ADVANCES IN MAGNETIC SEPARATION OF ORES

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.

by L. A. ROE

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 orginated 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.

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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-

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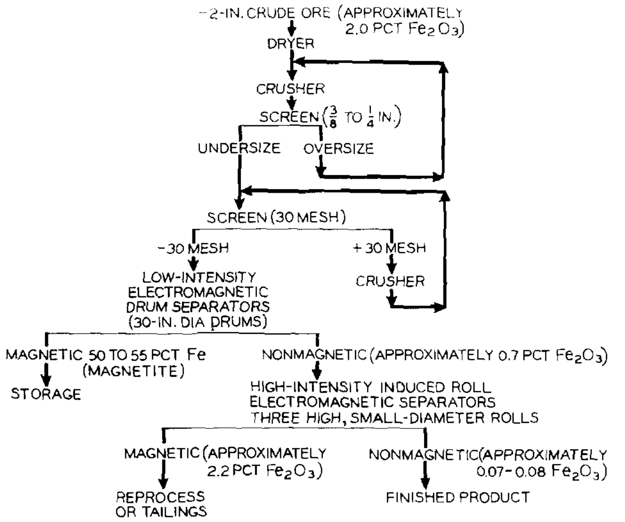


Fig. 1—Dry magnetic processing of nepheline syenite.

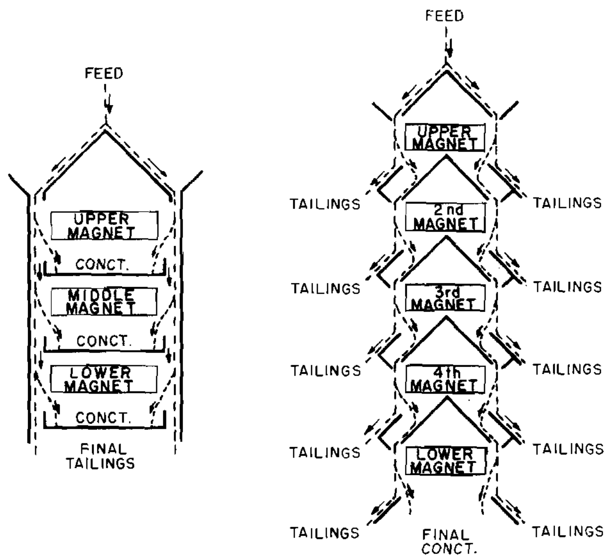


Fig. 2—No. 1 (left) and No. 3 Edison separators, 1890.

netic 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 of iron ore have been in the field of dry processing, where a major revolution in iron ore beneficiation 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

Mineral	Crude Ore, Fe_2O_3, Pct	Beneficiated Product, Fe_2O_3, Pct
Aplite	0.60 to 1.30	0.30
Glass sand	0.15 to 0.20	0.01 to 0.03
Feldspar	0.15	0.05 to 0.07
Nepheline syenite	1.7 to 2.1	0.07 to 0.08

Table II. Typical Results Obtained with Edison Dry Magnetic Separator

Feed	20 pct Fe (0.7 to 0.8 pct P)
No. 1 machine concentrate	40 pct Fe (tails 0.8 pct Fe)
No. 2 machine concentrate	60.0 pct Fe
No. 3 machine concentrate	68.0 pct Fe
Total concentrate	68.0 pct Fe, 2 to 3 pct SiO_2
Total tail	1.12 pct Fe
Finished Briquettes	
Fe, 67 to 68 pct	Mn, 0.05 to 0.10 pct
SiO_2, 2 to 3 pct	P, 0.028 to 0.33 pct
Al_2O_3, 0.4 to 0.8 pct	Traces of CaO, Mgo, and S

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 Nephton, Ont., is unique in its uniform quality and low percentage of iron-bearing minerals. This orebody, 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-

* Feldspar has been used in China as a ceramic material since 621 A. D.

