FIG. 1

Heavy Media Tailings
Tailing Pond Fines
or Semitaconite
25 to 50% Iron

Crush and/or Grind
to Free the Iron Oxide

Partial Concentration
to Separate Iron Mineral
from Waste Product
by one of Following Processes

A or B or C

High Intensity Wet
Magnetic Separation
Partial Concentrate
Waste Product

Froth Flotation
Partial Concentrate
Partial Waste Product

Gravity Separation
Partial Concentrate
Waste Product

Gravity Concentrates or
Partial Concentrates
From "A" or "B" or "C"
40 to 58% Iron

Crush and Grind
to Liberate Silica

Coarse Fraction
Minus 0.010" plus 0.003"
0 to 75% Weight

Dryer

Electrodynamic Process
to Separate
Iron Oxides and Silica
Silica Product
to Waste

Iron Oxide Concentrate
62 to 65% Iron
5% Silica

Froth Flotation Process
to Separate
Iron Oxides and Silica
Silica Product
to Waste

Fine Fraction
Less than 0.003"
25 to 100% Weight

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ATTORNEYS
IRON ORE BENEFICIATION PROCESS

Tailings

Grind through 28 to 48 Mesh

Sizing

Gravity Separations

Middling

Concentrate

Open Circuit Rod Mill

Filter and Dry

Electrostatic Separation

Tailing

Concentrate

To Waste

Gravity Separation

or to

Gravity Separation

Tailings

Grind through 35 to 48 Mesh

Float with Fatty Acid, Fatty Acid Soap, or with Petroleum Sulfonate

Iron Oxide Froth Product

Silica Cell Product

Open Circuit Rod Mill

Waste

Filter and Dry

Electrostatic Separation

Final Concentrate

Tailing

To Waste

or to

Gravity Separation

To Briquetting Plant

FIG. 3

FIG. 4
Tailings
Grind through 35 to 48 Mesh
Float with Fatty Acid, Fatty Acid Soap, or with Petroleum Sulfonate
Iron Oxide Froth Product
Open Circuit Rod Mill
Scrub with 10 lb Sulfuric Acid/Ton Ore
Wash
Float with Calcium Ion and Fatty Acid
Iron Oxide Cell Product
Filter and Dry
Electrostatic Separation
Final Concentrate
To Briquetting Plant
Silica Froth Product
Waste
Silica Cell Product
Waste
Crude Ore
\[ \text{% Wt.} \ 100.00 \quad \text{% Fe} \ 31.31 \]
Crush & Grind to Liberation

Wet or Dry Low Intensity Magnetic Separation

Magnetite Concentrate
\[ \text{% Wt.} \ 1.00 \quad \text{% Fe} \ 60.00 \]

Magnetite Free Product
\[ \text{% Wt.} \ 99.00 \quad \text{% Fe} \ 30.01 \]

High Intensity Wet Magnetic Rougher Separator

Rougher Tailing
\[ \text{% Wt.} \ 34.95 \quad \text{% Fe} \ 8.63 \]

Rougher Concentrate
\[ \text{% Wt.} \ 64.05 \quad \text{% Fe} \ 43.24 \]

High Intensity Wet Magnetic Cleaner Separator

Cleaner Concentrate
\[ \text{% Wt.} \ 46.23 \quad \text{% Fe} \ 52.29 \]

Cleaner Tailing
\[ \text{% Wt.} \ 17.82 \quad \text{% Fe} \ 19.76 \]

High Intensity Wet Magnetic Recleaner Separator

Recleaner Concentrate
\[ \text{% Wt.} \ 37.22 \quad \text{% Fe} \ 58.23 \]

Recleaner Tailing
\[ \text{% Wt.} \ 9.01 \quad \text{% Fe} \ 27.76 \]

Silica Flotation by Calcium Activation

Final Conc.
\[ \text{% Wt.} \ 29.45 \quad \text{% Fe} \ 64.16 \quad \text{% Insol.} \ 5.02 \quad \text{% Fe Rec.} \ 62.34 \]
Tailing
\[ \text{% Wt.} \ 7.77 \]

Silica Flotation Using an Amine

Final Conc.
\[ \text{% Wt.} \ 26.85 \quad \text{% Fe} \ 64.16 \quad \text{% Insol.} \ 5.01 \quad \text{% Fe Rec.} \ 56.84 \]
Tailing
\[ \text{% Wt.} \ 10.37 \quad \text{% Fe} \ 42.87 \]
IRON ORE BENEFICIATION PROCESS

