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ELECTROSTATIC ORE CONCENTRATOR

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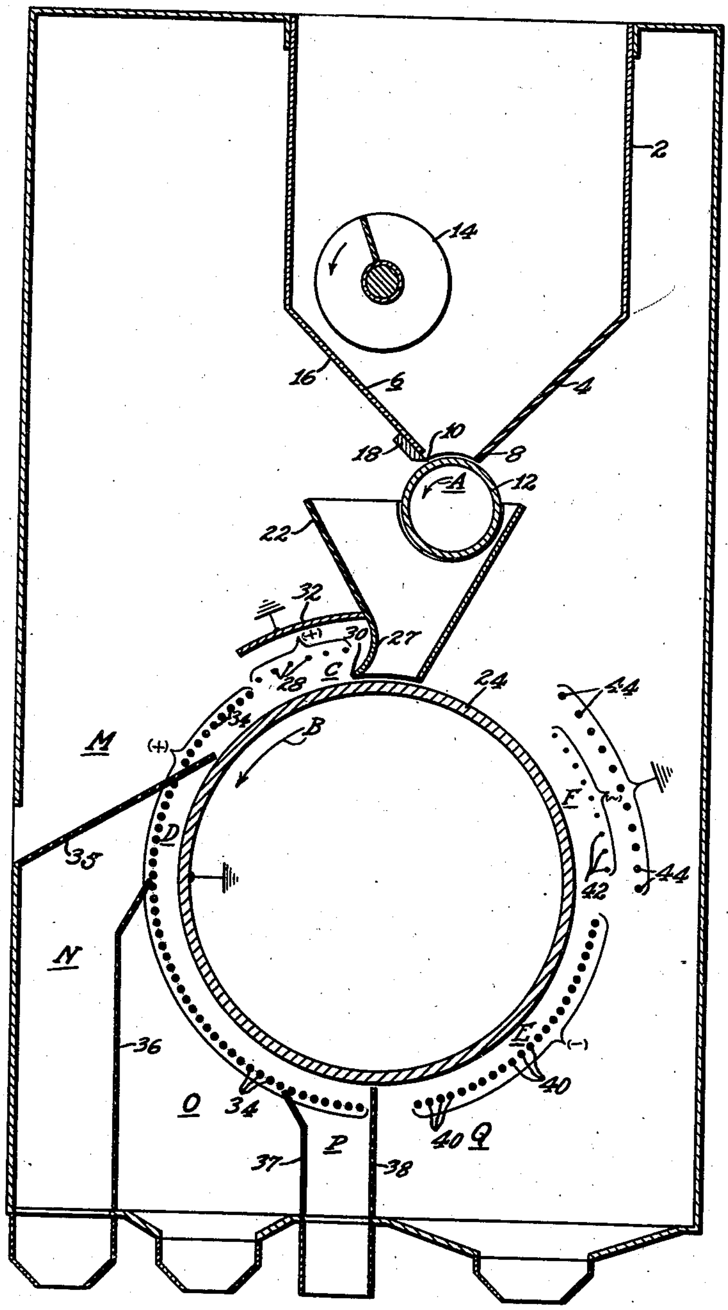

Fig. 1.

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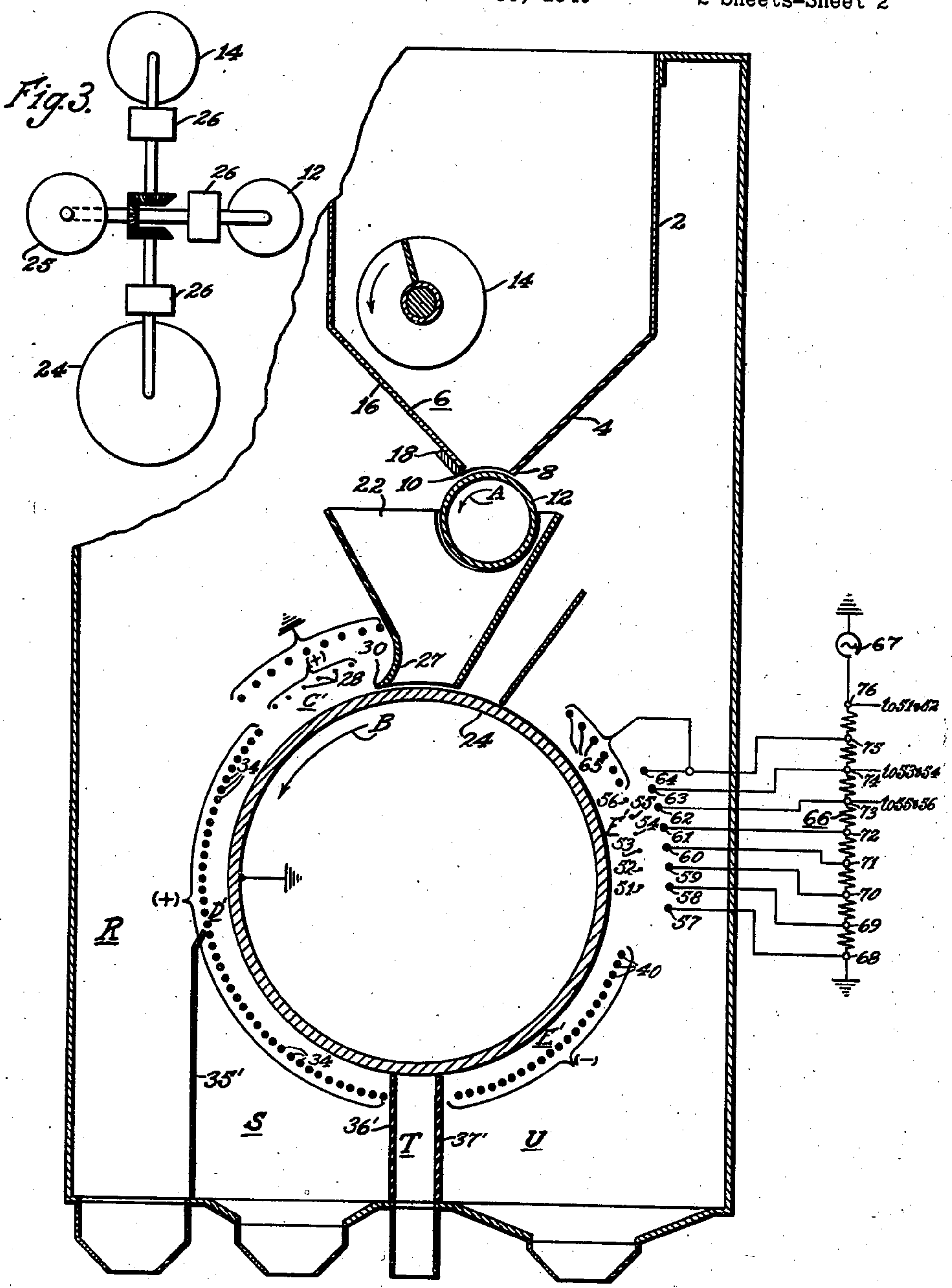