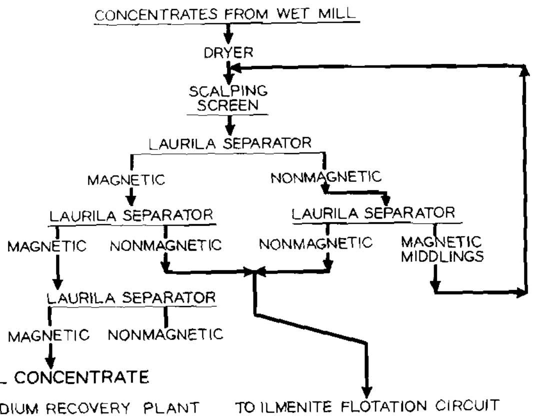


Fig. 3 (above)—Otanmaki dry magnetic separation plant.

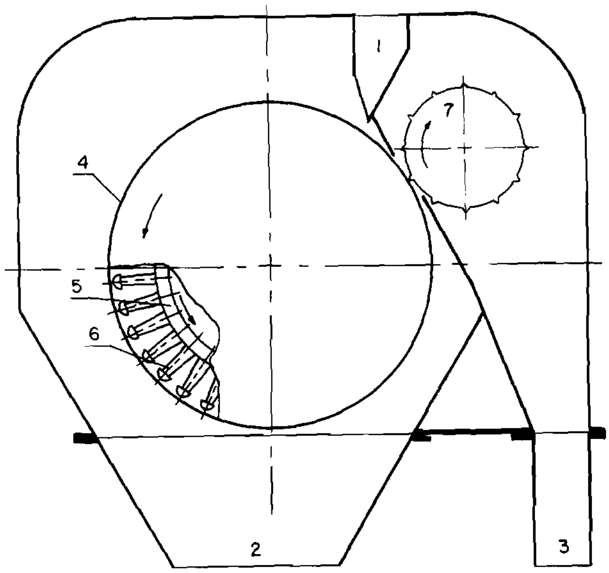


Fig. 4 (right)—Laurila separator: 1) feed introduction, 2) tailing discharge, 3) concentrate discharge, 4) drum, 5) magnet carrying wheel, 6) permanent magnet, 7) induction roller. (Also see Figs. 5A and B, p. 1264.)

ating in Canada are American Nepheline Co., successor to Canadian Nepheline Syenite Ltd., and International Minerals & Chemical Corp. (Canada) Ltd. For purposes of this article the overall flowsheets of these plants will not be discussed, but the magnetic separation features will be described.

Dry Magnetic Separation of Nepheline Syenite: The first equipment used in magnetic separation of nepheline syenite is a low-intensity, large-diameter drum separator to remove highly magnetic minerals —primarily magnetite or mixtures of magnetite and other elements. The magnetics removed by this electromagnetic separator are placed in a storage pile or sold as byproduct magnetite. The magnetite concentrate analyzes 50 to 55 pct Fe. The nonmagnetic product from the first separator is stored in surge bins, from which it is drawn for distribution to high-intensity induced-roll magnetic separators, which remove feebly magnetic minerals.

Generally about 25 pct of the ore fed to a nepheline syenite plant is lost as waste during crushing, drying, grinding, and reduction of iron content, which is usually lowered from 2.0 to 0.08 pct. Table I compares iron analyses of several crude and beneficiated ceramic raw materials that undergo dry magnetic separation.