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This invention relates to a process for the beneficiation or upgrading of low grade iron-containing minerals and, more particularly, to the beneficiation of semi-taconite ores or altered taconites which have become partially leached and oxidized, present plant concentrates produced by gravity separation which are of marginal usefulness because of unfavorable physical and chemical properties, and tailing stock piles from prior gravity separation operations. There are huge reserves in the Western Mesabi range of Minnesota, and elsewhere, of these relatively low grade iron ores, unsellable concentrates and tailings dumps which are becoming of increasing interest and importance in our nation’s economy as richer ores and more easily concentrated minerals are becoming less readily available. Although methods are known by which these low grade minerals may be concentrated and upgraded, they are unsatisfactory in many instances, either because the upgraded or concentrated product is not salable because it does not meet the minimum and increasingly strict requirements of the steel mills, or because it is prohibitively expensive, or both.

The principal object of the present invention is to provide an economical iron ore beneficiation process for the production of salable concentrates which are acceptable to the steel mills because they meet the requirements of the mills. Such concentrates should contain more than about 60% iron and less than about 7% silica. The present process provides for the highest iron recovery with minimum capital and operating costs. The process is adapted to the upgrading of present heavy duty and spiral concentrates and to the concentration of present plant waste products as well as crude semi-taconite ores, and in some cases, even fine-grained oxidized taconite. Capital costs are minimized by largely utilizing presently existing equipment.

The iron in semi-taconites is present largely in the form of goethite and hematite with minor amounts of magnetite. The insoluble material is largely quartz. It is well-known that silica can be floated by calcium and magnesium ion activation with an anionic collector. This procedure has the advantage of minimum difficulty with slimes, but the cores require rather fine grinding and the float seems to be inherently weak and the treatment is very expensive. Thus, a calcium-activated silica float does not lend itself to rejecting a large quantity of coarse silica tailing as a preliminary scalping operation. Although it is possible to float much coarse silica with various amines, the reagent cost is high and, in general, amine flotation procedures are extremely slime sensitive. Further, a large percentage of the quartz in semi-taconite ores is stained with iron and thus remains with the iron concentrate in either an amine float or a calcium-activated silica float.

It is also well known that iron minerals can be floated, either by various fatty acids, or by petroleum sulfonates. Floation of the iron minerals has the advantages that a scalping operation at a coarse grind is possible, that the reagent cost is modest, and that only partial desliming is necessary. The production of high grade concentrates is usually precluded, however, because iron stained quartz tends to remain with the iron concentrate. Certain ores also contain small quantities of calcium and magnesium so that a fatty acid flotation concentrate usually contains an undesirable portion of the quartz grains due to activation.

Concentration is also possible by gravity methods, using such devices as spirals, tables or vanishing concentrators. In general, however, gravity concentration of the larger sizes produces a concentrate high in silica unless numerous regrinding stages and large circulating loads are used.

It is also known that many of these ores can be concentrated by using high intensity magnetic separators. High intensity dry magnetic separators have been used commercially for years. However, low grade semi-taconite cannot be economically concentrated in this manner due to the high capital costs of such separators and to the drying costs implicit in such a process.

Electrodynamic concentration can also be used to beneficiate ores of this type provided that the feed is thoroughly deslimed and that the ore is thoroughly dry. In such a process, however, drying costs are high because a large portion of the original feed would eventually be discarded as a tailing. The problem is to produce a high grade concentrate at high iron recovery with a minimum capital and operating cost.

In view of the known capabilities and the known disadvantages of various prior art beneficiation methods, it is apparent that no single beneficiation process can be found which will lend itself to an economically feasible flow sheet for the production of acceptable salable concentrates from semi-taconite ore, from low grade concentrates and waste products from previous separations, and other similar services of low grade iron minerals. Accordingly, the present invention is based upon the utilization of the advantageous characteristics of a combination of concentrating procedures. By utilizing several types of processing equipment, it is possible to sort the minerals in the ore so that advantage can be taken of the particular physical and chemical properties of each one group by using a combination of concentrating procedures.