Fig. 3.

Fig. 2.

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Patented Mar. 30, 1943

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UNITED STATES PATENT OFFICE

2,314,939

ELECTROSTATIC ORE-CONCENTRATOR

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Application October 30, 1940, Serial No. 363,443

12 Claims. (Cl. 209—127)

This invention generally relates to means and methods for separating particles of certain physical characteristics from a mass of aggregated particles having similar physical characteristics but to different degrees, and more particularly relates to electrical apparatus and methods for electrostatically beneficiating a finely divided or pulverized low-grade or lean metal-bearing ore.

It is an object of our invention to provide a device for electrostatically treating a low-grade or lean ore for the purpose of separating the metal-bearing constituent from the gangue to the end that an ore of commercially-usable higher quality can be obtained.

It is among the objects of our invention to provide a practical, low-cost, electrical ore-treating device having small space requirements but having high ore-treating capacity together with an exceptional operating-efficiency for separating metal-bearing ore particles from the intermixed gangue.

Generally and briefly stated, the preferred forms of our invention, as herein described, include a means for continuously feeding a thin layer of ore particles upon an endless conveyor in the form of a cylindrical treating drum having a grounded electricity-conducting surface rotating about a horizontal axis. In accordance with the purpose of our invention to provide an ore-treating device of high operating capacity, the drum rotates at a relatively high speed and the drum surface moves at a high linear speed, much higher than prior electrostatic ore-concentrating devices using this expedient. All of the particles are then given an electric charge by bombardment with ions, the bombardment being maintained for a time sufficient to charge substantially all of the particles, so that these particles will remain in close contact with the grounded drum as a result of this bombardment and the resulting charge on the particles.

After passing through this first ionizing or charging zone, which is preferably near the top of the drum so that gravity also acts to retain the particles on the drum, the particles pass into an extended length of a substantially non-ionized electrostatic field of a polarity and direction tending to repel against the drum those particles which have such characteristics that they retain all or some fraction of their original charges, and tending to pull from the drum those particles which have such characteristics that they lose most of their original charge, and perhaps even take on an opposite charge by conduction from the drum. In this zone particles of relatively low resistivity, that is, high conductivity, lose their charges to the conducting surface of the drum so that the electrical forces tending to retain them in contact with the drum decrease and may disappear entirely. The high rotational speed of the drum imparts sufficient momentum to the discharged or discharging particles to cause them to fly off by the action of centrifugal forces so that these particles separate in this zone from the particles retained on the drum. Particles of a very high conductivity on the drum may have their charges reversed by conduction from the drum, these reversed charges reacting with the field of this second zone to establish electrostatic forces tending to pull the particles away from the drum.

The separation of the particles is further aided, in our invention, by locating this non-ionized or separating zone along the vertical portion of the drum so that gravity also acts to pull from the drum surface those particles which have little or no forces tending to make them adhere to the drum. By proper correlation of the extent and strength of the electrostatic field, and the angular velocity of the drum, the electrostatic forces on charged particles can be made sufficient to hold them on the drum against the separating action of gravitational and centrifugal forces, while the particles which have lost most or all of their original charges cannot react with this electrostatic field to produce a counteracting force, and leave the drum.

After passing through the particle-repelling electrostatic field, the relatively high resistivity particles are separated from the drum because of continued charge leakage which lessens the retaining electrostatic forces to below the separating action of the centrifugal and gravitational forces. This final separation can be improved by providing a third zone having an electrostatic field which will electrically react with the charged particles, tending to pull them from the drum, or neutralizing their charges so that they will fly or fall off.

By providing a device operating in the general manner above stated, we have been able to confine the equipment to an exceptionally small size in comparison to the large volume of ore it can handle, one reason for this being that we can utilize a good-sized drum rotating at a relatively high speed. Additionally, with a proper location of suitable electrodes, relatively low voltages in the order of 12,000 volts are sufficient for establishing the various electrostatic fields.

An important feature of our invention resides in the fact that the separation of the particles is accomplished while they rest on the drum, and not as they fall through the air. Consequently, air resistance has little, if any, effect on the separation, and interaction between mixed charged and uncharged particles is considerably reduced.

It is also an object of our invention to remove fine high-resistivity particles from a moving conveyor to which they tend to stick by virtue of electric forces.

Further objects, advantages, features and innovations of our invention in addition to those described above will be apparent from the following description thereof, to be taken in conjunction with the accompanying drawings which are deliberately simplified so that our invention can be better understood.

In these drawings in which similar numerals refer to similar parts:

Figure 1 is a schematic vertical cross-sectional view of an electrostatic ore-concentrator embodying our invention;

Fig. 2 is a similar view of a second form of an electrostatic ore-concentrator embodying our invention; and

Fig. 3 is a schematic view, on a decreased scale, of a driving means for the rotating parts of an ore-concentrator.