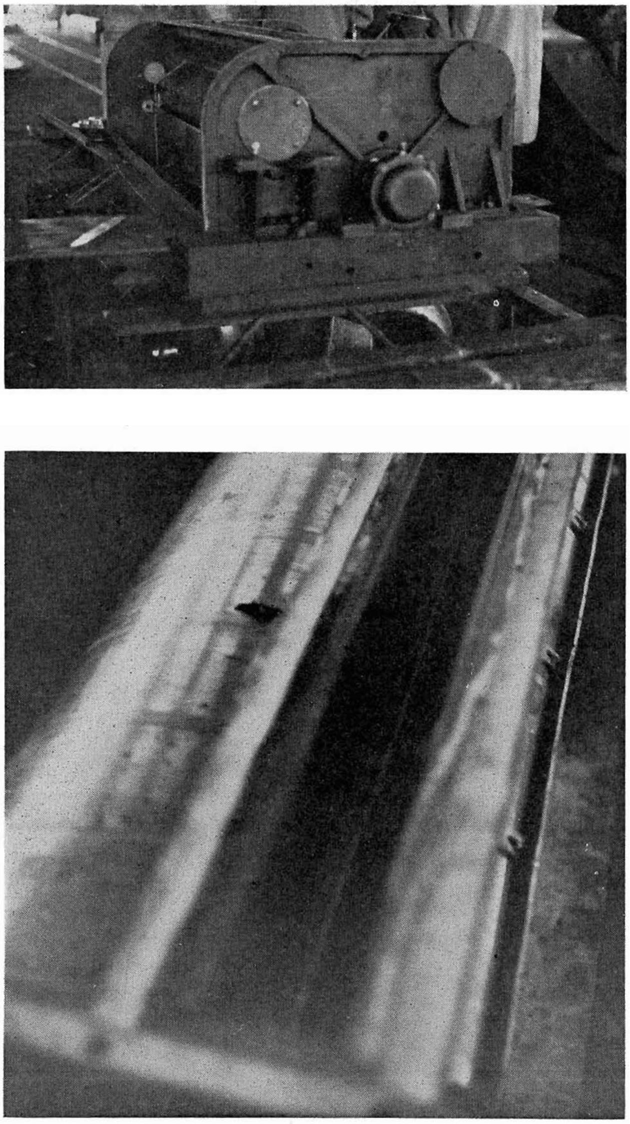
Dry Magnetic Separation of Iron Ore: There are many inherent advantages in processes that utilize dry magnetic separation to beneficiate iron ore. Wet concentration of magnetite ore, in comparison, requires 500 to 1000 gal of water per ton of concentrate produced. This means extensive use of water resources, as well as disposal systems and sometimes complicated water reclamation systems. Some of the new low grade iron ore discoveries in Canada are in areas where the climate encourages use of dry processing methods.

Production of superconcentrates also favors these methods for iron ores. As Thomas Edison demonstrated more than 50 years ago, it is not difficult to produce large tonnages of concentrates containing 68 pct Fe and only 2 to 3 pct SiO_2 when dry magnetic separation procedures are used. One of Edison's pilot plants consistently produced concentrates of more than 71 pct Fe.

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.

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 Catasauqua, 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.



Figs 5A and 5B—Laurila separator in the Otanmaki Co. shop. Lower view is close-up of the drum.

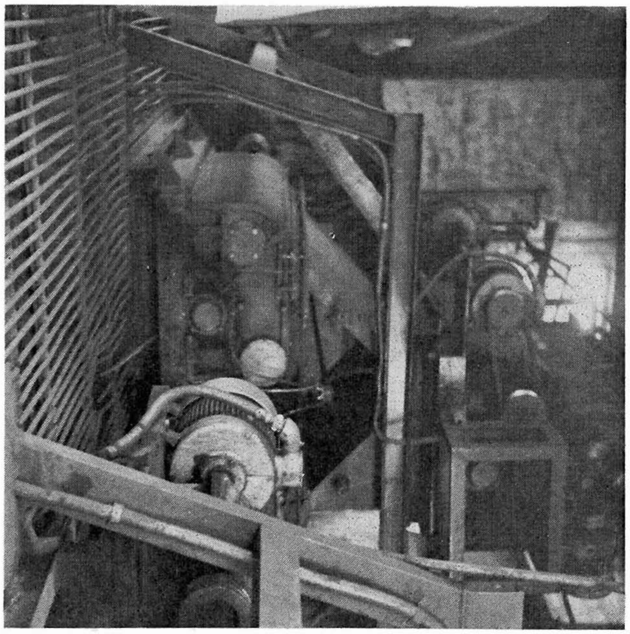


Fig. 6—The Laurila separators in commercial operation.

