Magnetic separation of iron ores is one of the fastest-growing segments of the minerals beneficiation industry. The tonnage of taconite ores processed annually by magnetic separation will, in a few years, reach 100 million.

Magnetic separation occupies an attractive position in the field of ore beneficiation. It is a simple yet effective method, used for some 150 years and steadily growing more important. This type of beneficiation originated in 1792, when William Fullarton was issued a British patent covering the separation of iron ore by magnetic attraction.

What is magnetism, and why are some materials capable of being magnetized and others not? The study involves many unknowns, and even a partial answer to these questions would be a dissertation in solid state physics and perhaps other fields of science. But the last two decades have revealed basic facts as to why certain materials are magnetic and what happens to them when they are magnetized.

Some of the newer studies in solid state physics have developed a theory that can be applied to studies of magnetism. It is claimed that magnetism stems fundamentally from the spin of electrons in atoms that tend to go in pairs, spinning in opposite directions. The atom as a whole can act as a magnet only when there is an imbalance of electronic spin. Whenever an atom has an odd number of electrons, therefore, this imbalance exists. This neutralizing effect explains why a piece of material that contains atomic magnets is not necessarily magnetic. The physicists tell us that iron is composed of many small magnetized regions called domains, which consist individually of millions of atoms. The piece of iron becomes magnetized when an external force lines up these domains in the same direction.

Fundamental data developed by physicists working in fields far removed from minerals beneficiation are now available for developing better magnetic separators for ore processing.

More Data Needed on Magnetic Properties of Minerals: There is less information on magnetic properties of minerals than there is for certain aspects of magnetic separator design. When the data on magnetic properties is available, it is often directed toward the study of powders for tape recorders and other highly scientific endeavors that are of little use to the beneficiation engineer. W. R. Crane's table of tractive forces, published in 1902, is still a guide in the study of magnetic minerals. Bits of other information regarding electrostatic conductivity, dielectric constant values, and permeability of various minerals have also appeared but are of small practical value in magnetic separation of ore.

It is extremely important to obtain pure mineral specimens for making investigations and to record results that may be of use in studies of magnetic processes. Reference to the large volume of data developed by those concerned with analysis and design of permanent magnets soon reveals that these people have extensively evaluated the effect of various impurities on magnetic properties. Much of the science of the ferrite industry is based upon spinel-type structures which are varied by substitution of selected elements or even subtraction of elements, leaving vacant sites in the space lattice.

Magnetic separators are used to beneficiate a wide variety of industrial minerals. In this application the relatively large volumes of nonmagnetics are usually the commercial products. The amount of mag-
magnetic material removed is quite small, and dry separation is the general rule.

Magnetic separation is also important in processing phosphate, titanium, chrome, manganese, tungsten, molybdenum, nickel, niobium, and tantalum ores.

**Pioneer Work on Dry Separation:** It is interesting to note that much of the pioneer work in magnetic processing of ores was done on dry material. In spite of the disadvantages of dusty, uncomfortable plants, the dry method has produced acceptable concentrates in most cases.

No definite date can be given for the change in emphasis from dry to wet processing of iron ore, but the wet processing method is treating by far the largest tonnage at the present time. In the past two or three years many advances in the science of magnetic separation may be taking place. But now consider an area of magnetic separation where dry methods have never lost their attractiveness.

---

**Table I. Iron Analysis of Crude and Beneficiated Minerals Used in the Ceramic Industry**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Crude Ore, Fe₂O₃, pct</th>
<th>Beneficiated Product, Fe₂O₃, pct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aplite</td>
<td>0.0 to 1.30</td>
<td>0.39</td>
</tr>
<tr>
<td>Glass sand</td>
<td>0.15 to 0.20</td>
<td>0.61 to 0.93</td>
</tr>
<tr>
<td>Feldspar</td>
<td>1.70</td>
<td>0.55 to 0.70</td>
</tr>
<tr>
<td>Nepheline syenite</td>
<td>1.7 to 2.1</td>
<td>0.07 to 0.08</td>
</tr>
</tbody>
</table>

**Table II. Typical Results Obtained with Edison Dry Magnetic Separator**

<table>
<thead>
<tr>
<th>Feed</th>
<th>Fe₂O₃, pct</th>
<th>SiO₂, pct</th>
<th>Al₂O₃, pct</th>
<th>Finished Briquettes</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1 machine concentrate</td>
<td>20 pct Fe (0.7 to 0.8 pct Fe)</td>
<td>40 pct Fe (tails 0.8 pct Fe)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 2 machine concentrate</td>
<td>60.0 pct Fe</td>
<td>68.0 pct Fe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 3 machine concentrate</td>
<td>68.0 pct Fe, 2 to 3 pct SiO₂</td>
<td>1.12 pct Fe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total concentrate</td>
<td>68.0 pct Fe, 2 to 3 pct SiO₂</td>
<td>1.12 pct Fe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total tail</td>
<td>-0.03 to 0.10 pct</td>
<td>0.028 to 0.33 pct</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Importance to Industrial Minerals Production:**
Several industrial minerals used in manufacturing ceramics have long been processed by dry magnetic separation—kyanite, quartz, aplite, feldspar, and nepheline syenite, which is currently processed in considerable quantities in Canada and Russia.