Referring more particularly to the drawings in which we describe by way of illustration and not as limitations, certain specific embodiments of our invention, in Fig. 1 the divided or pulverized ore to be beneficiated is dumped or continually fed into a storage hopper 2 having slanting bottom sides 4 and 6, slanting toward each other to provide an elongated rectangular discharge opening having lengthwise sides which are bounded by lower edges 8 and 10 of the bottom sides 4 and 6, respectively, these edges terminating close to a rotatable cylindrical feeding drum 12 of about 4" in diameter, for moving ore particles away from the discharge opening of the hopper. A rotating spiral agitator 14, within the hopper, and rotatably mounted in the ends of the hopper, agitates the ore particles to insure a steady and continuous flow to the feeding drum. The feeding drum 12 is somewhat longer than the discharge opening and its direction of rotation, as indicated by the arrow A, is such that the lower edge 10 of the bottom side 6 defines the trailing edge of the discharge opening.

The quantity of ore particles fed by the feeding drum 12 is determined by the speed of the feeding drum, which is adjustable, and the distance of the edge 10 from the feeding drum; the bottom side 6 being constructed so that this distance is also adjustable. To this end the bottom side comprises an upper fixed member 16 terminating a relatively long distance from the feeding drum, and a lower slidable gate-plate 18, which includes the lower edge 10, extending across the length of the member 16 and adjustably positionable so that the lower edge 10 can be spaced any desired distance from the feeding drum.

The layer of mixed ore particles which is continuously fed by the feeding drum 12, falls through a guiding trough 22, which confines the spread of the layer onto the surface of a grounded rotatable cylindrical treating drum 24 of about 12½" in diameter, and which rotates, in this case, in the same direction as the feeding drum, as indicated by the arrow B. The feeding drum 12, the agitator 14, and the treating drum 24 are preferably driven from a single power drive, such as a motor 25, through any common adjustable gearing 26 which permits their rotational velocities to be individually adjusted and relatively controlled. The thickness of the ore-particle layer on the drum 24 can be further controlled by the relative speeds of the feeding and treating drums.

The treating drum 24 has a highly conducting outer surface which is obtained by making the treating drum in the form of a hollow metal tube, although a cloth surface treated with a liquid containing colloidal graphite to render the surface highly conducting has been successfully used for the outside surface of the drum. The other parts of the device thus far shown and described are also preferably made of metal and electrically grounded.

The guiding trough 22 has a spout shorter than the treating drum 24, located at the top of the drum, spanning only a few degrees of its periphery, and immediately following the trailing side 27 of the guiding trough is an ionizing zone C for charging the ore particles on the drum 24.

In the embodiment shown in Fig. 1, this ionizing zone C starts at about 9° counter-clockwise from the vertical which is assumed to be the reference line, and includes a plurality, in this case six, of relatively small ionizing wires 28 spaced 4½° apart along an arc concentric with, and about one inch from the surface of the drum 24. We have found 4½ mil tungsten wires to be suitable although other size wire can be used. The wires are conductively connected together and insulated from ground in any suitable way, and connected to the positive terminal of a source of unidirectional potential whose other terminal is grounded, so that an ionized electrostatic field is established in conjunction with the grounded part of the drum within the angle subtended by the ionizing wires which constitute ionizing electrodes.

In order to get the ionizing zone C close to the depositing point of the ore particles on the drum 24, the trailing side 27 of the guiding trough 22 is curved concave toward the zone so that the leading end of the arc of the wires 28 can be disposed over the lower trailing edge 30 of the side 27 and still be sufficiently well insulated from the side 27 to prevent flashover and undue current leakage.

It is desirable to have the ionization in the zone C dense and uniform on the surface of the drum 24 and to this end the ionizing wires 28 are backed by a concentric grounded sheet-metal electrode 32 of approximately the same angular extent and size, or even overlapping the wires, and disposed one inch radial outwardly from the wires. The electrode 32 is a field-modifying means which causes a more uniform ion current distribution on the surface of the drum and an increased ion current density.

The ionizing zone is followed by a particle separating zone D, the two zones merging into one another and together occupying about the entire half-circle, more or less, through which the treating drum surface has a downward component of motion. In the actual embodiment being described the zone D extends from 36° to 180°, and includes a plurality of 63 mil copper wires **34** spaced 3° apart circumferentially. The wires **34** form an insulated series of electrodes, each having a relatively large diameter so that a high gradient can be produced without the generation of any significant amount of ions. This means that the electrodes are of the non-discharging type, and produce a non-ionized field. The wires **34** are spaced in an arc concentric with the surface of the drum and about ¾" from it, the wires being conductively connected together and insulated from ground in any suitable manner, and connected to a positive terminal of a unidirectional voltage supply having its other terminal grounded. The polarity of the non-discharging electrodes is the same as that of the ionizing electrodes or wires **28**, and in conjunction with the drum **24** creates a substantially non-ionized electrostatic field in the particle separating zone D.

In the operation of the apparatus thus far described, ore particles of appropriate size are fed through the discharge opening of the storage hopper **2** onto the feeding drum **12** which feeds the particles to the drum **24**. The speed of the treating drum **24** is primarily determined by the size and electrical characteristics of the particles, and is preferably adjusted to as high a value as is consistent with the desired quality of ore-beneficiation. The rate of feed of ore particles to the drum **24** can be controlled by the position of the edge **10** and the speed of the feeding drum **12**.

