. 3 agrees well with acceptable variations and that Eq. 3 is valid for practical cases. Although it provides the largest magnetic induction value, it is not always the best case for all feed sizes as is mentioned in Eq. 3.

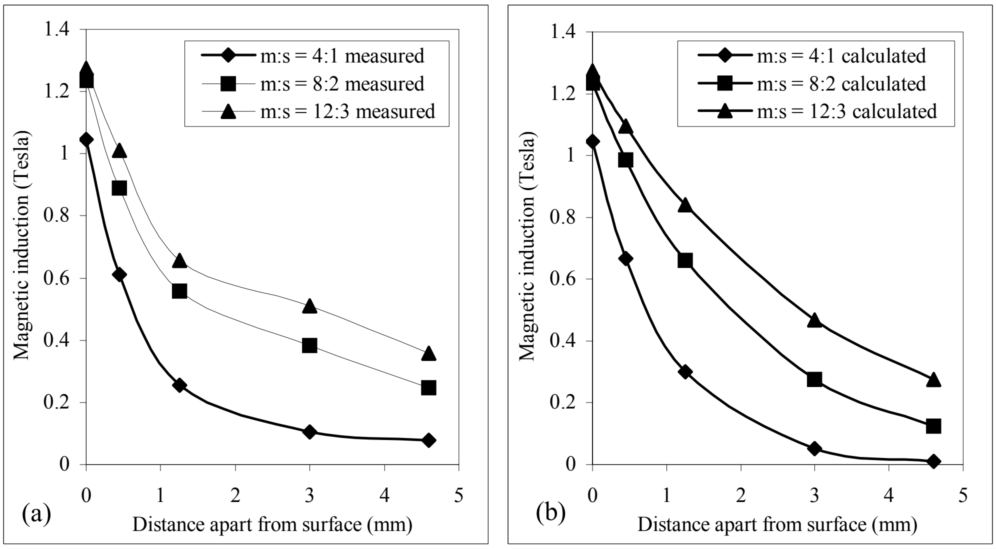

Fig. 6. (a) measured, (b) calculated, magnetic induction (B_{max}) change apart from roll surface for different magnet:steel width ratios

The magnetic separation test results of -2+0.075 mm, -1+0.075 mm and -0.5+0.075 mm size fractions at three different magnet-steel configurations are given in Tables 2, 3 and 4 respectively.

Table 2. Magnetic separation test results of -2+0.075 mm size fraction

	Magnet:steel width ratio		
Weight	4:1	8:2	12:3
Tailings (%)	7.55	8.29	16.8
Concentrate (%)	92.45	91.71	83.20
Concentrate chemical composition			
SiO_2	65.71	65.71	65.74
Al_2O_3	20.50	20.50	20.20
Fe_2O_3	0.119	0.113	0.090
TiO_2	0.310	0.320	0.280

Table 2. - continuation			
CaO	2.03	2.02	2.04
MgO	0.31	0.32	0.24
Na_2O	10.31	10.35	10.38
K_2O	0.38	0.37	0.34
P_2O_5	0.14	0.13	0.14
LOI	0.19	0.17	0.15
Total	99.999	100.003	99.600

Table 3. Magnetic separation test results of -1+0.075 mm size fraction

	Magnet:steel width ratio		
Weight	4:1	8:2	12:3
Tailings (%)	8.22	9.09	25.72
Concentrate (%)	91.78	90.91	74.28
Concentrate chemical composition			
SiO_2	66.13	65.82	66.09
Al_2O_3	20.60	20.50	20.50
Fe_2O_3	0.041	0.046	0.060
TiO_2	0.220	0.230	0.240
CaO	2.04	2.04	2.06
MgO	0.12	0.12	0.15
Na_2O	10.36	10.36	10.37
K_2O	0.26	0.28	0.30
P_2O_5	0.14	0.13	0.14
LOI	0.09	0.47	0.09
Total	100.001	99.996	100.000

Table 4. Magnetic separation test results of -0.5+0.075 mm size fraction

	Magnet:steel width ratio		
Weight	4:1	8:2	12:3
Tailings (%)	9.98	13.07	14.00
Concentrate (%)	90.02	86.93	86.00
Concentrate chemical composition			
SiO_2	66.26	66.25	66.20
Al_2O_3	20.50	20.50	20.40
Fe_2O_3	0.026	0.030	0.050
TiO_2	0.200	0.200	0.219
CaO	1.92	1.93	1.94
MgO	0.06	0.07	0.13
Na_2O	10.53	10.46	10.50
K_2O	0.24	0.25	0.28
P_2O_5	0.19	0.18	0.16
LOI	0.07	0.13	0.12
Total	99.996	100.000	99.999

The chemical analysis show that the magnetic separation provide high amount of reduction in iron content, the lowest content certainly existing in the finest fraction due to liberation. Besides, considerable amount of TiO_2 is also removed with biotite. Changes in concentrate Fe_2O_3 content and Fe_2O_3 removal recovery depending on magnet-steel configuration are given in Fig. 7.