The invention is illustrated in the accompanying drawing in which:

FIGURE 1 is an exemplary schematic flow sheet of a process for the beneficiation of crude semi-taconite ore; or for the treatment of tailings from previous separation or concentration processes; or upgrading the concentrate product of present concentrating plants;

FIGURE 2 is a flow sheet illustrating and showing typical data of a process for the concentration of crude semi-taconite ore;

FIGURES 3, 4 and 5 are alternative flow sheets of processes for the treatment of tailings from previous crude separation or concentration treatments;

FIGURE 6 is a flow sheet illustrating and showing typical data for a process of treating crude ore using high intensity wet magnetic separation to make an initial crude concentrate and froth flotation to make a final high grade concentrate; and

FIGURE 7 is a graphic illustration of the separation coefficient plotted against maximum ore temperature showing the effect of heat on separation by electrodynamic means.

Broadly stated, the present invention is directed to an economically feasible process for the production of a final high grade concentrate from low grade iron ore, with high iron recovery, by electrodynamic and/or froth flotation concentration and, in some cases, in combination with high intensity wet magnetic separation. The process is used for concentrating feebly magnetic material. As seen in FIGURE 1, the material is first crushed and/or ground to free the iron oxide and a crude concentrate is produced by gravity methods, high intensity wet magnetic separation methods, or by froth flotation. This concentrate will assay from 40 to 58% iron and must then be further treated by electrodynamic concentration and/or by additional grinding and froth flotation to pro-
duce a final concentrate. The concentrating scheme takes advantage of utilizing differences in the electric, magnetic, surface, and gravity properties between the valuable and gangue minerals. It is well known that a partial concentra-
tion can be easily produced by gravity methods, and under favorable conditions by froth flotation. Interfering gangue materials, however, have in the past precluded the production of a high-grade concentrate. The process makes use of the differences in the properties of the mineral species to be sorted in such a manner that it is always possible to eliminate interfering minerals and, subsequently, produce a high-grade concentrate.

The details of electrical concentration of minerals are described in "Fundamentals of Electrical Concentration of Minerals" by James E. Lawer, Mines Magazine, January 1960. "Electrodynamic" separation refers to use of a corona type separator, requiring corona current. "Electrostatic" separation refers to use of a separator not requiring corona current. It is relatively simple, but expen-
tive, to produce a high-grade concentrate by utilizing an electrodynamic separator. The present invention is di-
rected to preconcentration of the low grade iron ore by separation of the initial feed into fractions susceptible to economic concentration by electrodynamic means, and other fractions susceptible to economic concentration by froth flotation to produce a high yield of high grade concentrate. High iron recovery renders the entire process economically feasible.

It has now been discovered that efficient electrodynamic separation of ores containing goethite is dependent upon a critical heating step to between about 100 to about 200° C. and not over about 250° C. The ore is subjected to electrodynamic separation while dry to take maximum advantage of surface conductivity. It had previously been thought to be desirable to heat goethite containing minerals to about 400° C. to cause the goethite to lose two molecules of water of hydration and become hematite which is more conductive. It has now been found, how-
ever, that the ore is damaged if heated excessively. As seen in FIGURE 7, the separation coefficient begins to fall rapidly when the ore is heated substantially above about 125° C. and, when the ore has been heated above 200 to 250° C., electrodynamic separation is not prac-
ticable. In determining the separation coefficient samples of ore were heated to elevated temperature for 12 hours or more and then separated at 100° C. FIGURE 7 is a plot of the electrodynamic separation coefficient K against the maximum temperature to which the ore was subjected prior to separation. The ore samples were heated for more than 12 hours to the maximum temperature and separated at 100° C.

As one example, as applied to crude semi-laticone ore, the process as illustrated in flow sheet form in FIGURE 2 comprises the steps of first sizing the crude ore to less than about 4 inch screen size. The +4 inch material is treated separately, as described hereinafter. The —4 inch material is crushed further and screened to about 14 mesh size. The —14 mesh ore is deslimed by scrubbing and discarding the slimes. This deslimed material is then subjected to spiral gravity concentration. The +14 mesh ore is subjected to heavy media gravity concentration. The crude concentrates from the spiral and heavy media separations are combined and reduced (as in a rod mill) to 100% less than about 48 mesh size. In order to mini-
mize the total loss in the extreme fines, the —325 mesh material is then subjected to calcium activated silica float. This concentrate is then added to the concentrate produced in the electrodynamic separa-
tions to furnish part of the fines required for bulling. The combined gravity separation concentrate of between about 48 and 325 mesh size is deslimed by screen washing to about 125° C. and then subjected to high tension electrodynamic separation. The tailings from at least the spiral and heavy media gravity concentrations (and optionally from the first electrodynamic separation) are combined and ground.