The particles fed on the drum **24** have different resistivities, but all of the particles will be positively charged in the ionizing or charging zone C, since they are continuously bombarded with ions, or the equivalent, from the positively charged ionizing wires **28**, during the time when the particles are passing through the charging zone. The particles being charged with respect to ground tend to adhere to the grounded drum. However, after the particles leave the charging zone C, so that they are no longer being bombarded with ions, and even during the bombardment, the charge on the particles is gradually leaking off by being conducted to the drum **24**, the rate of leakage being a function of the resistivity of the individual particles and the voltage gradient of the electrostatic field through which they pass. The electrostatic forces causing each particle to adhere to the drum decrease with leakage of charge from the particle, these forces being primarily the attractive force between a charged particle and the drum, and the repellent force between a charged particle and the non-ionizing electrodes **34**, which have a polarity of the same sign as the original charge on the particle. A point is soon reached when the particles of low resistivity or relatively better conductivity will have lost their charges to a sufficient extent so that they will leave the drum **24** through the action of centrifugal or gravitational forces, or both; and the best-conducting particles on the drum may even become charged with a polarity opposite to that of their original charge, so that these particles will be acted upon by electrostatic forces which encourage the separation of these particles from the drum. The separated particles can be collected in any suitable receptacles or other collecting means, any desired number of insulating partitions or baffles, such as **35**, **36**, **37** and **38** terminating near the drum or the electrodes, serving to confine the particles within the spaces defined by them, and acting as dividing partitions for segregating the particles falling in the bins M, N, O, P and Q.

However, the high-resistivity particles do not lose their charge as rapidly as particles of relatively lower resistivity, and the charges they retain create continuously operating electrostatic forces causing them to constantly adhere, more or less, to the drum as they rotate therewith, throughout the circumferential extent D of the non-discharging electrodes **34**. The relatively most conducting particles discharge most rapidly by conduction to the drum, and leave the drum first, while the particles having relatively higher resistivity will not be sufficiently discharged until farther points along the arc of rotation are reached. As the particles separate from the drum, they can be collected in the separate bins M, N, O, P and Q, it being understood that as many bins can be provided as desired, and that the partitions may be spaced apart differently.

For the highest degree of separation, the insulating particles or gangue should be carried around on the drum beyond the separating zone D, and in order to remove such particles a third particle-pull-off zone E is provided, which includes insulated non-discharging electrodes **40** of the same construction and arrangement as those in zone D, but connected to a voltage supply so as to be at a polarity opposite to that of the electrodes **34**, and opposite to the charge retained by the high-resistivity particles. In the specific embodiment being described, the zone E extends from about 195° to 261°, although this zone may be extended farther to as much as almost 360°, in such case being the last treating zone of the device. The zone E, accordingly, has a non-ionized electrostatic field which tends to counteract the effect of the charge on the particles on the drum and to establish on the particles remaining on the drum an attracting force toward the electrodes **40** so that they will be pulled off of the drum.

In the treatment of some ores, very fine particles of very high resistivity have been found still to stick to the drum after passing through the zone E, so that it has been found desirable to provide, in addition to the zone E, a neutralizing or charge-counteracting zone F extending from about 270° to 330°, including discharging ionizing electrodes **42** in the form of relatively fine wires similar in construction and arrangement to those of the ionizing zone C, connected to an alternating-current voltage supply and backed by grounded non-discharging electrodes **44**, so that the charge on any particles reaching zone F is considerably decreased, and even neutralized in this zone, removing the electrostatic force tending to keep them on the drum so that these particles will fly off, or may be easily brushed off.

It is a primary purpose of our invention to provide a device of the character described which will be capable of economically treating large quantities of ore with reasonably small equipment. To this end it is desirable to operate the treating drum at sufficiently high linear speeds to treat the required quantities of ore, since the amount of ore feed is a function of this speed. At the same time, however, the rotational speed and diameter of the drum, which are components of the centrifugal force on the particles, affect the quality of separation, and this force must not be made so high in comparison with the electrostatic forces that the particles, particularly the larger ones, fly off prematurely. The larger the equipment, of course, the greater its cost, and a practical drum diameter should be used which provides a circumference not much longer than the necessary extents of the electrostatic fields, bearing in mind that the particles should be subjected to these fields for sufficient intervals of time to provide good separation. The capacity of the drum can be made greater by increasing its axial length.

Utilizing a drum of 12½" diameter in the benefication of Minnesota iron ore of different particle sizes, some of the results of which are given later, we have utilized with satisfactory results linear speeds, in round figures, from about 200 feet per minute to 1500 feet per minute, and even more, which represents angular velocities of about 61 to 457 revolutions per minute, and above, for the drum 24. However, too low a speed should not be used for then the high-resistivity particles have an opportunity to lose their charge and fly off before they have moved very far from the points where the relatively conductive particles fly off, while too high a speed results in an increased centrifugal force which causes the particles to fly off quickly without an opportunity for selective separation.

The initial charging zone C is placed as close as possible to the point of ore feed, considering the required insulation, so as to prevent particles from prematurely flying off, and is long enough in comparison to the linear speed of the surface of the drum so that the particles receive substantially their maximum obtainable charge by the time they travel through the zone. In the initial charging zone C a dense, distributed and circumferentially uniform ionizing current from the wires 28 to the drum without danger of sparkover is desirable. While greater spacing between the wires and the drum would give more uniform ionization, a higher voltage would be required, increasing the voltage supply and insulation problems. Consequently the radial spacing of the wires is a compromise to permit a relative low voltage to be used while still obtaining a satisfactory ionized field. Positive ionization is preferred. The grounded backing electrode 32 improves the distribution and uniformity of the field between the wires 28 and drum 24. In actual practice, some particles fed to the drum 24 fly out of the trough 22 below the edge 30, and are charged while still in the air, being attracted to the drum electrically.

The electrodes of both the ionizing zone C and the separating zone D are arranged so that the electrostatic field at the drum is continuous, which is obtained by having the field established by the electrodes 34 merge into the field established by the electrodes 28. Consequently, an electrostatic field acts on the particles as soon as they charge, and continues to act on the particles retaining a sufficient charge during their subsequent travel on the drum surface. The intensity of the field at the surface of the drum where the zones C and D merge preferably should be uniform so that in effect the two zones C and D comprise a single electrostatic field, the initial portion of which is ionized, and the final portion non-ionized. Considerably improved separation is obtained by this arrangement.