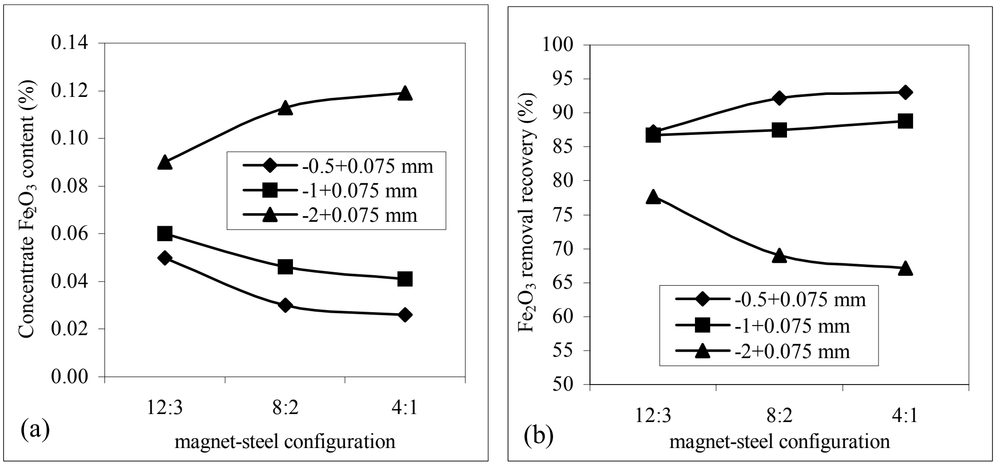

Fig. 7. (a) Concentrate Fe_2O_3 contents, (b) Fe_2O_3 removal recoveries, obtained in different magnet-steel configurations

Concentrate Fe_2O_3 content and Fe_2O_3 removal recovery values (Fig. 7) of different particle sizes should not be compared with each other, as naturally the liberation is the fact that causes the differences in content and recovery values. However, the important point is the change in the trends of the curves in different particle sizes. Concentrate Fe_2O_3 contents of -1+0.075mm and -0.5+0.075 mm size fractions decrease in the order of 12:3 > 8:2 > 4:1 (Fig. 7a). On the contrary, the Fe_2O_3 content of -2+0.075 mm concentrate exhibits the reverse order as 12:3 < 8:2 < 4:1 of which the liberation could not be responsible. Same relations also apply for Fe_2O_3 removal recovery values (Fig. 7b) but in reverse orders for all size fractions. The values show that 4:1 configuration provides the lowest Fe_2O_3 content and highest recovery for -1+0.075mm and -0.5+0.075mm size fractions where as 12:3 configuration provides lowest Fe_2O_3 content and highest recovery for -2+0.075mm fraction.

This behavior clearly indicates the importance of selection of suitable magnet:steel ratio configuration and that highest B_{max} values does not always provide the best separation for all particle sizes. Although Eq. 3 suggests that the average particle size should be half the steel width of the separator, in most cases it is not always possible to determine the average particle size of a distribution. However, it is evident that higher magnetic induction and m:s configurations are required as the feed gets coarser.

CONCLUSIONS

The results clearly show that magnet:steel width ratio has a considerable effect on concentrate Fe_2O_3 content and Fe_2O_3 removal recovery in feldspar concentration. It is clear that the suitable size fraction should be fed to a specific magnetic separator or the magnetic separator should be designed specifically for the material that is to be concentrated.

Although the theory suggests equations for the selection of the optimum magnet:steel configuration, they are not practically applicable as the average particle size cannot be determined exactly for a particle size distribution. However, the theory can provide reasonable solutions where feed with very narrow size distribution is to be separated.

Nevertheless, obtaining the best solutions for a specific ore always requires thorough studies on both the ore and the magnetic separator.

REFERENCES

ARVIDSON, B. (1990), *Recent developments in dry high intensity magnetic separation*, Australian IMM 1990 Annual Conference, March 1990.

BAYRAKTAR, İ., GÜLSOY, Ö.Y., CAN, N. M., ORHAN, E.C., (2001), *Concentration of feldspars*, 4th Industrial Minerals Symposium, pp.97-105, Chamber of Mining Engineers of Turkey, İzmir, Turkey.

DEER, W.A., HOWIE, R.A., ZUSSMAN, J., (1974), *An Introduction to the Rock Forming Minerals*, Longman, p. 193-203, London.

KOPP, J., (1984), *Permanent magnet disk separators*, IEEE Transactions on Magnetics, Vol. MAG-20, No.5, September.

PARKER, M.R., (1977), *The physics of magnetic separation*, Contemporary Physics, Vol. 18, No. 3, pp. 279-306.

Gülsoy Ö.Y., Orhan E.C., *Teoretyczne i praktyczne aspekty konfiguracji dysków magnetycznych i stalowych w separatorach rolkowych ze stałymi magnesami*, Physicochemical Problems of Mineral Processing, 38, (2004) 301-309 (w jęz. ang.).

Separatory magnetyczne rolkowe ze stałymi magnesami znalazły szerokie zastosowanie do rozdziału minerałów o właściwościach słabo magnetycznych po wprowadzeniu ceramicznych magnesów Nd-Fe-B. Zaletą tych urządzeń są proste zasady operacji przy względnie wysokiej wartości indukcji magnetycznej i niskich kosztach operacyjnych i inwestycyjnych. Obok wysokiego natężenia pola magnetycznego ważnym parametrem tych separatorów jest wzajemna konfiguracja dysków stalowych i dysków magnetycznych w wałku roboczym. Konfiguracja to powinna być ściśle dobrana m.in. w zależności od uziarnienia nadawy. W pracy badano wpływ konfiguracji dysków stalowych i magnetycznych na skuteczność usuwania zażelazionych zanieczyszczeń z surowca skaleniowego.