These ground tailings are then subjected to concentration by flotation. The resulting flotation concentrate is dried by heating to about 125° C. and subjected to further concentration by high tension electrodynamic separation. The two electrodynamic separation concentrates are then combined with the fine flotation concentrate and agglom-
erate to produce a satisfactory furnace burden. The heat from the agglomeration plant is desirably utilized in drying the intermediate crude concentrates for the final electrodynamic separation.

A concentrate of 65% iron and 5% silica was produced according to this procedure from a crude semi-laticone ore containing 59.35% iron and 41.19% silica. After crushing and screening, the —4 inch ore represented 84.45% of the original ore and contained 40.19% iron. The combined concentrate from the electrodynamic sepa-
ration of the +325 mesh gravity separation concentra-
tes and the flotation concentrate of the —325 mesh gravity separation concentrates amounted to 30.0% of the total weight and assayed 65% iron and 5% silica. The flotation concentrate from the tailings on the heavy media and spiral separations assayed 50% iron. When dried and subjected to electrodynamic separation, the resulting concentrate amounted to 10.93% of the initial ore and assayed 65% iron and 5% silica. The final concentrate produced from both the heavy media and spiral separation concentrates and tailings thus amounted to 40.97% of the initial weight and assayed 65% and 5% silica. Of the iron in the crude ore, 67.68% was recovered. Of the iron in the —4 inch ore resulting from the primary crushing, 78.52% of the iron was re-
covered.

According to an alternative process the crude ore is crushed to less than about 4 inch screen size, the sized ore is deslimed by scrubbing and the slimes are discarded. The sized and deslimed ore is then crushed to about 14 mesh size and screened and subjected to a first gravity separation, which may be by available gravity separation equipment to produce a crude heavy media concentrate, cyclone concentrate or spiral concentrate. This resulting crude gravity separation concentrate is then comminuted to less than about 28 or 48 mesh. The mineral of less than about 325 mesh size may be separated and subjected to slime flotation. The remaining material between about 28 and 325 mesh size is dried to about 125° C. and then subjected to an electrostatic separation. The gravity separa-
tion concentrate is deslimed by scrubbing and the heat from the briquetting plant in which the concentrates are agglomerated.

The tailings from the first gravity separation and the electrostatic separation are reduced and sized to less than about 28 mesh size. These tailings may be subjected to a further preliminary separation according to one of three separate flow sheets as described in detail herein-
after. The concentrate resulting from the preliminary separation is further reduced by passage through an open or closed circuit rod mill, filtered and dried and subjected to an electrostatic separation. The final electrostatic separa-
tion concentrates are agglomerated to produce a satisf-
cy furnace burden, preferably by briquetting.

According to the first alternative flow sheet for treatment of the tailings, as shown in FIGURE 3, the pre-
liminary separation of the reduced and sized tailings is by gravity separation methods. The middlings from this gravity separation, the —325 mesh material, may be further tailing for further processing and the tailings of this further gravity separation are discarded to waste. The tailings from the further electrostatic separation of the briquetting plant agglomerate may likewise be recycled for admix-
ture with original tailings for further processing.

According to the second alternative flow sheet for treatment of tailings, as shown in FIGURE 4, the reduced and sized tailings are subjected to a flotation separation with fatty acid, fatty acid soap or petroleum sul-
fonate. The silica cell product is discarded as waste and
the iron oxide froth product is passed through the open circuit rod mill and subjected to a second flotation with fatty acid or soap. The iron oxide froth product of this second flotation separation is then filtered, dried and subjected to electrostatic separation. The silica cell product of the second flotation separation may be recycled along with the tailings from the final electrostatic separation for further grinding and recycling.

According to the third alternative flow sheet, as shown in FIGURE 5, the tailings are first floated with fatty acid, fatty acid soap or petroleum sulfonate. The silica cell product is discarded as waste and the iron oxide froth product is passed through a rod or ball mill, scrubbed with acid and washed and then subjected to a second flotation with calcium or magnesium ion and fatty acid. The silica froth product of this second flotation separation is discarded as waste. The iron oxide cell product is filtered and dried and subjected to electrostatic separation.