The charged electrodes for establishing the different electric fields are elongated, having lengths somewhat longer than the guiding trough 22, and are made in the form of grids, so that the thrown-off particles easily pass through them. There is very little tendency for the thrown-off particles to stick to the electrodes 28 and 34 because whatever charge is on a particle is of the same sign, or assumes the charge of the same sign, as the polarity of the electrodes 28 or 34. Particles which may adhere to the electrodes 40 may be dislodged by occasional rapping of the electrodes if vibration of the electrodes and other effects do not maintain them clean. It is desirable to establish strong non-ionized electrostatic fields in the zones D and E, limited only by the breakdown gradient of the air. We have found that potentials of from 9 to 15 kilovolts, and somewhat more, on the electrodes positioned as described produce intense electrostatic fields which do not break down too readily when the thrown-off particles fly through the stressed fields.

In operating a device of the type described, it is desirable that the ore to be treated be fairly dry, since a relatively high humidity tends to obscure the resistivity distinctions between the particles by rendering them all relatively conducting to degrees depending to a large extent on the humidity which is the same for all particles. Generally, for efficient and rapid separation, the humidity should be less than 30%, although with some ores satisfactory results were obtained with humidities up to 40%, and somewhat more. Heating or drying the ore being treated produces large improvements in the quality and speed of ore concentration.

The particle size is also a factor in the speed of separation because the charge on a particle depends on its surface area while the rotational and gravitational forces depend on the mass of the particle. We have successfully concentrated ores passing through a No. 8 mesh sieve, but a smaller and more uniform size of the particles of ore permits more rapid utilizable concentrations.

Actually, ore particles vary in size, shape and the manner in which they contact the separating drum surface. Since the separation or concentration depends on the charge imparted to the particle, the rate at which the charge can leak off, and the masses of the particles, which is determined by their densities and sizes, the quality and speed of treatment will depend on these physical factors and characteristics, in addition to the relative resistivities of the different particles. By providing extended treating zones, each of which performs an individual function, we have been able to harmonize the effects of the aforesaid physical characteristics to the end that high quality separation is obtainable with high capacity.

By utilizing an extended charging zone, which is fairly dense, distributed and uniform, a charging of all of the particles substantially to their maximum obtainable charge, which is a factor of their surface area, is assured. Consequently, outside the ionized field a larger particle which has a higher centrifugal force acting upon it directed away from the treating drum, has a relatively higher electric charge and a correspondingly larger electrostatic force tending to keep the particle on the drum in opposition to the action of the centrifugal force, the electrostatic force, however, diminishing as the charge on the particle leaks off, this leakage being dependent on particle-resistivity, the factor which we utilize mostly to accomplish separation. For separating particles having a large ratio of resistivities, the range of particle size can be rather wide with good quality and speed of concentration. For separating particles with a relatively small ratio of resistivities, the range of particle size should preferably be decreased, or multiple treatments resorted to, each treatment improving the size grading of the particles and the ore concentration. By extending the separating zone D, which is in reality a zone in which the particles of relatively higher resistivity are made to adhere or hold-on to the drum although they are slowly losing their charge, the degree and permissible speed of separation are further improved.

The embodiment shown in Fig. 2 is essentially the same as that shown in Fig. 1, but has slightly different zone extents, and a different form of neutralizing zone. The ionizing zone C' of Fig. 2, extends from 18° to 40½° and is backed by a plurality of grounded spaced 63 mil copper wires one inch away, the wires beginning at the guiding trough **22**. The separating zone D' and particle-pull-off zone E' are essentially the same as their counterparts in Fig. 1, but extend from 45° to 171° and from 192° to 252°, respectively. The neutralizing zone F' of Fig. 2, however, differs considerably from that shown in Fig. 1, in that its ionizing field is better distributed for bringing the charge on the particles reaching this zone to as near zero as possible so that centrifugal force and gravity will throw the particles off, or so that they can be brushed or scraped off, leaving the drum surface about to go beneath the guiding trough clean.

The zone F' includes six tungsten wires of 4½ mil size providing ionizing electrodes **51** to **56**, inclusive, spaced 4½° apart and about one inch from the treating drum. A plurality of spaced 63 mil copper wire non-discharging electrodes **57–64**, inclusive, is arranged in back of these ionizing electrodes, being in an arc spaced one inch from them. Following the ionizing electrodes in the same circle is a plurality of spaced non-discharging electrodes **65** of 63 mil copper wire. The ionizing electrodes of the zone F' are connected to be at gradually lower alternating current potentials in the direction of rotation of the drum, while the back-up electrodes are connected to further decrease the intensity of the ionized field in that direction so that the particles still on the drum in passing through this zone pass through an alternating ionized field of gradually decreasing strength for gradually neutralizing the charge on the particles to the point where they fly off the treating drum. For obtaining the desired potentials on the electrodes of the zone F', a potentiometer **66**, connected across an alternating current voltage supply **67**, and having nine taps separated by resistances of 5 megohms each, can be utilized. The tap **68** is preferably grounded and is connected to the non-discharging electrode **57** while the successive taps **69** through **75** are connected to the non-discharging electrodes **57–64**, respectively, the tap **75** also being connected to the non-discharging electrodes **65** which are, therefore, at the same potential.

The ionizing electrodes **51** and **52** are at the highest potential with respect to ground and connect to the tap **76**, the ionizing-electrodes **53** and **54** being connected to the tap **74**, and the ionizing electrodes **55** and **56** to the tap **73**.