Extensive deposits of nepheline syenite occur in Russia, Scandinavia, India, the U. S., and Canada. The Canadian deposit that is commercially exploited, near Nepton, Ont., is unique in its uniform quality and low percentage of iron-bearing minerals. This bedrock, known as Blue Mountain, is more than five miles long and up to a mile wide. Located by Norman Davis in 1912, it has long been known to be one of the world's most extensive deposits of this material. Before the Blue Mountain ore was considered for use in the ceramic industry, it was studied as a possible source of aluminum and also as a source of potash.

Instead of bauxite, according to a recent Russian announcement, the Volkhov Aluminum Works near Leningrad is successfully using nepheline, which comes from the extensive apatite deposits of the Kola Peninsula. Besides aluminum, the Russians are recovering gallium, sodium and potash salts, and constituents of Portland cement.

With the formation of Canadian Nepheline Syenite Ltd. in 1935, the Canadian deposit was seriously investigated as a feldspar substitute for the ceramic industry. Feldspar that has a relatively high alkali and alumina content has also been preferred by the glassmakers to the less readily available potash feldspar. The search for a substitute that might be even better in some cases than feldspar led to investigation of the nepheline syenite deposits in Canada. The first test sample, weighing 30 tons, was concentrated by high-intensity magnetic separation and distributed to ceramic plants in Canada and the U. S. for test purposes. It soon appeared that nepheline syenite would be a useful substitute for feldspar, and the market has grown steadily until now it is considered one of the major minerals used in the ceramic industry. Among the companies now oper-
plants consistently produced concentrates of more than 71 pct Fe. For purposes of this article the overall processing methods for iron resources, as well as disposal systems and some-thing limiting ore supplies in the East, Edison developed a method of separating iron minerals from the iron-bearing sand he had observed along the shore of Long Island. After preliminary small-scale tests with these sands, he constructed a large plant near Lake Hopatcong, N. J., to beneficiate a low grade magnetite ore and founded the town of Edison, N. J., to provide homes for the workers. Among the plant’s many innovations were new crushers, belt conveyors, dryers, and briquetting machines, as well as inventions in magnetic separation.

Edison’s developments in magnetic separation, which have not been widely publicized, were characterized by simple construction. The separators he finally installed in his commercial plant consisted of several electromagnets arranged one above the other, utilizing a free-fall principle to separate gangue from magnetite. The commercial plant in New Jersey used four separators, which he designated Nos. 1 through 4. It is significant, with reference to the data for this plant listed in Table II, that ore containing only 12 to 20 pct Fe was upgraded to concentrate containing 68 pct Fe. Present-day proponents of the smelting advantages of extremely high grade iron ore concentrates will be interested in the outcome of tests made with Edison high grade iron ore concentrate at Catasaqua, Pa. Results of a five-day test were spectacular. On the regular ore charge this furnace produced 100 to 110 tons of pig iron per day. When briquetted concentrates from Edison’s plant were used, furnace output rose to more than 138 tpd. Altogether, 477 magnetic separators were installed in the New Jersey plant.

After Edison’s New Jersey plant failed, U. S. interest in large-scale magnetic separation of iron ore decreased. Edison’s failure was caused primarily by the sudden drop in the iron ore market following discovery of the great Mesabi Range. The New Jersey deposit, moreover, was inadequately prospected and of lower quality than anticipated.

Edison devoted eight years, at a cost of more than $2 million, to inventing a magnetic process and constructing a plant for concentrating low grade iron ore into desirable furnace feed. In the 1890’s, recognizing the iron industry’s dependence on the somewhat limited ore supplies in the East, Edison developed a method of separating iron minerals from the iron-bearing sand he had observed along the shore of Long Island. After preliminary small-scale tests with these sands, he constructed a large plant near Lake Hopatcong, N. J., to beneficiate a low grade magnetite ore and founded the town of Edison, N. J., to provide homes for the workers. Among the plant’s many innovations were new crushers, belt conveyors, dryers, and briquetting machines, as well as inventions in magnetic separation.