Many of the iron ore deposits throughout the world are easily beneficiated because the principal iron mineral is magnetite. The mineral magnetite, being ferro-magnetic, is easily removed from its gangue material by weak magnets, and practically no sophisticated metallurgy is involved to produce a concentrate. Many of the other iron minerals, however, are para-magnetic and can be concentrated magnetically only in machines having very high magnetic fields and high field gradients. For many years dry high intensity magnetic separators have been on the market, and in fact, dry high intensity magnetic separators are used commercially in processing certain ores. The low capacity and concomitant operating costs of these units, however, preclude their use as a concentrating device for low grade Minnesota and other domestic ores. There are also several high intensity wet magnetic separators being built, but until recently, none of the available units have had sufficient capacity or sufficiently low operating costs to be usable with low grade iron ores. It has now been possible to devise a process for beneficiating the so-called nonmagnetic iron ores. A combination process of high intensity wet magnetic separation followed by either froth flotation or electrodynamic separation permits the production of high grade concentrates with low capital investment and low operating costs.

A typical process in which a wet high intensity magnetic separation is made is as follows. The ore, in which the iron minerals consist essentially of the so-called nonmagnetic iron oxides, hematite and goethite, is first crushed to liberation. The highly magnetic mineral, which is always present in at least trace quantities, is removed by a low intensity magnetic separator, after which a partial concentrate is then made using a wet high intensity magnetic separator (Carpo) in order to reject the bulk of the gangue material from the ore and produce a concentrate appreciably higher in iron content than the feed. If the original comminution step is such that the gangue materials are completely liberated in the magnetic concentrate, the concentrate is then further treated by either flotation or by electrodynamic separation. If complete liberation is not obtained in the initial grind, the partial concentrate is further ground before subjecting it to the finishing steps by flotation or electrodynamic separation.

Flotation is carried out floating the silica either with a cationic reagent, such as amine, or by calcium (or other metal) ion activation and an anionic reagent, such as tall oil. By making a silica float on the material that has been partially concentrated magnetically, it is possible to produce high grade concentrates that cannot be made by flotation alone. This is because, where the iron ore concentrate is used as the flotation feed, it differs from the crude ore in that it has been freed of many of the objectionable impurities normally causing difficulty in flotation. The final concentrate, whether from flotation or from electrodynamic separation, is then agglomerated. When the subsequent agglomeration step is such that it is economical to dry rougher magnetic concentrate that is, the concentrate from the wet high intensity magnetic separation then the use of costly flotation agents can be avoided and a high grade product is produced by utilizing differences in electrical conductivity and in contact potential charging phenomena, thus sorting the valuable iron minerals from their gangue in an electrical field.

An exemplary flow sheet and typical data illustrating open circuit tests demonstrating wet magnetic separation and two typical silica floats on a magnetic concentrate are shown in FIGURE 6. Concentrates of about 64% iron and 5% silica are produced from crude ore containing only about 30% iron. The crude ore is first crushed and ground to liberate the iron oxides. This crushed and ground ore is then subjected to a low intensity magnetic separation to remove the magnetite present. Magnetite concentrate in the amount of 1% of the crude ore and containing 60% iron is separated at this stage. The remaining magnetite-free product is then subjected to high intensity wet magnetic separation in three stages.

The initial rougher separator divides the magnetite-free product into two fractions of which the concentrate amounts to 64.05% of the initial weight in which the iron content is upgraded to 43.24%. This rougher concentrate is then optionally reground and subjected to an intermediate stage cleaner high intensity wet magnetic separation. Again two fractions result, of which the concentrate amounts to 46.23%, of the initial ore weight and is upgraded to 52.29% iron content. This cleaner concentrate is subjected to a further high intensity, wet magnetic re-cleaner separation stage, from which the concentrate amounts to 37.22% of the initial ore weight and contains 58.23% iron.

This is below the minimum requirement for an acceptable concentrate. Accordingly, this material must be further concentrated in order to be suitable for the steel mills. Two alternative silica flotation systems are shown. In the first a calcium activated silica float is used. The final concentrate corresponds to 29.45% of the initial weight. It has an iron content of 64.16% and a silica content of 5.02%. Both of these are well within the requirements of the steel mills. By this method, 62.34% of the iron initially present was recovered. As an alternative, the re-cleaner concentrate is subjected to a silica flotation using an amine. This produces a final concentrate corresponding to 26.85% of the initial ore weight. This concentrate has an iron content of 64.16% along with 7.01% silica and corresponds to an iron recovery of 56.84% of that initially present.

Alternatively, the re-cleaner concentrates from the last high intensity wet magnetic separation stage may be processed further according to the flow sheet of FIGURE 1 by being dried to about 125° C. and then subjected to further electrodynamic separation to further concentrate the iron values. As used herein "high intensity" refers to a field of the order of about 20,000 to 22,000 gauss and a high field gradient (non-uniform) and "low intensity" refers to a field of the order of about 500 to 1500 gauss.