In the operation of the neutralizing system shown in Fig. 2, the ionizing electrode **51** is at the relatively highest potential and the associated non-discharging electrodes in back of it at the relatively lowest potential so that the alternating field toward the grounded treating drum is relatively strongest. However, in the direction of the rotation of the drum the potentials of the ionizing electrodes gradually decrease, while the potentials of the associated back-up electrodes approach those of the ionizing electrodes so that their aiding effect on the field is gradually changed to a shielding effect weakening the intensity of the field. This produces a gradually weaker ionized field in the zone F' in the direction of rotation of the drum. Ore concentrations with neutralizing zones are disclosed and claimed in copending application of G. W. Hewitt, Serial No. 363,444, filed concurrently herewith, and assigned to Westinghouse Electric & Manufacturing Company.

In the neutralizing zones of both embodiments, the frequency of the alternating-current voltage source should be high enough to cause, in effect, several reversals of the charge on the particle during the time the particle is in the neutralizing zone, but should be low enough to prevent neutralization of the ion and electronic streams before they reach the particles. A frequency of about 500 cycles has produced satisfactory neutralization of such particles as have reached this zone with drum speeds such as later indicated. This neutralizing zone can be omitted, the zone E being made longer, if necessary. However, in general, better results have been obtained with the neutralizing zone included.

An indication of the effectiveness of our invention for separating metal-bearing particles from gangue is illustrated, by way of example, by the results we obtained in the beneficiation of Minnesota iron ore. The tabulations to follow are for different sample ores containing F_2O_3, silica, and very small amounts of clay, which together constituted about 98% of the ore. In obtaining the results the separated ore was collected in different groups of bins to provide concentrates and tailings, and in some tests, middlings; the bins M, N, O, P and Q being defined in Fig. 1 between partitions **35**, **36**, **37** and **38** placed at 51°, 90°, 157° and 180° respectively, with the partitions **35** and **38** about one-sixteenth of an inch from the drum, and the partitions **36** and **37** close to the electrodes **34**, and the bins R, S, T and U in Fig. 2 being defined by similar partitions **35'**, **36'** and **37'** located at 103°, 175° and 185°, respectively. The particle size of the original ore is indicated by a minus (—) sign before the mesh size of the sieve which the particles pass through and a plus (+) sign before the mesh size which caught the particles.

In the following tables, Table No. 1 indicates results obtained with an ore-treating device constructed in accordance with Fig. 1, while Table No. 2 indicates results obtained with an ore-treating device constructed in accordance with Fig. 2. The ore feed was from 5 to 7 pounds per minute per axial foot of length of the drum.

For Table No. 1, the electrodes **28**, **34** and **40** were energized from unidirectional voltage supplies, and were maintained at a positive potential of 13.5 to 14 kilovolts, a positive potential of 10 to 10.5 kilovolts, and a negative potential of 15 kilovolts, respectively, the values of the potentials applied to the corresponding electrodes for Table No. 2 being respectively +12.5, +9.5, and —10.3 kilovolts. The voltage source for energizing the neutralizing zone electrodes in all runs produced a 500 cycle alternating current having a 10 kilovolt root mean square value, and the current in the ionizing electrodes of zone C was about 100 microamperes per foot of wire. For the results in Table No. 2, the ore was heated.

In the following tables, the columns indicated by the different lower case letters represent the following:

a=mesh size
b=per cent relative humidity of surrounding atmosphere
c=linear speed of the drum 24 in feet per minute
d=richness of the ore in per cent Fe, before treatment
e=bins used to collect concentrate
f=bins used to collect middlings
g=bins used to collect tailings
h=per cent of the weight of the original ore collected as concentrate
i=per cent of the weight of the original ore collected as middlings
j=richness of the concentrate in per cent of Fe
k=per cent of total Fe available in original ore which was collected in concentrate

Table No. 1

a	*b*	*c*	*d*	*e*	*g*	*h*	*j*	*k*
−16, +40	16	314	52.5	M	NOPQ	76.8	56	81.8
−100, +200	21	1000	14.2	M, N	OPQ	23.9	51	85.9
−80, +150	20	900	24	M, N, O	PQ	39.1	56.5	92.1
−40, +80	20	700	44	M, N, O	PQ	71.2	55	89.1

Table No. 2

a	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*
−60, +100	490	35	R	ST	U	48.4	14.4	59	82.3
−100	786	44.8	RS	T	U	64.5	26.8	56.8	81.7
−100	1140	46.3	R	S	TU	49.4	31	61.7	64.8
−100	1500	46.3	R	ST	U	43.6	50.4	59.5	55.8
−40	327	41.2	RS	T	U	59.6	12.2	57	82.5

From these tables it is evident that the original ore was considerably beneficiated by the treatment, resulting in concentrates having a fraction of the weight of the original ore, but containing most of the iron available in the original ore. The last three runs of Table 2, which were on ores containing about 3% moisture, produced concentrates of about one-half the weight of the original ore but with richness of iron in the neighborhood of 60% which is equivalent to about 86% Fe_2O_3. By repeated treatments, any comcentrate or middlings can be further improved as to iron content, and if desired selected bins may discharge into storage hoppers of similar devices for continuous treatment.

In order to obtain an idea of the relative resistivities (in ohms per centimeter cube) of the particles a fiber tube having an area three square inches and a length of one-half inch, protected by a guarding ring to render the effect of leakage on the tube negligible, was filled with collected particles compressed by their own weight, and an electrode of 600 grams. An original ore (size −150, +200) produced a concentrate having 62–65% Fe, which concentrate showed a resistivity at 21% relative humidity of 1.2 to 2.3 times 10^{10} and a tailings having 5–10% Fe which showed a resistivity of 4700×10^{10}. At 41% relative humidity the values were, respectively, .8 to 2.8 times 10^{10}, and 384 to 468 times 10^{10}.

A second sample of ore, (size −100, +200) produced a concentrate (55% Fe) with a resistivity of 2.1×10^{10}, and a tailings (2–5% Fe) of 79×10^{10}, at a humidity of 21%. At high humidities the relative resistivity values of this sample were not sufficiently different to yield utilizable separation.