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Now there is renewed interest in dry magnetic separation of iron ores. Some of the more recent studies of dry separation methods have been undertaken in: 1) the Ontario Research Foundation; 2) the Finland Institute of Technology, Helsinki, and the Otanmaki Co; 3) the ore dressing laboratory of the Royal Institute of Technology in Stockholm, Sweden; 4) Carpco Research & Engineering Div., Carpco Mfg. Co., Florida; and 5) various German laboratories and the Salzgitter Co.

Otanmaki Commercial Plant Operations: The Otanmaki Co. in Finland is processing, in considerable tonnages, ilmenite-magnetite-pyrite ore similar to that mined at Tahawus, N. Y. As this article is concerned chiefly with new developments in dry magnetic separation, no description will be given of the wet mill, but it should be mentioned that a highly efficient wet magnetic separation circuit is used to remove a very large percentage of magnetite from the ilmenite. This is important, since any magnetite going to the ilmenite flotation circuit is lost to the ilmenite and downgrades the ilmenite product.

Fig. 3 is a flowsheet of the dry magnetic separation plant at Otanmaki. Wet filtered magnetic concentrate is picked up by a magnetic pulley from a conveyor belt and fed into a drum dryer. The dried concentrate is fed by elevator to the dry magnetic separation section.* Here a scalping screen removes tramp oversize prior to the dry separation step. The dried concentrate is then fed to Laurila separators, where centrifugal force separates the nonmagnetic or weakly magnetic particles from the magnetic. Invented by Erkki Laurila of the Finland Institute of Technology, this drum-type separator incorporates permanent magnets made of Alnico V or similar material. The machine is undergoing further development, both at the Institute and at Otanmaki. It is now manufactured by Maschinen-und Stahlbau, Krupp Rheinhausen, Germany.

At Otanmaki the rougher concentrate is cleaned twice by dry separators. The rougher tailing is sent over a cleaner separator operating at lower speed, and the final tailing containing ilmenite is sent back to the ilmenite flotation section.

Operating conditions in the dry separator section are difficult. Separator design includes an oil mist lubrication system to spray the bearings, since the dry magnetite concentrate is at 120° to 140°C. Thermal expansion of the separator shells has also caused trouble.

During the period covered by the Otanmaki commercial plant results listed in Table III, the magnet wheel was stationary and the drum speed was 230 rpm on the rougher and 180 rpm on the scavenger separator. These results show that 11 pct of the

<table>
<thead>
<tr>
<th>Feed</th>
<th>Fe, Pct</th>
<th>TiO₂, Pct</th>
<th>Fe₂O₃, Pct</th>
<th>Wt, Pct</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.5</td>
<td>5.7</td>
<td>86.9</td>
<td>90.0</td>
<td>11.0</td>
</tr>
<tr>
<td>68.6</td>
<td>2.15</td>
<td>96.8</td>
<td>89.0</td>
<td></td>
</tr>
<tr>
<td>60.5</td>
<td>8.3</td>
<td>72.8</td>
<td>10 to 15</td>
<td></td>
</tr>
</tbody>
</table>

Magnet wheels stationary. Drum speeds 230 rpm, except scavenger separator at 180 rpm.
perconcentrates needed for sponge iron tests. Re-
used dry concentration methods to produce the
range, though as yet there are no commercial in-
stallations. For several years this institution has
ore beneficiation, each for a specific particle size
veral new dry magnetic separators designed for
duced rolls have corrugated surfaces and the spac-
Davis tube separator. The magnetic circuit is en-
ergized by two air-cooled d-c coils. The four in-
to a maximum of 14,000 gausses in a laboratory
intensity of 23,000 gausses, which can be compared
6 tph of hematite and goethite ores at about 1 kw-hr

Stripa mill

Haksberg mill

Persberg

Bodas mill

Kallsfallet

Langnas

Darnemora

Bastkern

Kanstorp

Grangesberg

Bloteberget

Tuolluvuara

Malmberget

Balsjo, Sweden

Carl Shaft mill, Stri-
berg, Sweden

Hematite HMS plant

Persberg

Balsjo, Sweden

Balsjo, Sweden

Hematite HMS plant

Persberg

Balsjo, Sweden

Kallsfallet

Langnas

Darnemora

Bastkern

Kanstorp

Grangesberg

Bloteberget

Tuolluvuara

Malmberget

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Lowenheim

Modified

(16) Lowenheim

(2) Vykanus countercurrent cobber

(2) MFG, Morgardshammer cobber

(25) Lowenheim

(1) Jeffrey rubber covered countercurrent drum

(25) Lowenheim

(3) Thunes (three-drum)

(9) Lowenheim

(9) Lowenheim

(9) Grondal

(20) Lowenheim

(2) Lowenheim

(2) Allians

(2) Allians

Thunes

Thunes

(15) Drum

(70) Harden

(8) Thunes

(perm magnets)

(3) perm magnets

(perm magnets)

(perm magnets)

(perm magnets)

(perm magnets)

Fe to more than 63 pct Fe.


d by A. Goltz of the Salzgitter Co.