The mineralogy, liberation characteristics and size distribution of the semi-ironic materials are such that any optimal process must be tailor-made to the ore. This is true in flotation as well as in electrodynamic or electrostatic separation. For example, microscopic study of the coarse and fine heavy media concentrates from a Western Mesabi semi-ironic show that there are three stages in the liberation of the entrapped silica from the concentrates. The first stage involves the liberation of cherty or flinty rock layers locked with the coarser heavy media concentrate sink fraction that can be substantially liberated by grinding through about one-quarter inch. The second stage involves liberation of hematite from the cherty layers at about 65 mesh. The third stage involves liberation of silica from the iron rich layer at —325 mesh. While...
study shows that these coarse and fine heavy media concentra
tes can be slightly upgraded by gravity methods by
grinding no finer than 10 mesh, substantial additional
improvement in grade requires further grinding below 65
mesh with supplementary concentration techniques.

In the case of cyclone concentrates, mineralogical obser
vations have shown that the dominant mineral is hematite
which is substantially liberated in the 65/100
mesh size range. In the case of spiral concentrates, it has
been shown that the most effectively concentrated ma
terial is in the 28/48 mesh size range whereas the 48/150
mesh size fraction is the least effectively concentrated.

Microscopic examination of heavy media tailings assaying
22.75 percent iron showed two liberation points. The
hematite grains are substantially liberated from the silica
gangue with a 28 to 48 mesh grind. However, concentrates
produced with this coarse grind have fine inclusions of
silica that require a 65 to 100 mesh grind for liberation.
Grinding costs and slime losses may be minimized by
rejecting a rougher tailings fraction after a coarse grind
and then regrinding the concentrate to effect complete
liberation. Comminuted and partly deslimed tailings from the
heavy media gravity separation is subjected to concen
tration by both gravity (tailing) and by froth flota
tion. The concentrate from this intermediate step is then
dried and upgraded by electromagnetic separation.
Studies have shown that the rock reject, that is, that
+4 inch material from initial crushing of crude ore, and
course and fine heavy media tailings, are often mineral
ogically and textureually equivalent. Improvement in grade
occurs about 48 mesh at the size where hematite is
beginning to be liberated from the cherty ground mass.
Cyclone tailings were found to contain nearly the same
hematite to goethite ratio as cyclone concentrate and are
amenable to the same type of supplementary concen
tration. Similarly, size or spiral tailings are found to compare
with rock reject and heavy media tailings. The mode of
treatment thus depends upon the nature of the initial ore
starting material. Where the initial feed is crude ore, it is,
of course, subjected to preliminary crushing and sizing
treatments which have already been performed as part of
another process in the case of plant concentrates and
tailings.
The percentage of iron in concentrates is raised several
points when a goethitic type concentrate is fired to make
a pellet. For example, a 62% iron product is raised to
about 65% by firing.

Heavy media concentrates can be easily upgraded by
utilizing differences in surface electrical conductivity be
 tween the goethitic concentrate and the quartz gangue. In
general, these materials can be sufficiently upgraded by
making about a 28/48 mesh grind, desliming the com
minuted material and making an electrodynamic sepa ratio
on the dried deslimed product. However, in order to
upgrade spiral and cyclone concentrates with high iron
recovery, it is necessary to utilize supplementary concen
tration techniques.

One embodiment of a process according to the present
invention utilized for upgrading present plant spiral and
cyclone concentrates is as follows. The concentrates are
first ground to 100% — 48 mesh or finer. This material
is then deslimed and that larger than 325 mesh is dried
and subjected to high tension electrodynamic separation.
The — 325 mesh material is treated with a thickener and
the extreme slimes discarded. The remaining material is
separated in flotation cells and the concentrate combined
with the electrodynamic separation concentrate.

By this method spiral and cyclone concentrates con taining 57.80% iron and 12.35% silica have been up
graded to produce a concentrate of 64.4% iron and 5.2%
silica with 83.9% iron recovery. Upon grinding and
screening, 70% of the weight and 60.9% of the iron of the
original concentrates were in the — 325 mesh frac
tion. After electrodynamic separation, the concentrate
amounted to 58.9% of the original weight, contained
65.2% iron, 5.0% silica and represented recovery of
66.4% of the original iron content of the concentrate
starting material. The — 325 mesh fraction represented
30% of the original weight and this fraction contained
50.5% iron. The flotation feed after discard of the slimes
represented 23.0% of the weight and contained 50.1%
iron. The flotation concentrate represented 16.4% of the
original weight, contained 61.5% iron and 5.7% silica
and represented recovery of 17.5% of the initial iron
content. The concentrates when combined represented
75.3% of the initial weight, contained 64.4% iron and
5.2% silica and represented 83.9% iron recovery.