In general, for good separation the gangue or high resistivity component of the ore particles, as measured in bulk, should have a resistivity of 10^{11}, or greater for particles passing through a 100 mesh sieve. These resistivity values which include the resistances of very many small area contacts between particles must not be confused with resistivity values of single large particles of a substance which are much lower, as indicated by measurements for silicon carbide, a single large particle of which may show a resistivity of 1 as compared to a resistivity of 10^9 for particles of −40, +60 mesh, measured in bulk.

From the foregoing, it is apparent that we have produced an ore-concentrator which will treat ore heretofore discarded, and yield ore satisfactory for commercial demands which require for economical smelting an ore of a richness of at least 40% under most favorable conditions for the specific iron mentioned hereinbefore. We have also treated ores of metals other than iron with satisfactory results, but have confined our specific examples to iron ore for illustrating the operational results of the equipment we have devised.

While we have described our invention in forms which we believe to represent preferred embodiments thereof, it is obvious that the nature of the invention is such that many alternative arrangements are possible, and equivalent structures utilized.

We claim as our invention:

1. The method of selectively separating a mixture of particles of different electrical properties, which comprises feeding a thin layer of the mixture of particles on the upper part of a conducting endless surface moving in an extended, substantially curved, path about a substantially horizontal axis, substantially immediately thereafter subjecting the particles moving on and with said surface to a generally unidirectional ionized electrostatic field, which has a considerable circumferential extent along said upper part of said surface, and which is substantially uniformly stressed and substantially uniformly ionized throughout its circumferential extent, said ionized electrostatic field terminating on said upper part of said surface a considerable distance before said curved path becomes vertical, and substantially immediately thereafter subjecting the particles moving on and with said surface to a generally unidirectional, substantially non-ionized, electrostatic field, which also has a considerable circumferential extent along said upper part of said surface, and which is substantially uniformly stressed throughout its circumferential extent, said substantially non-ionized electrostatic field continuing on the under side of the curved path to a point materially beyond the point where said curved path becomes substantially vertical, whereby gravity may act on said particles for causing the particles having charges which leak off rapidly by conduction to said surface to fall away from said surface, and then removing particles still remaining on said surface before they return to the feeding point.

2. The method of selectively separating a mixture of particles of different electrical properties, which comprises feeding a thin layer of the mixture of particles on the upper part of a conducting endless surface moving in an extended, substantially curved, path about a substantially

horizontal axis, substantially immediately thereafter subjecting the particles moving on and with said surface to a generally unidirectional ionized electrostatic field, which has a considerable circumferential extent along said upper part of said surface, and which is substantially uniformly stressed and substantially uniformly ionized throughout its circumferential extent, said ionized electrostatic field terminating on said upper part of said surface a considerable distance before said curved path becomes vertical, and substantially immediately thereafter subjecting the particles moving on and with said surface to a generally unidirectional, substantially non-ionized, electrostatic field, which also has a considerable circumferential extent along said upper part of said surface, and which is substantially uniformly stressed throughout its circumferential extent, said substantially non-ionized electrostatic field continuing on the under side of the curved path to a point materially beyond the point where said curved path becomes substantially vertical, whereby gravity may act on said particles for causing some of the particles having charges which leak off rapidly by conduction to said surface to fall away from said surface, meanwhile rotating said surface at a speed sufficient to impose a material centrifugal force on the particles on said surface, and then removing particles still remaining on said surface before they return to the feeding point.

3. The method of treating a mixture of particles including particles of relatively low resistivity and particles of relatively high resistivity, which comprises continually feeding a thin layer of the mixture on the upper part of a conducting surface of an endless conveyor rotatable about a substantially horizontal axis, rotating said conveyor, subjecting the particles fed to said conveyor to an extended ionized unidirectional electrostatic field for charging the particles, and then subjecting the particles to an extended non-ionized unidirectional electrostatic field tending to repel to said surface those particles which retain an appreciable portion of their charge, the said conveyor being rotated at such speed that relatively low resistivity particles which do not retain charges are caused to fly off of said drum while relatively high resistivity particles adhere to said surface because of the action of the non-ionized field, and then subjecting particles which remain on said surface to electric reactions for reducing the electrical forces on the last said particles tending to cause them to adhere to said surface.

4. The method of treating a mixture of particles including particles of relatively low resistivity and particles of relatively high resistivity, which comprises continually feeding a thin layer of the mixture on the upper part of a conducting surface of an endless conveyor rotatable about a substantially horizontal axis, rotating said conveyor with the particles on its surface, subjecting the particles fed to said conveyor to an extended ionized electrostatic field for charging the particles, and then subjecting the particles to an extended non-ionized field tending to repel to said surface those particles which retain an appreciable portion of their charge, the said conveyor being rotated at such speed that relatively low resistivity particles which do not retain charges are caused to leave said drum while relatively high resistivity particles adhere to said surface because of the action of the non-ionized field, and then subjecting particles which remain on said surface to a non-ionized electrostatic field tending to pull away from said surface the particles remaining on said surface.

5. A device of the class described for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising a cylindrical drum having a conducting surface, means for rotating said drum, means for depositing a thin layer of particles on the upper part of said drum, means associated with said drum for establishing a unidirectional ionized electrostatic field toward said drum, said field being of substantially uniform density circumferentially for an appreciable angular extent, means associated with said drum for establishing a non-ionized unidirectional electrostatic field merging into said ionized field and of the same general polarity, and means associated with said drum for establishing a unidirectional electrostatic field following said non-ionized field, the last said field having a polarity generally opposite to said non-ionized field.

6. A device for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising a cylindrical drum having a conducting surface; means for rotating said drum; means for depositing a thin layer of particles on said drum; and a plurality of means disposed substantially concentrically about said drum following the last said means in the following order: means including a plurality of spaced ionizing electrodes for charging said particles, means including a plurality of non-discharging electrodes in grid-form for producing an electrostatic field reacting with charged particles to tend to repel them toward the drum, and electric field means for reacting with the charges on particles still on the drum for increasing their tendency to separate from the drum.