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

* It should be realized that the ilmenite-magnetite operation at Otanmaki involves a separation that could not be made economically by wet magnetic methods.

Table III. Otanmaki Plant Results with Dry Magnetic Separation

	Fe, Pct	TiO_2, Pct	Fe_3O_4, Pct	Distribution, Wt, Pct
Feed	65.5	5.7	86.9	100.0
Magnetite concentration	68.6	2.15	95.6	89.0
Middlings	60.5	8.3	75.8	10 to 15
Tailing	36.2	36.9	7.5	11.0

Magnet wheels stationary. Drum speeds 230 rpm, except scavenger separator at 180 rpm.

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

Mill	Separator, Type	Size, In. Diam x Length	Drum, Rpm	Power, Kw
Balsjo, Sweden	Lowenhielm in (rougher) (2) series		39 52	2.5
	Lowenhielm in cleaners (3) series		52 65 75	
Carl Shaft mill, Striberg, Sweden	Lowenhielm	24x35	40	2.1
Hematite HMS plant	(8) magnetic circuit			
	(19) Lowenhielm	24x35	64	3.7
Stripa mill	Lowenhielm			1.45
	Rougher, two in parallel cleaner			1.45
Haksberg mill	(2) Vulcanus countercurrent cobber	37x34	35	3.7
	(2) MF2, Morgardshammer cobber	28x33	36	—
	(26) Lowenhielm	24x34	46 to 50	1.25
Persberg	(1) Jeffrey rubber covered counter-current drum	35x36		1.5 hp
	(25) Lowenhielm	24x34	44 to 60	1.4 hp
	(3) Thunes (three-drum) (perm magnets)	24x69		
Bodas mill	(9) Lowenhielm 3-mm thick rubber-covered drum	24x34	50	1.9 hp
Kallfallet	(9) Grondal	31x35	45	1.5 hp
Langnas	(20) Lowenhielm	24x34	54 to 62	2
Dannemora	(6) Morgardshammer GW617P (perm magnets) rubber-covered (three in series)	25x68	103	1
Bastkarn	Lowenhielm	24x34	75	2.5 ph
Kantorp	(5) Lowenhielm			
	(2) Allians			
Grangesberg	Allians	30x32		
	Thunes (perm magnets)	24x69		
Blotberget	Thunes (perm magnets)	24x71		2
Tuolluvaara	(15) Drum (perm magnets)	24x67		
Malmberget	(70) Harden	32x32	30 to 32	
	(8) Thunes (perm magnets)	24x67	30 to 32	

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

original feed is removed as a tailing product. Examination of the middlings has shown that no reasonable amount of regrinding will liberate the minute veinlets of magnetite in this fraction.

Early work on the Otanmaki dry magnetic process indicated that fatty acid materials added during drying operations were beneficial in the dry separation of this ore. Materials such as oleic acid, fuel oil, sulfuric acid, tall oil, and caustic soda were added prior to the drying stage. The fatty acid reagents formed a coating on individual particles which apparently helped disperse the mineral particles. Despite these initial successes, however, the commercial plant has stopped using fatty acids and is obtaining satisfactory results without adding chemicals to the magnetite.

Salzgitter Separator: In Germany the 30-in. dry magnetic separator* manufactured by Erzbergau 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 energized by two air-cooled d-c coils. The four induced rolls have corrugated surfaces and the spacing between the pole pieces and the rolls is considered critical.

* Designed by A. Goltz of the Salzgitter Co.

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 installations. For several years this institution has used dry concentration methods to produce the superconcentrates needed for sponge iron tests. Recent 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 concentrate, 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 September 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 reduction in silica content of concentrates such as taconite pellets.

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

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