Salzgitter A. G. is now commercially treating 5 to
6 tph of hematite and goethite ores at about 1 kw-hr
per ton of feed. This unit uses a maximum field
intensity of 23,000 gausses, which can be compared
to a maximum of 14,000 gausses in a laboratory
Davis tube separator. The magnetic circuit is en-
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ered critical.

The Ontario Research Foundation has developed
several new dry magnetic separators designed for
ore beneficiation, each for a specific particle size
range, though as yet there are no commercial in-
stallations. For several years this institution has
used dry concentration methods to produce the su-
perconcentrates needed for sponge iron tests. Re-
cent investigations have developed a complete dry
magnetic separation flowsheet, which has been used
upgrade on ore from 25 pct Fe to more than 63 pct Fe.

Wet Magnetic Separation of Iron Ore in Sweden:
In Europe, especially Scandinavia, the drum-type
wet magnetic separator is very popular, both the
electromagnetic and permanent magnet types. A
major difference as compared to U. S. separators is
that the drum is near the surface of the pulp. In
other words, the pulp level is very low, as it was
in the early Grondal separator, used successfully
since the turn of the century.

In general, it can be said that foreign plants favor
large numbers of lower-capacity machines. At the
same time, they often produce a higher grade con-
centrate, which is in much demand for sponge iron
and powdered iron production.

It is highly important to the iron ore industry that
more efficient magnetic separators be developed. A
speaker at the American Mining Congress in Sep-
tember 1957 stated that the steel industry is shifting
emphasis from cost of ore to cost of steel in the
ladle. Further, it was claimed that steel costs can be
reduced 26\% per ton for each percentage point re-
duction in silica content of concentrates such as
taconite pellets.

Recent success in new designs of dry magnetic
separation machines points up the impending pro-
duction of higher-quality iron ore. This trend will
be accelerated by the growing sponge-iron indus-
try's demand for superconcentrates. And in the
industrial minerals field more efficient removal of
iron-bearing minerals can be expected as develop-
ments encouraged by the iron ore industry are
adopted by industrial minerals operations.

Table IV. Types of Magnetic Separators Used in Swedish Iron Ore Mills

<table>
<thead>
<tr>
<th>Mill</th>
<th>Separator, Type</th>
<th>Size, In. Diam x Length</th>
<th>Drum, Rpm</th>
<th>Power, Kw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balsjo, Sweden</td>
<td>Lowenheim in (rougher) (2) series</td>
<td>39</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lowenheim in cleaners (3) series</td>
<td>52</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lowenheim magnetic circuit</td>
<td>65</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lowenheim</td>
<td>75</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Stripa mill</td>
<td>Lowenheim</td>
<td>24x35</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Haksberg mill</td>
<td>Rougher, two in parallel cleaner</td>
<td>28x34</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td>Persberg</td>
<td>(1) Jeffrey rubber covered countercurrent drum</td>
<td>35x36</td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>Persberg</td>
<td>(26) Lowenheim</td>
<td>24x34</td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>Bodas mill</td>
<td>(3) Thunes (three-drum)</td>
<td>24x69</td>
<td>1.4 hp</td>
<td></td>
</tr>
<tr>
<td>Kallsfallet</td>
<td>(9) Lowenheim</td>
<td>24x34</td>
<td>1.9 hp</td>
<td></td>
</tr>
<tr>
<td>Langnas</td>
<td>Lowenheim</td>
<td>31x35</td>
<td>1.5 hp</td>
<td></td>
</tr>
<tr>
<td>Darnemora</td>
<td>(6) Morgardshammer GW617P</td>
<td>25x68</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Bastkern</td>
<td>(5) Lowenheim</td>
<td>24x34</td>
<td>2.5 hp</td>
<td></td>
</tr>
<tr>
<td>Kanstorp</td>
<td>(1) Allians</td>
<td>30x32</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Grangesberg</td>
<td>Allians</td>
<td>24x69</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Bloteberget</td>
<td>Thunes</td>
<td>24x71</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Tuolluvuara</td>
<td>(15) Drum</td>
<td>24x67</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Malmberget</td>
<td>(70) Harden</td>
<td>32x32</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8) Thunes</td>
<td>24x67</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Note: Number of separators installed noted in parentheses. Power in kilowatts unless otherwise specified.