7. A device for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising an endless conveyor rotatable in a closed path about a substantially horizontal axis, means for rotating said conveyor, means for depositing a thin layer of particles on the upper part of said conveyor, means comprising ionizing electrodes arranged in grid form in the general direction of the movement of said particles, for charging the particles deposited in said conveyor, subsequent means comprising electrodes arranged in extended grid-form for producing a subsequent electrostatic field, following said ionized field, for reacting with charged particles to produce a force tending to repel them to said conveyor, means subsequent to the last said means and comprising electrodes arranged in extended grid form for producing an electrostatic field, following the last said subsequent electrostatic field, for reacting with charged particles to produce a force tending to separate them from said conveyor, particles leaving said conveyor being capable of passing through the spaces of said grid-forms, and distributed bin means for collecting segregated portions of the particles leaving said conveyor.

8. A device for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising an endless conveyor having a conducting surface rotatable in a closed path about a substantially horizontal axis, means for rotating said conveyor, means for depositing a thin layer of particles on the upper part of

said conveyor, means comprising ionizing electrodes arranged in grid-form in the general direction of the movement of said particles for charging the particles deposited in said conveyor, subsequent means comprising electrodes arranged in extended grid form for producing a subsequent electrostatic field, following said ionized field, for reacting with charged particles to produce a force tending to repel them to said conveyor, means subsequent to the last said means and comprising electrodes arranged in extended grid-form for producing an electric field for increasing the tendency of charged particles to leave said drum.

9. A device of the class described for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising a substantially horizontal cylindrical drum, means for rotating said drum, means for depositing a thin layer of particles on the upper part of said drum, means for establishing a unidirectional ionized electrostatic field to said drum, said field being of substantially uniform density circumferentially for an appreciable angular extent, subsequent means for establishing a non-ionized unidirectional electrostatic field to said drum, merging into said ionized field and of the same general polarity, said non-ionized field being of substantially uniform density circumferentially for an appreciable angular extent, and means for establishing a non-ionized unidirectional electrostatic field to said drum, following the first said non-ionized field, the last said field being substantially uniform and having a polarity generally opposite to the first said non-ionized field.

10. A device for selectively separating a mixture of particles of different electrical properties, comprising a rotating drum of large diameter, having an electrically conducting surface, means for continuously supplying a thin layer of the particles to an upper portion of the drum, means for continuously rotating the drum at a speed sufficient to impose a material centrifugal force on the particles carried by said drum, means for continuously subjecting the particles, for a considerable portion of a revolution, soon after they are deposited on the drum, to a unidirectional ionized field with respect to the electrically conducting surface of the drum, means for immediately thereafter subjecting the same particles to a substantially non-ionized field of the same polarity with respect to the electrically conducting surface of the drum, said substantially non-ionized field merging with the ionized field and having a considerable circumferential extent along the upper portion of the drum, and also extending down around underneath the drum, for a material distance past the point where gravity first tends to cause the particles to fall off of the drum, whereby the particles which retain their ionization are continuously subjected to a repellant force, from the substantially non-ionized field, in a direction tending to hold them to the drum against centrifugal action, from the ionizing zone at least as far as the point where gravity tends to cause the particles to fall off of the drum, and means for segregatingly collecting the particles which come away from the drum at different points around its circumference.

11. A device for selectively separating a mixture of particles of different electrical properties, comprising means for providing a conducting endless surface moving in an extended, substantially curved, path about a substantially horizontal axis, means for feeding a thin layer of the mixture of particles on the upper part of said endless surface, means for substantially immediately thereafter subjecting the particles moving on and with said surface to a generally unidirectional ionized electrostatic field, which has a considerable circumferential extent along said upper part of said surface, and which is substantially uniformly stressed and substantially uniformly ionized throughout its circumferential extent, said ionized electrostatic field terminating on said upper part of said surface a considerable distance before said curved path becomes vertical, means for substantially immediately thereafter subjecting the particles moving on and with said surface to a generally unidirectional, substantially non-ionized, electrostatic field, which also has a considerable circumferential extent along said upper part of said surface, and which is substantially uniformly stressed throughout its circumferential extent, said substantially non-ionized electrostatic field continuing on the under side of the curved path to a point materially beyond the point where said curved path becomes substantially vertical, whereby gravity may act on said particles for causing the particles having charges which leak off rapidly by conduction to said surface to fall away from said surface, and means for subsequently removing particles still remaining on said surface before they return to the feeding point.

12. A device for selectively separating a mixture of particles of different electrical properties, comprising means for providing a conducting endless surface moving in an extended, substantially curved, path about a substantially horizontal axis, means for feeding a thin layer of the mixture of particles on the upper part of said endless surface, means for substantially immediately thereafter subjecting the particles moving on and with said surface to a generally unidirectional ionized electrostatic field, which has a considerable circumferential extent along said upper part of said surface, and which is substantially uniformly stressed and substantially uniformly ionized throughout its circumferential extent, said ionized electrostatic field terminating on said upper part of said surface a considerable distance before said curved path becomes vertical, means for substantially immediately thereafter subjecting the particles moving on and with said surface to a generally unidirectional, substantially non-ionized, electrostatic field, which also has a considerable circumferential extent along said upper part of said surface, and which is substantially uniformly stressed throughout its circumferential extent, said substantially non-ionized electrostatic field continuing on the under side of the curved path to a point materially beyond the point where said curved path becomes substantially vertical, whereby gravity may act on said particles for causing some of the particles having charges which leak off rapidly by conduction to said surface to fall away from said surface, means for rotating said surface at a speed sufficient to impose a material centrifugal force on the particles on said surface, and means for subsequently removing particles still remaining on said surface before they return to the feeding point.

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