It is apparent that many modifications and variations
of this invention as hereinbefore set forth may be made
without departing from the spirit and scope thereof. The
specific embodiment described are given by way of ex
ample only and the invention is limited only by the terms
of the appended claims.

1. A process for the beneficiation of low-grade iron
ore material containing principally goethite and hematite
to produce a concentrate of at least about 60% iron with
no more than about 7% silica, which process comprises:
(A) crushing the low-grade ore material to liber
eration size to free the iron oxides,
(B) separating the iron mineral from waste product
 to form an initial crude concentrate,
(C) crushing and grinding the initial crude concen
trate to less than about 0.010 inch particle size
to liberate the silica,
(D) separating the iron oxides from the silica and
(E) agglomerating the iron oxide concentrate.

2. A process according to claim 1 further characterized
in that:
(A) the crushed and ground initial crude concentrate
is separated into fractions including a fine fraction
of less than about 0.003 inch particle size and
(B) said fine fraction is subjected to froth flotation
to separate the iron oxides from siliceous gangue.

3. A process according to claim 1 further characterized
in that the crushed and ground initial concentrate is:
(A) separated into fractions including a coarse frac
tion of more than about 0.003 inch particle size,
(B) said coarse fraction is dried by heating to at least
about 100° C. and no more than about 250° C., and
(C) subjected to high tension electrodynamic separa
tion to separate the iron oxides from waste product.

4. A process according to claim 1 further characterized
in that:
(A) said low-grade iron ore material is selected from
the class consisting of semimentite ore and tailings
from other iron ore beneficiation processes contain ing
25 to 50% iron, and
(B) said initial crude concentrate is produced by high
intensity wet magnetic separation, and
(C) said initial crude concentrate is upgraded by silica
flotation.

5. A process according to claim 4 further character ized
in that said high intensity wet magnetic separation
is carried out in a plurality of successive stages in a field
of about 14,000 to 22,000 gauss.

6. A process according to claim 1 further character ized
in that:
(A) said low-grade iron ore material is selected from
the class consisting of semi-taalconite ore and tailings
from other iron ore beneficiation processes contain ing
25 to 50% iron, and
(B) said initial concentrate is produced by froth
flotation.

7. A process according to claim 1 further characterized
in that:
(A) said low-grade iron ore material is selected from
the class consisting of semimentite ore, tailings from
other iron ore beneficiation processes containing 25
to 50% iron and low-grade hematite ore and
A process for the beneficiation of low-grade iron ore material containing principally goethite and hematite to produce a concentrate of at least about 60% iron with no more than about 7% silica, which process comprises:

(A) crushing the low-grade iron ore material to liberation size to free the iron oxides,
(B) separating the iron mineral from waste products to form an initial crude concentrate,
(C) crushing and grinding the initial concentrate to less than about 0.010 inch particle size to liberate the silica,
(D) separating said concentrate into fractions including a coarse fraction and a fine fraction of less than about 0.003 inch particle size and subjecting said fine fraction to froth flotation to separate the iron oxides from siliceous gangue,
(E) drying the coarse fraction of crushed and ground initial concentrate by heating to at least about 100° C. and no more than about 250° C.,
(F) subjecting the dried coarse fraction to electrodynamic separation and to separate the iron oxides from waste products,
(G) combining the iron oxides from the froth flotation and electrodynamic separations and agglomerating.

A process for the beneficiation of low-grade iron ore material containing principally goethite and hematite to produce a concentrate of at least about 60% iron with no more than about 7% silica, which process comprises:

(A) crushing the low-grade iron ore material to liberation size to free the iron oxides,
(B) separating the crushed iron ore material to high intensity wet magnetic separation to separate the iron mineral from waste products to form an initial crude concentrate,
(C) separating the iron oxides from the silica in the initial crude concentrate, and
(D) agglomerating the iron ore concentrate.

A process according to claim 9 further characterized in that said high intensity wet separation is carried out in a field of about 14,000 to 22,000 gauss.

A process according to claim 9 further characterized in that said high intensity wet magnetic separation is subjected to an initial low intensity magnetic separation carried out in a field of about 500 to 1500 gauss to remove any magnetite present in the ore material.

A process according to claim 9 further characterized in that said high intensity wet magnetic separation is carried out in a plurality of stages, the partial concentrate from each preceding stage then being further concentrated in a next succeeding stage.

A process according to claim 9 further characterized in that the silica in the initial crude concentrate from the high intensity wet magnetic separation is separated from the iron oxide by silica froth flotation.

A process according to claim 13 further characterized in that said silica flotation is carried out by use of a flotation reagent selected from the class consisting of cationic flotation reagents and metal ion activated anionic flotation reagents.

A process according to claim 9 further characterized in that the initial crude concentrate from the high intensity wet magnetic separation is first dried and the iron oxide is separated from the silica by electrodynamic separation.

A process for the beneficiation of crude semi-foam iron ore to produce an ore concentrate of at least about 60% iron with no more than about 7% silica, which process comprises:

(A) sizing the crude ore to less than about 4 inch screen size,
(B) crushing the —4 inch ore and screening to about 14 mesh size,
(C) scrubbing the —14 mesh ore and discarding the slimes,
(D) subjecting the scrubbed —14 mesh ore to gravity separation,
(E) subjecting the +14 mesh ore to a heavy media gravity separation,
(F) combining the concentrates from at least the gravity separations and reducing to less than about 48 mesh size,
(G) separating the concentrate into fractions including a coarse fraction and a fine fraction of gravity separation concentrate of less than about 325 mesh size and subjecting that fine fraction to metal ion activated silica flotation using an anionic collector,
(H) drying the coarse gravity separation concentrate of between about 48 and 325 mesh size by heating to at least about 100° C. and no more than about 250° C. and subjecting to a first electrodynamic separation,
(I) combining the tailings from the gravity separations and grinding,
(J) subjecting the ground tailings to concentration by flotation,
(K) drying the resulting flotation concentrate by heating to at least about 100° C. and no more than about 250° C. and subjecting to further concentration by a second electrodynamic separation, and
(L) combining and agglomerating the first and second electrodynamic concentrates along with the —325 mesh flotation concentrate.

A process for upgrading gravity separated spiral and cyclone concentrates of low grade iron ores containing principally goethite and hematite to produce an improved ore concentrate of at least about 60% iron with no more than about 7% silica, which method comprises:

(A) reducing the gravity separation concentrate to less than about 48 mesh size,
(B) separating the concentrate into a coarse fraction and a fine fraction and drying the coarse sized gravity separation concentrate of between about 48 and 325 mesh size by heating to at least about 100° C. and no more than about 250° C. and subjecting to electrodynamic separation,
(C) thickening the fine concentrate of less than about 325 mesh size and discarding the slimes,
(D) subjecting the thickened fine gravity separation concentrate to further concentration by froth flotation,
(E) combining the electrodynamic and cell flotation concentrates, and
(F) agglomerating the combined concentrates.

A process for upgrading tailings containing principally goethite and hematite from prior beneficiation treatments or iron ores to produce from the tailings an ore concentrate of at least about 60% iron with no more than about 7% silica, which method comprises:

(A) reducing the tailings and sizing to less than about 28 mesh size,
(B) subjecting the reduced and sized tailings to a preliminary separation into a concentrate and a waste product,
(C) further reducing the concentrate of the preliminary tailings separation,
(D) filtering and drying the concentrate by heating to at least about 100° C. and no more about 250° C.
(E) subjecting the filtered and dried concentrate to electrodynamic separation into a further concentrate and further waste product, and
(F) agglomerating the electrodynamic separation concentrate.

A process according to claim 18 further characterized in that the electrodynamic separation concentrates are agglomerated by briquetting.

References on following page
<table>
<thead>
<tr>
<th>References Cited</th>
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</thead>
<tbody>
<tr>
<td>UNITED STATES PATENTS</td>
</tr>
<tr>
<td>2,075,466</td>
</tr>
<tr>
<td>2,175,484</td>
</tr>
<tr>
<td>2,307,064</td>
</tr>
<tr>
<td>2,557,059</td>
</tr>
<tr>
<td>2,558,635</td>
</tr>
</tbody>
</table>

2,675,966 | 4/1954 | Kilblstedt | 241-24 X |
2,962,231 | 11/1960 | Weston | 241-24 |
3,022,956 | 2/1962 | Haseman | 241-24 |
3,067,957 | 12/1962 | Eck | 241-24 X |

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